ASME BPVC.III.1.NC-2015

SECTION III

Rules for Construction of Nuclear Facility Components

2015 ASME Boiler and Pressure Vessel Code

An International Code

Division 1 — Subsection NC

Class 2 Components

ASME
SETTING THE STANDARD

AN INTERNATIONAL CODE

2015 ASME Boiler & Pressure Vessel Code

2015 Edition July 1, 2015

III

RULES FOR CONSTRUCTION OF NUCLEAR FACILITY COMPONENTS

Division 1 - Subsection NC

Class 2 Components

ASME Boiler and Pressure Vessel Committee on Nuclear Power

The American Society of Mechanical Engineers

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TABLE OF CONTENTS

FIGURES

TABLES

(15)

LIST OF SECTIONS

SECTIONS

I Rules for Construction of Power Boilers

II Materials
- Part A — Ferrous Material Specifications
- Part B — Nonferrous Material Specifications
- Part C — Specifications for Welding Rods, Electrodes, and Filler Metals
- Part D — Properties (Customary)
- Part D — Properties (Metric)

III Rules for Construction of Nuclear Facility Components
- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1
  - Subsection NB — Class 1 Components
  - Subsection NC — Class 2 Components
  - Subsection ND — Class 3 Components
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
  - Subsection NH — Class 1 Components in Elevated Temperature Service*
- Division 2 — Code for Concrete Containments
- Division 3 — Containments for Transportation and Storage of Spent Nuclear Fuel and High Level Radioactive Material and Waste
- Division 5 — High Temperature Reactors

IV Rules for Construction of Heating Boilers

V Nondestructive Examination

VI Recommended Rules for the Care and Operation of Heating Boilers

VII Recommended Guidelines for the Care of Power Boilers

VIII Rules for Construction of Pressure Vessels
- Division 1
- Division 2 — Alternative Rules
- Division 3 — Alternative Rules for Construction of High Pressure Vessels

IX Welding, Brazing, and Fusing Qualifications

X Fiber-Reinforced Plastic Pressure Vessels

XI Rules for Inservice Inspection of Nuclear Power Plant Components

XII Rules for Construction and Continued Service of Transport Tanks

* The 2015 Edition of Section III is the last edition in which Section III, Division 1, Subsection NH, *Class 1 Components in Elevated Temperature Service*, will be published. The requirements located within Subsection NH have been moved to Section III, Division 5, Subsection HB, Subpart B for the elevated temperature construction of Class A components.

INTERPRETATIONS

Interpretations of the Code have historically been posted in January and July at http://cstools.asme.org/interpretations.cfm. Interpretations issued during the previous two calendar years are included with the publication of the applicable Section of the Code in the 2015 Edition. Interpretations of Section III, Divisions 1 and 2 and Section III Appendices are included with Subsection NCA.

Following the 2015 Edition, interpretations will not be included in editions; they will be issued in real time in ASME's Interpretations Database at http://go.asme.org/Interpretations. Historical BPVC interpretations may also be found in the Database.

CODE CASES

The Boiler and Pressure Vessel Code committees meet regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements or provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases that have been adopted will appear in the appropriate 2015 Code Cases book: "Boilers and Pressure Vessels" or "Nuclear Components." Supplements will be sent or made available automatically to the purchasers of the Code Cases books up to the publication of the 2017 Code.

(15)

FOREWORD*

In 1911, The American Society of Mechanical Engineers established the Boiler and Pressure Vessel Committee to formulate standard rules for the construction of steam boilers and other pressure vessels. In 2009, the Boiler and Pressure Vessel Committee was superseded by the following committees:

(a) Committee on Power Boilers (I)

(b) Committee on Materials (II)

(c) Committee on Construction of Nuclear Facility Components (III)

(d) Committee on Heating Boilers (IV)

(e) Committee on Nondestructive Examination (V)

(f) Committee on Pressure Vessels (VIII)

(g) Committee on Welding, Brazing, and Fusing (IX)

(h) Committee on Fiber-Reinforced Plastic Pressure Vessels (X)

(i) Committee on Nuclear Inservice Inspection (XI)

(j) Committee on Transport Tanks (XII)

(k) Technical Oversight Management Committee (TOMC)

Where reference is made to "the Committee" in this Foreword, each of these committees is included individually and collectively.

The Committee's function is to establish rules of safety relating only to pressure integrity, which govern the construction** of boilers, pressure vessels, transport tanks, and nuclear components, and the inservice inspection of nuclear components and transport tanks. The Committee also interprets these rules when questions arise regarding their intent. The technical consistency of the Sections of the Code and coordination of standards development activities of the Committees is supported and guided by the Technical Oversight Management Committee. This Code does not address other safety issues relating to the construction of boilers, pressure vessels, transport tanks, or nuclear components, or the inservice inspection of nuclear components or transport tanks. Users of the Code should refer to the pertinent codes, standards, laws, regulations, or other relevant documents for safety issues other than those relating to pressure integrity. Except for Sections XI and XII, and with a few other exceptions, the rules do not, of practical necessity, reflect the likelihood and consequences of deterioration in service related to specific service fluids or external operating environments. In formulating the rules, the Committee considers the needs of users, manufacturers, and inspectors of pressure vessels. The objective of the rules is to afford reasonably certain protection of life and property, and to provide a margin for deterioration in service to give a reasonably long, safe period of usefulness. Advancements in design and materials and evidence of experience have been recognized.

This Code contains mandatory requirements, specific prohibitions, and nonmandatory guidance for construction activities and inservice inspection and testing activities. The Code does not address all aspects of these activities and those aspects that are not specifically addressed should not be considered prohibited. The Code is not a handbook and cannot replace education, experience, and the use of engineering judgment. The phrase *engineering judgement* refers to technical judgments made by knowledgeable engineers experienced in the application of the Code. Engineering judgments must be consistent with Code philosophy, and such judgments must never be used to overrule mandatory requirements or specific prohibitions of the Code.

The Committee recognizes that tools and techniques used for design and analysis change as technology progresses and expects engineers to use good judgment in the application of these tools. The designer is responsible for complying with Code rules and demonstrating compliance with Code equations when such equations are mandatory. The Code neither requires nor prohibits the use of computers for the design or analysis of components constructed to the

* The information contained in this Foreword is not part of this American National Standard (ANS) and has not been processed in accordance with ANSI's requirements for an ANS. Therefore, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the Code.

** *Construction*, as used in this Foreword, is an all-inclusive term comprising materials, design, fabrication, examination, inspection, testing, certification, and pressure relief.

requirements of the Code. However, designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and the application of these programs to their design.

The rules established by the Committee are not to be interpreted as approving, recommending, or endorsing any proprietary or specific design, or as limiting in any way the manufacturer's freedom to choose any method of design or any form of construction that conforms to the Code rules.

The Committee meets regularly to consider revisions of the rules, new rules as dictated by technological development, Code Cases, and requests for interpretations. Only the Committee has the authority to provide official interpretations of this Code. Requests for revisions, new rules, Code Cases, or interpretations shall be addressed to the Secretary in writing and shall give full particulars in order to receive consideration and action (see Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees). Proposed revisions to the Code resulting from inquiries will be presented to the Committee for appropriate action. The action of the Committee becomes effective only after confirmation by ballot of the Committee and approval by ASME. Proposed revisions to the Code approved by the Committee are submitted to the American National Standards Institute (ANSI) and published at http://go.asme.org/BPVCPublicReview to invite comments from all interested persons. After public review and final approval by ASME, revisions are published at regular intervals in Editions of the Code.

The Committee does not rule on whether a component shall or shall not be constructed to the provisions of the Code. The scope of each Section has been established to identify the components and parameters considered by the Committee in formulating the Code rules.

Questions or issues regarding compliance of a specific component with the Code rules are to be directed to the ASME Certificate Holder (Manufacturer). Inquiries concerning the interpretation of the Code are to be directed to the Committee. ASME is to be notified should questions arise concerning improper use of an ASME Certification Mark.

When required by context in this Section, the singular shall be interpreted as the plural, and vice versa, and the feminine, masculine, or neuter gender shall be treated as such other gender as appropriate.

STATEMENT OF POLICY ON THE USE OF THE CERTIFICATION MARK AND CODE AUTHORIZATION IN ADVERTISING

ASME has established procedures to authorize qualified organizations to perform various activities in accordance with the requirements of the ASME Boiler and Pressure Vessel Code. It is the aim of the Society to provide recognition of organizations so authorized. An organization holding authorization to perform various activities in accordance with the requirements of the Code may state this capability in its advertising literature.

Organizations that are authorized to use the Certification Mark for marking items or constructions that have been constructed and inspected in compliance with the ASME Boiler and Pressure Vessel Code are issued Certificates of Authorization. It is the aim of the Society to maintain the standing of the Certification Mark for the benefit of the users, the enforcement jurisdictions, and the holders of the Certification Mark who comply with all requirements.

Based on these objectives, the following policy has been established on the usage in advertising of facsimiles of the Certification Mark, Certificates of Authorization, and reference to Code construction. The American Society of Mechanical Engineers does not "approve," "certify," "rate," or "endorse" any item, construction, or activity and there shall be no statements or implications that might so indicate. An organization holding the Certification Mark and/or a Certificate of Authorization may state in advertising literature that items, constructions, or activities "are built (produced or performed) or activities conducted in accordance with the requirements of the ASME Boiler and Pressure Vessel Code," or "meet the requirements of the ASME Boiler and Pressure Vessel Code." An ASME corporate logo shall not be used by any organization other than ASME.

The Certification Mark shall be used only for stamping and nameplates as specifically provided in the Code. However, facsimiles may be used for the purpose of fostering the use of such construction. Such usage may be by an association or a society, or by a holder of the Certification Mark who may also use the facsimile in advertising to show that clearly specified items will carry the Certification Mark. General usage is permitted only when all of a manufacturer's items are constructed under the rules.

STATEMENT OF POLICY ON THE USE OF ASME MARKING TO IDENTIFY MANUFACTURED ITEMS

The ASME Boiler and Pressure Vessel Code provides rules for the construction of boilers, pressure vessels, and nuclear components. This includes requirements for materials, design, fabrication, examination, inspection, and stamping. Items constructed in accordance with all of the applicable rules of the Code are identified with the official Certification Mark described in the governing Section of the Code.

Markings such as "ASME," "ASME Standard," or any other marking including "ASME" or the Certification Mark shall not be used on any item that is not constructed in accordance with all of the applicable requirements of the Code.

Items shall not be described on ASME Data Report Forms nor on similar forms referring to ASME that tend to imply that all Code requirements have been met when, in fact, they have not been. Data Report Forms covering items not fully complying with ASME requirements should not refer to ASME or they should clearly identify all exceptions to the ASME requirements.

(15) # SUBMITTAL OF TECHNICAL INQUIRIES TO THE BOILER AND PRESSURE VESSEL STANDARDS COMMITTEES

1 INTRODUCTION

(a) The following information provides guidance to Code users for submitting technical inquiries to the committees. See Guideline on the Approval of New Materials Under the ASME Boiler and Pressure Vessel Code in Section II, Parts C and D for additional requirements for requests involving adding new materials to the Code. Technical inquiries include requests for revisions or additions to the Code rules, requests for Code Cases, and requests for Code Interpretations, as described below.

(1) Code Revisions. Code revisions are considered to accommodate technological developments, address administrative requirements, incorporate Code Cases, or to clarify Code intent.

(2) Code Cases. Code Cases represent alternatives or additions to existing Code rules. Code Cases are written as a question and reply, and are usually intended to be incorporated into the Code at a later date. When used, Code Cases prescribe mandatory requirements in the same sense as the text of the Code. However, users are cautioned that not all jurisdictions or owners automatically accept Code Cases. The most common applications for Code Cases are:

(-a) to permit early implementation of an approved Code revision based on an urgent need

(-b) to permit the use of a new material for Code construction

(-c) to gain experience with new materials or alternative rules prior to incorporation directly into the Code

(3) Code Interpretations. Code Interpretations provide clarification of the meaning of existing rules in the Code, and are also presented in question and reply format. Interpretations do not introduce new requirements. In cases where existing Code text does not fully convey the meaning that was intended, and revision of the rules is required to support an interpretation, an Intent Interpretation will be issued and the Code will be revised.

(b) The Code rules, Code Cases, and Code Interpretations established by the committees are not to be considered as approving, recommending, certifying, or endorsing any proprietary or specific design, or as limiting in any way the freedom of manufacturers, constructors, or owners to choose any method of design or any form of construction that conforms to the Code rules.

(c) Inquiries that do not comply with these provisions or that do not provide sufficient information for a committee's full understanding may result in the request being returned to the inquirer with no action.

2 INQUIRY FORMAT

Submittals to a committee shall include:

(a) Purpose. Specify one of the following:

(1) revision of present Code rules

(2) new or additional Code rules

(3) Code Case

(4) Code Interpretation

(b) Background. Provide the information needed for the committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Division, edition, addenda (if applicable), paragraphs, figures, and tables. Preferably, provide a copy of the specific referenced portions of the Code.

(c) Presentations. The inquirer may desire or be asked to attend a meeting of the committee to make a formal presentation or to answer questions from the committee members with regard to the inquiry. Attendance at a committee meeting shall be at the expense of the inquirer. The inquirer's attendance or lack of attendance at a meeting shall not be a basis for acceptance or rejection of the inquiry by the committee.

3 CODE REVISIONS OR ADDITIONS

Requests for Code revisions or additions shall provide the following:

(a) Proposed Revisions or Additions. For revisions, identify the rules of the Code that require revision and submit a copy of the appropriate rules as they appear in the Code, marked up with the proposed revision. For additions, provide the recommended wording referenced to the existing Code rules.

(b) Statement of Need. Provide a brief explanation of the need for the revision or addition.

(c) Background Information. Provide background information to support the revision or addition, including any data or changes in technology that form the basis for the request that will allow the committee to adequately evaluate the proposed revision or addition. Sketches, tables, figures, and graphs should be submitted as appropriate. When applicable, identify any pertinent paragraph in the Code that would be affected by the revision or addition and identify paragraphs in the Code that reference the paragraphs that are to be revised or added.

4 CODE CASES

Requests for Code Cases shall provide a Statement of Need and Background Information similar to that defined in 3(b) and 3(c), respectively, for Code revisions or additions. The urgency of the Code Case (e.g., project underway or imminent, new procedure, etc.) must be defined and it must be confirmed that the request is in connection with equipment that will bear the Certification Mark, with the exception of Section XI applications. The proposed Code Case should identify the Code Section and Division, and be written as a *Question* and a *Reply* in the same format as existing Code Cases. Requests for Code Cases should also indicate the applicable Code editions and addenda (if applicable) to which the proposed Code Case applies.

5 CODE INTERPRETATIONS

(a) Requests for Code Interpretations shall provide the following:

(1) Inquiry. Provide a condensed and precise question, omitting superfluous background information and, when possible, composed in such a way that a “yes” or a “no” *Reply,* with brief provisos if needed, is acceptable. The question should be technically and editorially correct.

(2) Reply. Provide a proposed *Reply* that will clearly and concisely answer the *Inquiry* question. Preferably, the *Reply* should be “yes” or “no,” with brief provisos if needed.

(3) Background Information. Provide any background information that will assist the committee in understanding the proposed *Inquiry* and *Reply.*

(b) Requests for Code Interpretations must be limited to an interpretation of a particular requirement in the Code or a Code Case. The committee cannot consider consulting type requests such as the following:

(1) a review of calculations, design drawings, welding qualifications, or descriptions of equipment or parts to determine compliance with Code requirements;

(2) a request for assistance in performing any Code-prescribed functions relating to, but not limited to, material selection, designs, calculations, fabrication, inspection, pressure testing, or installation;

(3) a request seeking the rationale for Code requirements.

6 SUBMITTALS

Submittals to and responses from the committees shall meet the following:

(a) Submittal. Inquiries from Code users shall be in English and preferably be submitted in typewritten form; however, legible handwritten inquiries will also be considered. They shall include the name, address, telephone number, fax number, and e-mail address, if available, of the inquirer and be mailed to the following address:

Secretary
ASME Boiler and Pressure Vessel Committee
Two Park Avenue
New York, NY 10016-5990

As an alternative, inquiries may be submitted via e-mail to: SecretaryBPV@asme.org or via our online tool at http://go.asme.org/InterpretationRequest.

(b) Response. The Secretary of the appropriate committee shall acknowledge receipt of each properly prepared inquiry and shall provide a written response to the inquirer upon completion of the requested action by the committee.

(15)

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January 1, 2015

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(15)

ORGANIZATION OF SECTION III

1 GENERAL

Section III consists of Division 1, Division 2, Division 3, and Division 5. These Divisions are broken down into Subsections and are designated by capital letters preceded by the letter "N" for Division 1, by the letter "C" for Division 2, by the letter "W" for Division 3, and by the letter "H" for Division 5. Each Subsection is published separately, with the exception of those listed for Divisions 2, 3, and 5.

- Subsection NCA — General Requirements for Division 1 and Division 2
- Appendices
- Division 1
  - Subsection NB — Class 1 Components
  - Subsection NC — Class 2 Components
  - Subsection ND — Class 3 Components
  - Subsection NE — Class MC Components
  - Subsection NF — Supports
  - Subsection NG — Core Support Structures
  - Subsection NH — Class 1 Components in Elevated Temperature Service[*]
- Division 2 — Code for Concrete Containments
  - Subsection CC — Concrete Containments
- Division 3 — Containments for Transportation and Storage of Spent Nuclear Fuel and High Level Radioactive Material and Waste
  - Subsection WA — General Requirements for Division 3
  - Subsection WB — Class TC Transportation Containments
  - Subsection WC — Class SC Storage Containments
- Division 5 — High Temperature Reactors
  - Subsection HA — General Requirements
    - Subpart A — Metallic Materials
    - Subpart B — Graphite Materials
    - Subpart C — Composite Materials
  - Subsection HB — Class A Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HC — Class B Metallic Pressure Boundary Components
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HF — Class A and B Metallic Supports
    - Subpart A — Low Temperature Service
  - Subsection HG — Class A Metallic Core Support Structures
    - Subpart A — Low Temperature Service
    - Subpart B — Elevated Temperature Service
  - Subsection HH — Class A Nonmetallic Core Support Structures
    - Subpart A — Graphite Materials
    - Subpart B — Composite Materials

2 SUBSECTIONS

Subsections are divided into Articles, subarticles, paragraphs, and, where necessary, subparagraphs and subsubparagraphs.

[*] The 2015 Edition of Section III is the last edition in which Section III, Division 1, Subsection NH, *Class 1 Components in Elevated Temperature Service*, will be published. The requirements located within Subsection NH have been moved to Section III, Division 5, Subsection HB, Subpart B for the elevated temperature construction of Class A components.

3 ARTICLES

Articles are designated by the applicable letters indicated above for the Subsections followed by Arabic numbers, such as NB-1000. Where possible, Articles dealing with the same topics are given the same number in each Subsection, except NCA, in accordance with the following general scheme:

Article Number	Title
1000	Introduction or Scope
2000	Material
3000	Design
4000	Fabrication and Installation
5000	Examination
6000	Testing
7000	Overpressure Protection
8000	Nameplates, Stamping With Certification Mark, and Reports

The numbering of Articles and the material contained in the Articles may not, however, be consecutive. Due to the fact that the complete outline may cover phases not applicable to a particular Subsection or Article, the rules have been prepared with some gaps in the numbering.

4 SUBARTICLES

Subarticles are numbered in units of 100, such as NB-1100.

5 SUBSUBARTICLES

Subsubarticles are numbered in units of 10, such as NB-2130, and generally have no text. When a number such as NB-1110 is followed by text, it is considered a paragraph.

6 PARAGRAPHS

Paragraphs are numbered in units of 1, such as NB-2121.

7 SUBPARAGRAPHS

Subparagraphs, when they are *major* subdivisions of a paragraph, are designated by adding a decimal followed by one or more digits to the paragraph number, such as NB-1132.1. When they are *minor* subdivisions of a paragraph, subparagraphs may be designated by lowercase letters in parentheses, such as NB-2121(a).

8 SUBSUBPARAGRAPHS

Subsubparagraphs are designated by adding lowercase letters in parentheses to the *major* subparagraph numbers, such as NB-1132.1(a). When further subdivisions of *minor* subparagraphs are necessary, subsubparagraphs are designated by adding Arabic numerals in parentheses to the subparagraph designation, such as NB-2121(a)(1).

9 REFERENCES

References used within Section III generally fall into one of the following four categories:

(a) References to Other Portions of Section III. When a reference is made to another Article, subarticle, or paragraph, all numbers subsidiary to that reference shall be included. For example, reference to NB-3000 includes all material in Article NB-3000; reference to NB-3200 includes all material in subarticle NB-3200; reference to NB-3230 includes all paragraphs, NB-3231 through NB-3236.

(b) References to Other Sections. Other Sections referred to in Section III are the following:

(1) Section II, Materials. When a requirement for a material, or for the examination or testing of a material, is to be in accordance with a specification such as SA-105, SA-370, or SB-160, the reference is to material specifications in Section II. These references begin with the letter "S."

(2) Section V, Nondestructive Examination. Section V references begin with the letter "T" and relate to the nondestructive examination of material or welds.

(3) Section IX, Welding and Brazing Qualifications. Section IX references begin with the letter "Q" and relate to welding and brazing requirements.

(4) Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components. When a reference is made to inservice inspection, the rules of Section XI shall apply.

(c) Reference to Specifications and Standards Other Than Published in Code Sections

(1) Specifications for examination methods and acceptance standards to be used in connection with them are published by the American Society for Testing and Materials (ASTM). At the time of publication of Section III, some such specifications were not included in Section II of this Code. A reference to ASTM E94 refers to the specification so designated by and published by ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

(2) Dimensional standards covering products such as valves, flanges, and fittings are sponsored and published by The American Society of Mechanical Engineers and approved by the American National Standards Institute.[**] When a product is to conform to such a standard, for example ASME B16.5, the standard is approved by the American National Standards Institute. The applicable year of issue is that suffixed to its numerical designation in Table NCA-7100-1, for example ASME B16.5-2003. Standards published by The American Society of Mechanical Engineers are available from ASME (https://www.asme.org/).

(3) Dimensional and other types of standards covering products such as valves, flanges, and fittings are also published by the Manufacturers Standardization Society of the Valve and Fittings Industry and are known as Standard Practices. When a product is required by these rules to conform to a Standard Practice, for example MSS SP-100, the Standard Practice referred to is published by the Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. (MSS), 127 Park Street, NE, Vienna, VA 22180. The applicable year of issue of such a Standard Practice is that suffixed to its numerical designation in Table NCA-7100-1, for example MSS SP-89-2003.

(4) Specifications for welding and brazing materials are published by the American Welding Society (AWS), 8669 Doral Boulevard, Suite 130, Doral, FL 33166. Specifications of this type are incorporated in Section II and are identified by the AWS designation with the prefix "SF," for example SFA-5.1.

(5) Standards applicable to the design and construction of tanks and flanges are published by the American Petroleum Institute and have designations such as API-605. When documents so designated are referred to in Section III, for example API-605–1988, they are standards published by the American Petroleum Institute and are listed in Table NCA-7100-1.

(d) References to Appendices. Section III uses two types of appendices that are designated as either Section III Appendices or Subsection Appendices. Either of these appendices is further designated as either Mandatory or Nonmandatory for use. Mandatory Appendices are referred to in the Section III rules and contain requirements that must be followed in construction. Nonmandatory Appendices provide additional information or guidance when using Section III.

(1) Section III Appendices are contained in a separate book titled "Appendices." These appendices have the potential for multiple subsection applicability. Mandatory Appendices are designated by a Roman numeral followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as II-1500 or XIII-2131. Nonmandatory Appendices are designated by a capital letter followed, when appropriate, by Arabic numerals to indicate various articles, subarticles, and paragraphs of the appendix, such as D-1200 or Y-1440.

(2) Subsection Appendices are specifically applicable to just one subsection and are contained within that subsection. Subsection-specific mandatory and nonmandatory appendices are numbered in the same manner as Section III Appendices, but with a subsection identifier (e.g., NF, NH, D2, etc.) preceding either the Roman numeral or the capital letter for a unique designation. For example, NF-II-1100 or NF-A-1200 would be part of a Subsection NF mandatory or nonmandatory appendix, respectively. For Subsection CC, D2-IV-1120 or D2-D-1330 would be part of a Subsection CC mandatory or nonmandatory appendix, respectively.

(3) It is the intent of this Section that the information provided in both Mandatory and Nonmandatory Appendices may be used to meet the rules of any Division or Subsection. In case of conflict between Appendix rules and Division/Subsection rules, the requirements contained in the Division/Subsection shall govern. Additional guidance on Appendix usage is provided in the front matter of Section III Appendices.

[**] The American National Standards Institute (ANSI) was formerly known as the American Standards Association. Standards approved by the Association were designated by the prefix "ASA" followed by the number of the standard and the year of publication. More recently, the American National Standards Institute was known as the United States of America Standards Institute. Standards were designated by the prefix "USAS" followed by the number of the standard and the year of publication. While the letters of the prefix have changed with the name of the organization, the numbers of the standards have remained unchanged.

SUMMARY OF CHANGES

After publication of the 2015 Edition, Errata to the BPV Code may be posted on the ASME Web site to provide corrections to incorrectly published items, or to correct typographical or grammatical errors in the BPV Code. Such Errata shall be used on the date posted.

Information regarding Special Notices and Errata is published by ASME at http://go.asme.org/BPVCerrata.

Changes given below are identified on the pages by a margin note, **(15)**, placed next to the affected area.

The Record Numbers listed below are explained in more detail in "List of Changes in Record Number Order" following this Summary of Changes.

Page	*Location*	*Change (Record Number)*
xii	List of Sections	Revised
xiv	Foreword	*(1)* Revised *(2)* New footnote added by errata *(13-860)*
xvii	Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees	In last line of 6(a), URL revised
xix	Personnel	Updated
xxxvi	Organization of Section III	*(1)* New footnote added *(2)* 9(d)(3) added *(13-1032)*
7	NC-2126.1	In subpara. (e), last two sentences added *(14-1713)*
15	NC-2420	In first paragraph, cross-reference to "Section IX, QW-492" corrected by errata to "Section IX, QG-109" *(14-2229)*
18	NC-2432.1	In subpara. (d), last sentence corrected by errata *(14-2229)*
25	Table NC-2571-1	In third column, ninth entry, cross-reference to "NC-2474" corrected by errata to "NC-2575" *(14-2229)*
41	NC-3218	In subpara. (a), cross-reference to "NC-6231" corrected by errata to "NC-6321" *(15-225)*
45	NC-3224.6	In last sentence, cross-reference to "Figure NC-3358-1" corrected by errata to "Figure NC-3358.1(a)-1" *(15-225, 15-1011)*
45	NC-3224.8	In second paragraph, last sentence, cross-reference to "Figure NC-3358-1" corrected by errata to "Figure NC-3358.1(a)-1" *(15-225, 15-1011)*
45	NC-3224.9	In last sentence, cross-reference to "Figure NC-3358-1" corrected by errata to "Figure NC-3358.1(a)-1" *(15-225, 15-1011)*
47	NC-3224.13	In subparas. (b)(3) and (c)(3), cross-reference to "NC-3252.2(b)" deleted by errata *(15-225, 15-1011)*
55	NC-3232.2	In subpara. (b), cross-reference to "NC-3234.1(c)" corrected by errata to "NC-3234.1(b)"*(15-225, 15-1011)*
57	NC-3235	In subpara. (d), cross-reference to "NC-4237" corrected by errata to "NC-3237" *(15-225, 15-1011)*

Page	Location	Change (Record Number)
59	NC-3237	In first sentence, cross-reference to "NC-3224.11(c)" corrected by errata to "NC-3224.13(d)" *(15-225, 15-1011)*
64	NC-3258.1	In subparas. (a) and (b), cross-references to "Figure NC-3358-1" corrected by errata to "Figure NC-3358.1(a)-1" *(15-225, 15-1011)*
66	NC-3261	In first paragraph and subpara. (b), cross-references to "Figure NC-3358-1" corrected by errata to "Figure NC-3358.1(a)-1" *(15-225, 15-1011)*
88	Figure NC-3335(b)-1	Revised editorially
90	NC-3351.2	Endnote reference corrected by errata *(14-1554)*
90	NC-3351.3	First endnote reference corrected by errata *(14-1554)*
90	NC-3351.4	Endnote reference corrected by errata *(14-1554)*
91	Figure NC-3352-1	Revised editorially
94	Figure NC-3358.1(a)-1	General Notes removed from the graphic by errata and redesignated as Notes (1) through (5) *(14-1224)*
100	NC-3432.1	In subpara. (c), cross-reference to "NC-1150" revised to "NC-1130" *(14-2214)*
110	NC-3441.9	In subpara. (a)(3), first sentence, the phrase "Except for flanged joints conforming to (5)" deleted by errata *(14-1561)*
117	NC-3512.2	Revised *(12-503)*
131	NC-3642.1	*(1)* Subparagraph (c) revised *(13-621)* *(2)* Former endnote 28 deleted; subsequent endnotes renumbered *(13-621)*
131	Table NC-3642.1(c)-1	Deleted *(13-621)*
140	NC-3647.2	*(1)* Nomenclature re-ordered by errata *(14-1533)* *(2)* In definition of S, "ksi" corrected by errata to "psi" *(13-1034)*
147	NC-3654.2	Subparagraph (a) revised *(12-1975, 13-1280)*
147	NC-3655	*(1)* Subparagraph (a)(2) revised *(12-1975, 13-1280)* *(2)* In subparas. (b)(2) and (b)(4), definition of S_h added *(13-1280)* *(3)* In subpara. (b)(3), definition of M_E revised *(13-832)*
153	Table NC-3673.2(b)-1	*(1)* "Run legs" equations for "Branch connection or unreinforced fabricated tee" revised *(10-1819)* *(2)* In General Note (a), definition of d_i added, and in Note (9), last sentence added *(10-1819)*
169	Figure NC-3862(a)-1	Revised editorially
171	Figure NC-3863-1	Revised editorially
167	NC-3911.1	In first sentence, endnote reference corrected by errata *(14-1554)*
175	Figure NC-3922.1-1	*(1)* Revised *(12-887)* *(2)* Callouts corrected by errata *(14-1551)* *(3)* In General Note (a), cross-reference to "Figure ND-3822.1-2" corrected by errata to "Figure NC-3922.1-2" *(14-1551)*
177	NC-3922.3	In subpara. (a), last two equations for S_{cs} revised, and in subpara. (b), second, fourth, and fifth equations for S_{ca} revised *(12-887)*
179	Table NC-3923.1-1	Revised *(12-887)*

Page	*Location*	*Change (Record Number)*
186	NC-3933.4	In subpara. (b), eq. (25) for SI units revised *(12-887)*
187	NC-3933.5(h)	Equation (26) for SI units revised *(12-887)*
209	NC-4223.1	Revised *(13-621)*
216	Figure NC-4243.1-1	Revised editorially
222	Figure NC-4244(e)-2	Revised editorially
228	NC-4266	In subpara. (c)(2)(-b), first sentence, cross-reference to "NC-3239.8" corrected by errata to "NC-3237" *(14-2229)*
231	Figure NC-4266(a)-1	Revised editorially
233	Figure NC-4266(b)-1	Revised editorially
236	Figure NC-4267-1	Revised editorially
237	NC-4324	Cross-references to Section IX, QW-201 and QW-300.20 deleted by errata *(14-2229)*
242	NC-4424	In first paragraph, cross-reference to "Table NB-3683.2-1" corrected by errata to "Table NC-3673.2(b)-1" *(14-2229)*
263	NC-5521	Subparagraphs (a), (a)(3), and (a)(4) revised *(12-454)*
273	NC-6922	In numerator of eq. (3), D corrected by errata to B *(14-2353)*
276	NC-7111	In subpara. (b), edition year for ASME PTC 25 deleted *(14-873)*
290	NC-7738	In first sentence, edition year for ASME PTC 25 deleted *(14-873)*
292	NC-7746	*(1)* In first sentence, edition year for ASME PTC 25 deleted *(14-873)* *(2)* In last sentence, endnote reference corrected by errata *(14-1172)*
294	NC-7755	*(1)* In first sentence, edition year for ASME PTC 25 deleted *(14-873)* *(2)* In last sentence, endnote reference corrected by errata *(14-1172)*
296	NC-7764	*(1)* In first sentence, edition year for ASME PTC 25 deleted *(14-873)* *(2)* In last sentence, endnote reference corrected by errata *(14-1172)*

NOTE: Volume 63 of the Interpretations to Section III, Divisions 1 and 2 of the ASME Boiler and Pressure Vessel Code follows the last page of Subsection NCA.

LIST OF CHANGES IN RECORD NUMBER ORDER

Record Number	Change
10-1819	In Table NC-3673.2(b)-1, revised stress indices and stress intensification factors for branch connections and unreinforced fabricated tees where $r/R \leq 0.5$.
12-454	Incorporated acceptance of the ASNT SNT-TC-1A 2011 standard into NC-5521 and clarified the requirement for the near-vision acuity examination.
12-503	Added standard design rules for socket-welded end and nonwelded end instrument, control, and sampling line valves, NPS 1 (DN 25) and smaller, to NC-3512.2.
12-887	Revised NC-3900.
12-1046	Editorial and stylistic revisions to correct changes made during the XML conversion.
12-1975	In NC-3654.2(a) and NC-3655(a)(2), changed “eqs. NC-3653.1(a)(9a) and NC-3653.1(b)(9b)” to “eq. NC-3653.1(a)(9a)” for appropriate application to Levels C and D Service Limits. Please see the proposal for further information.
13-621	Deleted Table NC-3642.1(c)-1 and replaced it with new Nonmandatory Appendix. Changed references to this Table in NC-3642 and NC-4223 to reference the new Appendix. Deleted NC-4223.1(b).
13-832	Made additions to the definition of M_E in NC-3655(b)(3) to definitively state that it includes weight and inertial loading, which is implied by the initial discussion in these sections but not clearly stated in the definition.
13-860	In the Foreword, the subtitle has been deleted and replaced with an ANSI disclaimer as a footnote.
13-1032	Added a subparagraph to the Organization of Section III, Article 9(d), *References to Appendices* to add guidance on the use of Nonmandatory Appendices for Section III.
13-1034	Errata correction. See Summary of Changes for details.
13-1280	Changed NC-3654.2(a), NC-3655(a)(2), NC-3655(b)(2), and NC-3655(b)(4) to state that S_h and S_y are taken at a temperature consistent with the load being considered.
13-1943	Errata changes to NC-3358.3 and NC-3358.4.
14-873	In NC-7111(b), NC-7738, NC-7746, NC-7755, and NC-7764, deleted ASME PTC-25 edition year.
14-1172	Errata correction. See Summary of Changes for details.
14-1224	Errata correction. See Summary of Changes for details.
14-1533	Errata correction. See Summary of Changes for details.
14-1551	Errata correction. See Summary of Changes for details.
14-1554	Errata correction. See Summary of Changes for details.
14-1561	Errata correction. See Summary of Changes for details.
14-1713	Revised NC-2126(e).
14-2214	Changed cross-reference to “NC-1150” to “NC-1130” in NC-3432.1(c).
14-2229	Errata correction. See Summary of Changes for details.
14-2353	Errata correction. See Summary of Changes for details.

CROSS-REFERENCING AND STYLISTIC CHANGES IN THE BOILER AND PRESSURE VESSEL CODE

There have been structural and stylistic changes to BPVC, starting with the 2011 Addenda, that should be noted to aid navigating the contents. The following is an overview of the changes:

Subparagraph Breakdowns/Nested Lists Hierarchy

- First-level breakdowns are designated as (a), (b), (c), etc., as in the past.
- Second-level breakdowns are designated as (1), (2), (3), etc., as in the past.
- Third-level breakdowns are now designated as (-a), (-b), (-c), etc.
- Fourth-level breakdowns are now designated as (-1), (-2), (-3), etc.
- Fifth-level breakdowns are now designated as (+a), (+b), (+c), etc.
- Sixth-level breakdowns are now designated as (+1), (+2), etc.

Footnotes

With the exception of those included in the front matter (roman-numbered pages), all footnotes are treated as endnotes. The endnotes are referenced in numeric order and appear at the end of each BPVC section/subsection.

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees

Submittal of Technical Inquiries to the Boiler and Pressure Vessel Standards Committees has been moved to the front matter. This information now appears in all Boiler Code Sections (except for Code Case books).

Cross-References

It is our intention to establish cross-reference link functionality in the current edition and moving forward. To facilitate this, cross-reference style has changed. Cross-references within a subsection or subarticle will not include the designator/identifier of that subsection/subarticle. Examples follow:

- *(Sub-)Paragraph Cross-References.* The cross-references to subparagraph breakdowns will follow the hierarchy of the designators under which the breakdown appears.
  - If subparagraph (-a) appears in X.1(c)(1) and is referenced in X.1(c)(1), it will be referenced as (-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(c)(2), it will be referenced as (1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.1(e)(1), it will be referenced as (c)(1)(-a).
  - If subparagraph (-a) appears in X.1(c)(1) but is referenced in X.2(c)(2), it will be referenced as X.1(c)(1)(-a).
- *Equation Cross-References.* The cross-references to equations will follow the same logic. For example, if eq. (1) appears in X.1(a)(1) but is referenced in X.1(b), it will be referenced as eq. (a)(1)(1). If eq. (1) appears in X.1(a)(1) but is referenced in a different subsection/subarticle/paragraph, it will be referenced as eq. X.1(a)(1)(1).

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ARTICLE NC-1000 INTRODUCTION

NC-1100 SCOPE

(a) Subsection NC contains rules for the material, design, fabrication, examination, testing, overpressure relief, marking, stamping, and preparation of reports by the Certificate Holder for items which are intended to conform to the requirements for Class 2 construction.

(b) The rules of Subsection NC cover the strength and pressure integrity of items the failure of which would violate the pressure-retaining boundary. The rules cover load stresses but do not cover deterioration which may occur in service as a result of corrosion, radiation effects, or instability of materials. NCA-1130 further limits the rules of this Subsection.

(c) Subsection NC does not contain rules to cover all details of construction of Class 2 vessels and storage tanks. Where complete details are not provided in this Subsection, it is intended that the N Certificate Holder, subject to the approval of the Owner or his designee and acceptance by the Inspector, shall provide details of construction which will be consistent with those provided by the rules of this Subsection.

NC-1120 TEMPERATURE LIMITS

Vessels are to be designed using the standard design method in NC-3300 or the alternative design rules of NC-3200, which allows the use of analysis with the higher design stress intensity values of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4.

NC-1130 BOUNDARIES OF JURISDICTION APPLICABLE TO THIS SUBSECTION

NC-1131 Boundary of Components

The Design Specification shall define the boundary of a component to which piping or another component is attached. The boundary shall not be closer to a vessel, tank, pump, or valve than:

(a) the first circumferential joint in welded connections (the connecting weld shall be considered part of the piping);

(b) the face of the first flange in bolted connections (the bolts shall be considered part of the piping);

(c) the first threaded joint in screwed connections.

NC-1132 Boundary Between Components and Attachments

NC-1132.1 Attachments.

(a) An *attachment* is an element in contact with or connected to the inside or outside of the pressure-retaining portion of a component.

(b) Attachments may have either a pressure-retaining function or a nonpressure-retaining function.

(1) Attachments with a pressure-retaining function include items such as:

(-a) pressure boundary stiffeners;

(-b) branch and vessel opening reinforcement.

(2) Attachments with a nonpressure-retaining function include items such as:

(-a) valve guides, thermal sleeves, and turning vanes;

(-b) vessel saddles, support and shear lugs, brackets, pipe clamps, trunnions, skirts, and other items within the component support load path.

(c) Attachments may also have either a structural or nonstructural function.

(1) Attachments with a structural function (structural attachments):

(-a) perform a pressure-retaining function;

(-b) are in the component support load path.

(2) Attachments with a nonstructural function (nonstructural attachments):

(-a) do not perform a pressure-retaining function;

(-b) are not in the component support load path;

(-c) may be permanent or temporary.

Nonstructural attachments include items such as nameplates, insulation supports, and locating and lifting lugs.

NC-1132.2 Jurisdictional Boundary. The jurisdictional boundary between a pressure-retaining component and an attachment defined in the Design Specification shall not be any closer to the pressure-retaining portion of the component than as defined in (a) through (g) below. Figures NC-1132.2-1 through NC-1132.2-3 are provided as an aid in defining the boundary and construction requirements of this Subsection.

(a) Attachments cast or forged with the component and weld buildup on the component surface shall be considered part of the component.

(b) Attachments, welds, and fasteners having a pressure-retaining function shall be considered part of the component.

(c) Except as provided in (d) and (e) below, the boundary between a pressure-retaining component and an attachment not having a pressure-retaining function shall be at the surface of the component.

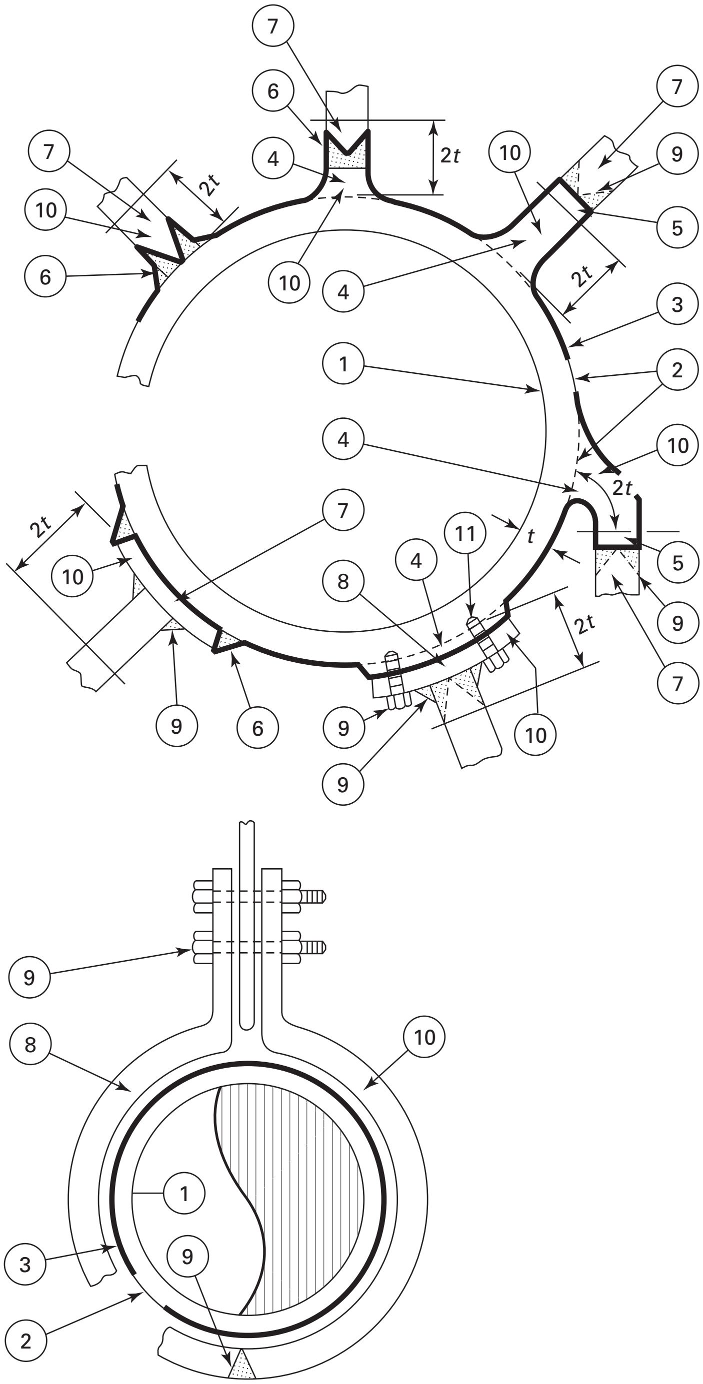
(d) The first connecting weld of a nonpressure-retaining structural attachment to a component shall be considered part of the component unless the weld is more than $2t$ from the pressure-retaining portion of the component, where t is the nominal thickness of the pressure-retaining material. Beyond $2t$ from the pressure-retaining portion of the component, the first weld shall be considered part of the attachment.

(e) The first connecting weld of a welded nonstructural attachment to a component shall be considered part of the attachment. At or within $2t$ from the pressure-retaining portion of the component the first connecting weld shall conform to NC-4430.

(f) Mechanical fasteners used to connect a nonpressure-retaining attachment to the component shall be considered part of the attachment.

(g) The boundary may be located further from the pressure-retaining portion of the component than as defined in (a) through (f) above when specified in the Design Specification.

Figure NC-1132.2-1
Attachments in the Component Support Load Path That Do Not Perform a Pressure-Retaining Function



(1) Component shall conform to Subsection NC.

(2) Pressure-retaining portion of the component.

(3) Jurisdictional boundary (heavy line).

(4) Cast or forged attachment or weld buildup shall conform to Subsection NC.

(5) Beyond 2*t* from the pressure-retaining portion of the component, the design rules of Article NF-3000 may be used as a substitute for the design rules of Article NC-3000.

(6) At or within 2*t* from the pressure-retaining portion of the component, the first connecting weld shall conform to Subsection NC.

(7) Beyond 2*t* from the pressure-retaining portion of the component or beyond the first connecting weld, the attachment shall conform to Subsection NF [see Note (1)].

(8) Bearing, clamped, or fastened attachment shall conform to Subsection NF [see Note (1)].

(9) Attachment connection shall conform to Subsection NF [see Note (1)].

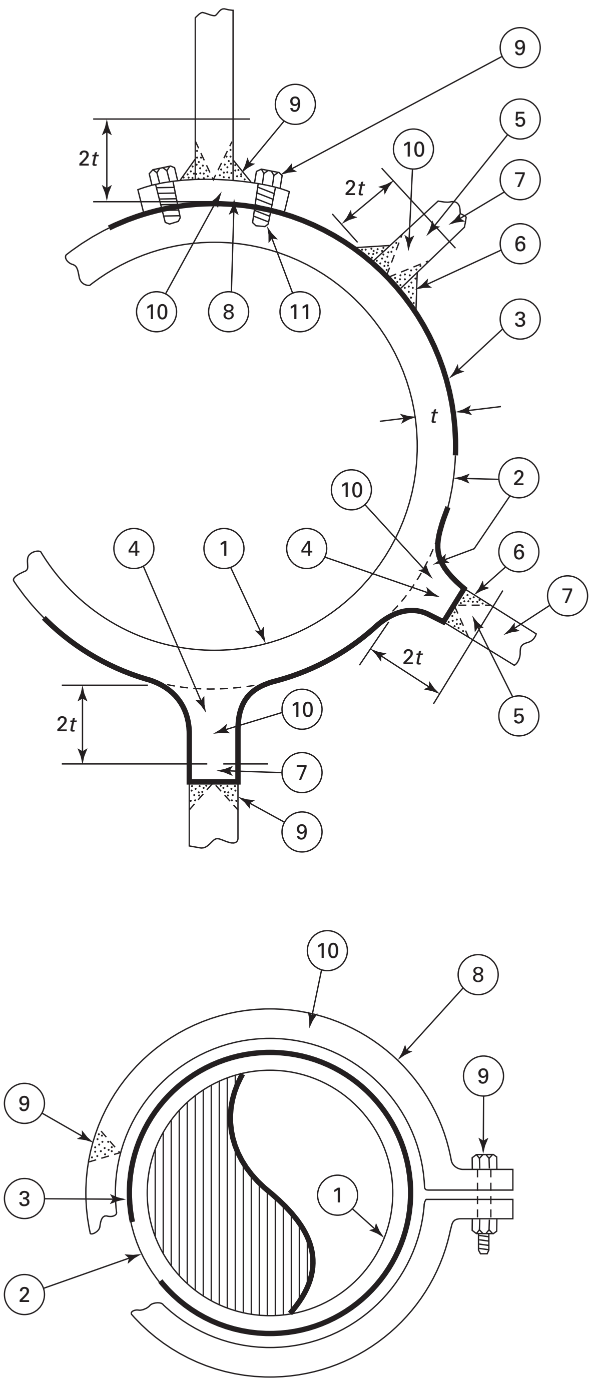
(10) At or within 2t from the pressure-retaining portion of the component, the interaction effects of the attachment shall be considered in accordance with NC-3135.

(11) Drilled holes shall conform to Subsection NC.

GENERAL NOTE: These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

NOTE:
(1) If the attachment is an intervening element [NF-1110(c)], material, design and connections, as appropriate, are outside Code jurisdiction.

Figure NC-1132.2-2
Attachments That Do Not Perform a Pressure-Retaining Function and Are Not in the Component Support Load Path (Nonstructural Attachments)



(1) Component shall conform to Subsection NC.

(2) Pressure-retaining portion of the component.

(3) Jurisdictional boundary (heavy line).

(4) Cast or forged attachment or weld buildup shall conform to Subsection NC.

(5) At or within 2*t* from the pressure-retaining portion of the component, the material of the first welded nonstructural attachment shall conform to NC-2190; design is outside Code jurisdiction.

(6) At or within 2*t* from the pressure-retaining portion of the component, the first connecting weld shall conform to NC-4430.

(7) Beyond 2*t* from the pressure-retaining portion of the component, the nonstructural attachment is outside Code jurisdiction.

(8) Bearing, clamped, or fastened nonstructural attachment is outside Code jurisdiction.

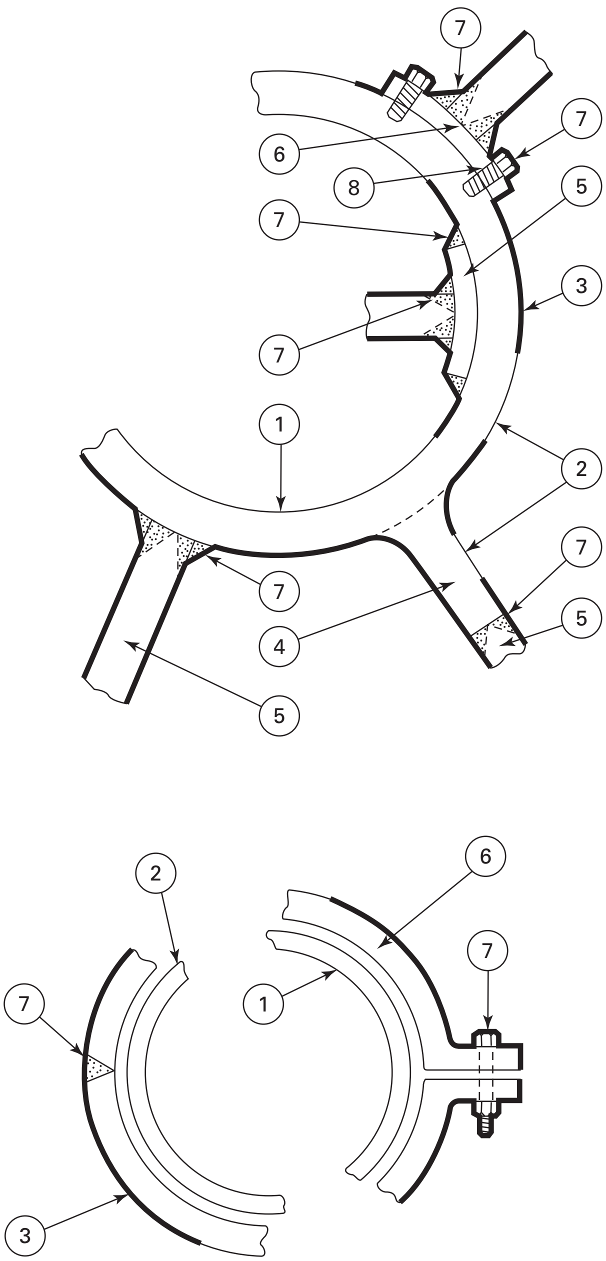
(9) Nonstructural attachment connection is outside Code jurisdiction.

(10) At or within 2*t* from the pressure-retaining portion of the component, the interaction effects of the nonstructural attachment shall be considered in accordance with NC-3135.

(11) Drilled holes shall conform to Subsection NC.

GENERAL NOTE: These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

Figure NC-1132.2-3
Attachments That Perform a Pressure-Retaining Function



(1) Component shall conform to Subsection NC.
(2) Pressure-retaining portion of the component.
(3) Jurisdictional boundary (heavy line).
(4) Cast or forged attachment or weld buildup shall conform to Subsection NC.
(5) Welded attachment shall conform to Subsection NC.
(6) Bearing, clamped, or fastened attachment shall conform to Subsection NC.
(7) Attachment connection shall conform to Subsection NC.
(8) Drilled holes shall conform to Subsection NC.

GENERAL NOTE: These sketches are intended to show jurisdictional concepts and should not be considered as recommended configurations.

ARTICLE NC-2000
MATERIAL

NC-2100 GENERAL REQUIREMENTS FOR MATERIAL

NC-2110 SCOPE OF PRINCIPAL TERMS EMPLOYED

(a) The term *material* as used in this Subsection is defined in NCA-1220. The term *Material Organization* is defined in Article NCA-9000.

(b) The term *pressure-retaining materials* as used in this Subsection applies to vessel shells, heads, and nozzles; pipes, tubes, and fittings; valve bodies, bonnets, and disks; pump casings and covers; and bolting that joins pressure-retaining items.

(c) The requirements of this Article make reference to the term *thickness*. For the purpose intended, the following definitions of nominal thickness apply:

(1) plate — the thickness is the dimension of the short transverse direction;

(2) forgings — the thickness is the dimension defined as follows:

(-a) hollow forgings — the nominal thickness is measured between the inside and outside surfaces (radial thickness);

(-b) disk forgings (axial length less than the outside diameter) — the nominal thickness is the axial length;

(-c) flat ring forgings (axial length less than the radial thickness) — for axial length ≤ 2 in. (50 mm), the axial length is the nominal thickness. For axial length > 2 in. (50 mm), the radial thickness is the nominal thickness.

(-d) rectangular solid forgings: the least rectangular dimension is the nominal thickness.

(3) Castings

(-a) Thickness t for fracture toughness testing is defined as the nominal pipe wall thickness of the connecting piping.

(-b) Thickness t for heat treatment purposes is defined as the thickness of the pressure-retaining wall of the casting excluding flanges and sections designated by the designer as nonpressure retaining.

NC-2120 PRESSURE-RETAINING MATERIAL

NC-2121 Permitted Material Specifications

(a) Pressure-retaining material shall conform to the requirements of one of the specifications for materials given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, including all applicable notes in the tables, and to all of the requirements of this Article that apply to the product form in which the material is used. Attachments that perform a pressure-retaining function shall be pressure-retaining material. For vessels that are designed in accordance with NC-3200, the materials shall be restricted to those materials listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, including all applicable notes in the tables, and to the following clad product specifications, provided they are composed of materials listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4:

(1) SA-263, Specification for Corrosion-Resisting Chromium-Steel Clad Plate, Sheet, and Strip

(2) SA-264, Specification for Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet, and Strip

(3) SA-265, Specification for Nickel and Nickel-Base Alloy Clad Steel Plate

(b) The requirements of this Article do not apply to material for items not associated with the pressure-retaining function of a component such as shafts, stems, trim, spray nozzles, bearings, bushings, springs, wear plates, nor to seals, packing, gaskets, valve seats, and ceramic insulating materials and special alloys used as seal materials in electrical penetration assemblies.

(c) Material made to specifications other than those specified in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 may be used for the following applications:

(1) safety valve disks and nozzles — when the nozzles are internally contained by the external body structure

(2) control valve disks and cages — when the valves function for flow control only

(3) line valve disks in valves — whose inlet connections are NPS 2 (DN 50) and smaller

(d) Material for line fittings and valves, NPS 1 (DN 25) and less, may be of material made to specifications other than those listed in Section II, Part D, Subpart 1, provided that the fittings are in conformance with the requirements of NC-3671.4, the valves meet the requirements of NC-3500, and the material is determined to be adequate for the service conditions by the piping system designer for fittings.

(e) Welding and brazing materials used in manufacture of items shall comply with an SFA specification in Section II, Part C, except as otherwise permitted in Section IX, and shall also comply with the applicable requirements of this Article. The requirements of this Article do not apply to materials used as backing rings or backing strips in welded joints.

(f) The requirements of this Article do not apply to hard surfacing or corrosion resistant weld metal overlay which is 10% or less of the thickness of the base material (NC-3122).

NC-2122 Special Requirements Conflicting With Permitted Material Specifications

Special requirements stipulated in this Article shall apply in lieu of the requirements of the material specifications wherever the special requirements conflict with the material specification requirements (NCA-3856). Where the special requirements include an examination, test, or treatment which is also required by the material specification, the examination, test, or treatment need be performed only once. Required nondestructive examinations shall be performed as specified for each product form in NC-2500. Any examination, repair, test, or treatment required by the material specification or by this Article may be performed by the Material Organization or the Certificate Holder as provided in NC-4121.1. Any hydrostatic or pneumatic pressure test required by a material specification need not be performed, provided the material is identified as not having been pressure tested and it is subsequently pressure tested in accordance with NC-6114, except where the location of the material in the component or the installation would prevent performing any nondestructive examination required by the material specification to be performed subsequent to the hydrostatic or pneumatic test.

(a) The stress rupture test of SA-453 and SA-638 for Grade 660 (UNS S66286) is not required for design temperatures of 800°F (427°C) and below.

(b) In addition to tension testing required by the material specification, forgings produced for flat heads and tubesheets with integrally forged hubs, for butt welding to the adjacent shell, head, or other pressure part, shall have tensile tests performed in accordance with NC-4243.1. The tension test specimen shall be located in accordance with NC-4243.1 and Figure NC-4243.1-1.

NC-2124 Material Size Ranges and Tolerances

(a) Material outside the limits of size or thickness given in any specification in Section II may be used if the material is in compliance with the other requirements of the specification and no size limitation is given in this Subsection. In those specifications in which chemical composition or mechanical properties are indicated to vary with size or thickness, any material outside the specification range shall be required to conform to the composition and mechanical properties shown for the nearest specified range (NCA-3856).

(b) Plate material shall be ordered not thinner than the design thickness. Components, except for piping, made of plate furnished with an undertolerance of not more than the lesser value of 0.01 in. (0.25 mm) or 6% of the ordered thickness, may be used at the full design pressure for the thickness ordered. If the specification to which the plate is ordered allows a greater undertolerance, the ordered thickness of the material shall be sufficiently greater than the design thickness so that the thickness of the material furnished is not more than the lesser of 0.01 in. (0.25 mm) or 6% under the design thickness.

(c) If pipe or tube is ordered by its nominal wall thickness, the manufacturing undertolerance on wall thickness shall be taken into account. The manufacturing undertolerances are given in the several pipe and tube specifications listed in the applicable Tables in Section II, Part D, Subpart 1. After the minimum wall thickness is determined (NC-3641.1), it shall be increased by an amount sufficient to provide for the manufacturing undertolerance allowed in the pipe or tube specification.

NC-2125 Material in Combination[1]

A component may be constructed of any combination of materials permitted in Article NC-2000, provided the applicable rules are followed and the requirements of Section IX for welding dissimilar metals are met.

NC-2126 Finned Tubes

NC-2126.1 Integrally Finned Tubes. Integrally finned tubes may be made from tubes that conform to one of the specifications for tubes listed in Section II, Part D, Subpart 1, Tables 1A and 1B and to all of the special requirements of this Article that apply to that product form. In addition, the following requirements shall apply: (**15**)

(a) The requirements of NC-2550 shall be met by the tube before finning.

(b) The tubes after finning shall conform to the applicable heat treatment requirements of the basic material specification.

(c) The allowable stress values shall be those given in Section II, Part D, Subpart 1, Tables 1A and 1B for the tube material from which the finned tube is made.

(d) After finning, each tube shall be subjected to one of the following tests:

(1) an internal pneumatic pressure test at not less than 250 psi (1.7 MPa) without evidence of leakage; the test method, such as immersion of the tube under water during the test, shall permit visual detection of any leakage;

(2) an individual tube hydrostatic test at 1.25 times the Design Pressure that permits complete examination of the tube for leakage.

(e) A visual examination shall be performed after finning. Material having discontinuities, such as laps, seams, or cracks, is unacceptable. The visual examination personnel shall be trained and qualified in accordance with the Material Organization's Quality System Program or the Certificate Holder's Quality Assurance Program. These examinations are not required to be performed either in accordance with procedures qualified to NC-5100 or by personnel qualified in accordance with NC-5500.

NC-2126.2 Welded Finned Tubes. Welded finned tubes may be made from P-No. 1 and P-No. 8 tubular products (pipe or tubing) that conform to one of the specifications for tubes listed in Section II, Part D, Subpart 1, Table 1A, and to all of the special requirements of this Article which apply to that product form. Heat transfer fins shall be of the same P-Number as the tube and shall be attached by a machine welding process, such as the electric resistance welding or the high frequency resistance welding process. In addition, the following requirements shall apply:

(a) The heat transfer fins need not be certified material. The material for the heat transfer fins shall be identified and suitable for welding; however, Certified Material Test Reports are not required.

(b) The machine welding process used to weld the heat transfer fins to the tubular material shall be performed in accordance with a Welding Procedure Specification.

(c) The procedure qualification shall require that a minimum of 12 cross-sections through the weld zone shall be examined at 5× minimum magnification. There shall be no cracks in the base material or weld; and the weld penetration shall be limited to 20% of the nominal tube wall thickness.

(d) For P-No. 1 material, the weld that attaches the fins to the tubing shall be heat treated after welding to a minimum temperature of 1,000°F (540°C).

(e) The fin is not considered to provide any support to the tube under pressure loading.

NC-2128 Bolting Material

(a) Material for bolts and studs shall conform to the requirements of one of the specifications listed in Section II, Part D, Subpart 1, Table 3. Material for nuts shall conform to SA-194 or to the requirements of one of the specifications for nuts or bolting listed in Section II, Part D, Subpart 1, Table 3. Refer to Section II, Part D, Subpart 1, Table 4 for bolting material for vessels designed to the requirements of NC-3200.

(b) The use of washers is optional. When used, they shall be made of wrought material with mechanical properties compatible with the nuts with which they are to be employed.

NC-2130 CERTIFICATION OF MATERIAL

All materials used in the construction of components shall be certified as required in NCA-3862 and NCA-3861. Certified Material Test Reports are required for pressure-retaining material except as provided by NCA-3861. A Certificate of Compliance may be provided in lieu of a Certified Material Test Report for all other material. Copies of all Certified Material Test Reports and Certificates of Compliance applicable to material used in a component shall be furnished with the material.

NC-2140 WELDING MATERIALS

For the requirements governing the materials to be used for welding, see NC-2400.

NC-2150 MATERIAL IDENTIFICATION

The identification of pressure-retaining material shall meet the requirements of NCA-3856. Material for small items shall be controlled during manufacture and installation of the component so that they are identifiable as acceptable material at all times. Welding and brazing materials shall be controlled during the repair of material and the manufacture and installation so that they are identifiable as acceptable until the material is actually consumed in the process (NC-4122).

NC-2160 DETERIORATION OF MATERIAL IN SERVICE

Consideration of deterioration of material caused by service is generally outside the scope of this Subsection. It is the responsibility of the Owner to select material suitable for the conditions stated in the Design Specifications (NCA-3250), with specific attention being given to the effects of service conditions upon the properties of the material.

NC-2170 HEAT TREATMENT TO ENHANCE IMPACT PROPERTIES

Carbon steels, low alloy steels, and high alloy chromium (Series 4XX) steels may be heat treated by quenching and tempering to enhance their impact properties. Postweld heat treatment of the component at a temperature of not less than 1,100°F (595°C) may be considered to be the tempering phase of the heat treatment.

NC-2180 PROCEDURES FOR HEAT TREATMENT OF MATERIAL

When heat treating temperature or time is required by the material specification and the rules of this Subsection, the heat treating shall be performed in temperature-surveyed and temperature-calibrated furnaces or the heat treating shall be controlled by measurement of material temperature by thermocouples in contact with the material or attached to blocks in contact with the material or by calibrated pyrometric instruments. Heat treating shall be performed under furnace loading conditions such that the heat treatment is in accordance with the material specification and the rules of this Subsection.

NC-2190 NONPRESSURE-RETAINING MATERIAL

(a) Material in the component support load path and not performing a pressure-retaining function (see NC-1130) welded to pressure-retaining material shall meet the requirements of Article NF-2000.

(b) Material not performing a pressure-retaining function and not in the component support load path (nonstructural attachments) welded at or within $2t$ of the

pressure-retaining portion of the component need not comply with Article NC-2000 or Article NF-2000 provided the requirements of NC-4430 are met.

(c) Structural steel rolled shapes, which are permitted by this Subsection to be furnished with a Certificate of Compliance, may be repaired by welding using the welders, documentation, and examination requirements specified in SA-6.

NC-2200 MATERIAL TEST COUPONS AND SPECIMENS FOR FERRITIC STEEL MATERIAL

NC-2210 HEAT TREATMENT REQUIREMENTS

NC-2211 Test Coupon Heat Treatment for Ferritic Material[2]

Where ferritic steel material is subjected to heat treatment during fabrication or installation of a component, the material used for the tensile and impact test specimens shall be heat treated in the same manner as the component, except that test coupons and specimens for P-No. 1 Group Nos. 1 and 2 material with a nominal thickness of 2 in. (50 mm) or less are not required to be so heat treated where nominal thickness for flanges refers to the wall thickness at the weld joint to the pipe or component. The Certificate Holder shall provide the Material Organization with the temperature and heating and cooling rate to be used. In the case of postweld heat treatment, the total time at temperature or temperatures for the test material shall be at least 80% of the total time at temperature or temperatures during actual postweld heat treatment of the material, and the total time at temperature or temperatures for the test material, coupon, or specimen may be performed in a single cycle.

NC-2212 Test Coupon Heat Treatment for Quenched and Tempered Material

NC-2212.1 Cooling Rates. Where ferritic steel material is subjected to quenching from the austenitizing temperature, the test coupons representing those materials shall be cooled at a rate similar to and no faster than the main body of the material except in the case of certain forgings and castings (NC-2223.3 and NC-2226). This rule shall apply for coupons taken directly from the material as well as for separate test coupons representing the material, and one of the general procedures described in NC-2212.2 or one of the specific procedures described in NC-2220 shall be used for each product form.

NC-2212.2 General Procedures. One of the general procedures in (a), (b), and (c) below may be applied to quenched and tempered material or test coupons representing the material, provided the specimens are taken relative to the surface of the product in accordance with NC-2220. Further specific details of the methods to be used shall be the obligation of the Material Organization and the Certificate Holder.

(a) Any procedure may be used which can be demonstrated to produce a cooling rate in the test material that matches the cooling rate of the main body of the product at the region midway between midthickness and the surface ($^1/_4t$) and no nearer any heat treated edge than a distance equal to the nominal thickness t being quenched within 25°F (14°C) and 20 sec at all temperatures after cooling begins from the austenitizing temperature.

(b) If cooling rate data for the material and cooling rate control devices for the test specimens are available, the test specimens may be heat treated in the device to represent the material, provided that the provisions of (a) above are met.

(c) When any of the specific procedures described in NC-2220 are used, faster cooling rates at the edges may be compensated for by:

(1) taking the test specimens at least t from a quenched edge, where t equals the material thickness;

(2) attaching a steel pad at least t wide by a partial penetration weld (which completely seals the buffered surface) to the edge where specimens are to be removed; or

(3) using thermal barriers or insulation at the edge where specimens are to be removed.

It shall be demonstrated (and this information shall be included in the Certified Material Test Report) that the cooling rates are equivalent to (a) or (b) above.

NC-2220 PROCEDURE FOR OBTAINING TEST COUPONS AND SPECIMENS FOR QUENCHED AND TEMPERED MATERIAL

NC-2221 General Requirements

The procedure for obtaining test specimens for quenched and tempered material is related to the product form. Coupon and specimen location shall be as required by the material specification, except as stated in the following paragraphs of this subarticle. References to dimensions signify nominal values.

NC-2222 Plates

NC-2222.1 Orientation and Location of Coupons. Coupons shall be taken so that specimens shall have their longitudinal axes at least $^1/_4t$ from a rolled surface and with the midlength of the specimen at least t from any heat treated edge, where t is the nominal thickness of the material.

NC-2222.2 Requirements for Separate Test Coupons. Where a separate test coupon is used to represent the component material, it shall be of sufficient size to ensure that the cooling rate of the region from which the test coupons are removed represents the cooling rate of the material at least $^1/_4t$ deep and t from any edge of the product. Unless cooling rates applicable to the bulk pieces or product are simulated in accordance with NC-2212.2, the dimensions of the coupon shall be not less than $3t \times 3t \times t$, where t is the nominal material thickness.

NC-2223 Forgings

NC-2223.1 Forgings With 2 in. (50 mm) Maximum Thickness. For forgings with a maximum thickness of 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at the midplane of the thickness or the center of the cross section and with the midlength of the specimens at least 2 in. (50 mm) from any second surface.

NC-2223.2 Forgings With Thickness Exceeding 2 in. (50 mm). For forgings exceeding a thickness of 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $^1/_4t$ of the maximum heat treated thickness from any surface and with the midlength of the specimens at least t from any second surface. This is normally referred to as $^1/_4t \times t$, where t is the maximum heat treated thickness. A thermal buffer may be used to achieve the above conditions [NC-2212.2(c)(3)] unless cooling rates applicable to the bulk forgings are simulated in accordance with NC-2212.2.

NC-2223.3 Very Thick and Complex Forgings. Test coupons for forgings which are both very thick and complex, such as contour nozzles, thick tubesheets, flanges, nozzles, and other complex forgings that are contour shaped or machined to essentially the finished product configuration prior to heat treatment, may be removed from prolongations or other stock provided on the product. The Certificate Holder shall specify the surfaces of the finished product subjected to high tensile stresses in service. The coupons shall be taken so that specimens shall have their longitudinal axes at a distance below the nearest heat treated surface, equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest surface during heat treatment, and with the midlength of the specimens a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the specimens shall not be nearer than $^3/_4$ in. (19 mm) to any heat treated surface and the midlength of the specimens shall be at least $1^1/_2$ in. (38 mm) from any heat treated surface.

NC-2223.4 Coupons From Separately Produced Test Forgings. Test coupons representing forgings from one heat and one heat treatment lot may be taken from a separately forged piece under the conditions given in (a) through (e) below.

(a) The separate test forging shall be of the same heat of material and shall be subjected to substantially the same reduction and working as the production forging it represents.

(b) The separate test forging shall be heat treated in the same furnace charge and under the same conditions as the production forging.

(c) The separate test forging shall be of the same nominal thickness as the production forging.

(d) Test coupons for simple forgings shall be taken so that specimens shall have their longitudinal axes at the region midway between midthickness and the surface and with the midlength of the specimens no nearer any heat treated edge than a distance equal to the forging thickness, except when the thickness–length ratio of the production forging does not permit, in which case a production forging shall be used as the test forging and the midlength of the specimens shall be at the midlength of the test forging.

(e) Test coupons for complex forgings shall be taken in accordance with NC-2223.3.

NC-2223.5 Test Specimens for Forgings. When test specimens for forgings are to be taken under the applicable specification, the Inspector shall have the option of witnessing the selection, placing an identifying stamp on them, and witnessing the testing of these specimens.

NC-2224 Bars and Bolting Material

NC-2224.1 Bars With 2 in. (50 mm) Maximum Thickness. For bars with diameters or thicknesses 2 in. (50 mm) or less, the coupons shall be taken so that specimens shall have their longitudinal axes on a line representing the center of the thickness and with the midlength of the specimens at least one diameter or thickness from a heat treated end.

NC-2224.2 Bars With Thicknesses Exceeding 2 in. (50 mm). For bars with diameters or thicknesses over 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $^1/_4t$ from the outside or rolled surface and with the midlength of the specimens at least t from a heat treated end, where t is either the bar diameter or thickness.

NC-2224.3 Bolting Material. For bolting material, the coupons shall be taken in conformance with the applicable material specification and with the midlength of the specimen at least one diameter or thickness from a heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NC-2225 Tubular Products

NC-2225.1 Tubular Products With 2 in. (50 mm) Maximum Thickness. For tubular products with 2 in. (50 mm) maximum wall thickness, the coupons shall be taken so that specimens shall have their longitudinal axes on a surface midway between the outside and inside surfaces and with the midlength of the specimens at least one wall thickness from a heat treated end.

NC-2225.2 Tubular Products Exceeding 2 in. (50 mm) Nominal Thickness. For tubular products with nominal wall thicknesses exceeding 2 in. (50 mm), the coupons shall be taken so that specimens shall have their longitudinal axes at least $^1/_4t$ from the outside surface and with the midlength of the specimens at least one wall thickness from a heat treated end.

NC-2225.3 Separately Produced Coupons Representing Fittings. Separately produced test coupons representing fittings may be used. When separately produced coupons are used, the requirements of NC-2223.4 shall be met.

NC-2226 Tensile Test Specimen Location (for Quenched and Tempered Ferritic Steel Castings)

NOTE: Users of this requirement should note that the hardenability of some grades may limit the usable section size.

(a) This section applies only to quenched-and-tempered ferritic steel castings with a thickness t exceeding 2 in. (50 mm), where t is the thickness of the pressure-retaining wall of the casting excluding flanges and sections designated by the designer as nonpressure retaining. The order, inquiry, and drawing shall designate what the thickness t is for the casting.

(b) One of the following shall apply:

(1) The longitudinal centering of the thickness of the tension test specimen shall be taken at least $^1/_4t$ from the t dimension surface. For cylindrical castings, the longitudinal center line of the specimens shall be taken at least $^1/_4t$ from the outside or inside surface, and the gage length at least t from the as-heat treated end.

(2) Where separately cast test coupons are used, their dimensions shall be not less than $3t \times 3t \times T$, and each specimen cut from it shall meet the requirements of (b). The test coupon shall be of the same heat of steel and shall receive substantially the same casting practices as the production casting it represents. (Centrifugal castings may be represented by statically cast coupons.) The test coupon shall be heat treated under the same conditions as the production casting(s). The t dimension of the test coupon shall be the same maximum thickness t as defined in (a) above. Where separate test blocks require reheat treatment, thermal buffers in accordance with (b) may be used.

(3) Where specimens are to be removed from the body of the casting, a steel, thermal buffer pad $1t \times 1t \times$ at least $3t$ shall be joined to the casting surface by a partial penetration weld completely sealing the buffered surface prior to the heat treatment process. The test specimens shall be removed from the casting in a location adjacent to the center third of the buffer pad. They shall be located at a minimum distance of $^1/_2$ in. (13 mm) from the buffered surface and $^1/_4t$ from the other heat treated surfaces.

(4) Where specimens are to be removed from the body of the casting, thermal insulation or other thermal barriers shall be used during the heat treatment process adjacent to the casting edge where specimens are to be removed. It shall be demonstrated that the cooling rate of the test specimen is no faster than that of specimens taken by the method described in (1). This information shall be included in the test reports.

(5) Where castings are cast or machined to essentially the finished product configuration prior to heat treatment, the test specimens shall be removed from a casting prolongation or other stock on the product at a location below the nearest heat treated surface indicated on the order. The specimens shall be located with their longitudinal axes a distance below the nearest heat treated surface equivalent to at least the greatest distance that the indicated high tensile stress surface will be from the nearest heat treated surface, and with their midlength a minimum of twice this distance from a second heat treated surface. In any case, the longitudinal axes of the test specimens shall be no nearer than $^1/_4$ in. (6 mm) to a heat treated surface and the midlength shall be at least $1^1/_2$ in. (38 mm) from a second heat treated surface. The component manufacturer shall specify the surfaces of the finished product subjected to high tensile stress in service.

NC-2300 FRACTURE TOUGHNESS REQUIREMENTS FOR MATERIAL

NC-2310 MATERIAL TO BE IMPACT TESTED

NC-2311 Material for Which Impact Testing Is Required

(a) Pressure-retaining material shall be impact tested in accordance with the requirements of NC-2330, except that impact testing of materials described in (1) through (9) below is not a requirement of this Subsection:

(1) material with a nominal section thickness of $^5/_8$ in. (16 mm) and less where thicknesses shall be taken as defined in (-a) through (-e) below:

(-a) for pumps, valves, and fittings, use the largest nominal pipe wall thickness of the connecting pipes;

(-b) for vessels and tanks, use the nominal thickness of the shell or head, as applicable;

(-c) for nozzles or parts welded to vessels, use the lesser of the vessel shell thickness to which the item is welded or the maximum radial thickness of the item exclusive of integral shell butt welding projections;

(-d) for flat heads, tubesheets, or flanges, use the maximum shell thickness associated with the butt welding hub;

(-e) for integral fittings used to attach process piping to the containment vessel (Figure NE-1120-1), use the larger nominal thickness of the pipe connections.

(2) bolting, including studs, nuts, and bolts, with a nominal size of 1 in. (25 mm) or less;

(3) bar with a nominal cross-sectional area that does not exceed 1 in.^{2} (650 mm^2);

(4) all thicknesses of material for pipe, tube, fittings, pumps, and valves with a diameter of NPS 6 (DN 150) and smaller;

(5) material for pumps, valves, and fittings with all pipe connections of $^5/_8$ in. (16 mm) nominal wall thickness and less;

(6) austenitic stainless steels, including precipitation hardened austenitic Grade 660 (UNS S66286);

(7) nonferrous materials;

(8) materials listed in Table NC-2311(a)-1 for which the listed value of T_{NDT}[3] is lower than the Lowest Service Temperature[4] (LST) by an amount established by the rules in Section III Appendices, Nonmandatory Appendix R. This exemption does not exempt either the weld metal (NC-2430) or the welding procedure qualification (NC-4335) from impact testing.

(9) materials for components for which the Lowest Service Temperature exceeds 150°F (65°C).

Table NC-2311(a)-1
Exemptions From Impact Testing Under NC-2311(a)(8)

Material [Note (1)]	Material Condition [Note (2)]	T_{NDT}, °F (°C) [Note (3)] and [Note (4)]
SA-537, Class 1	N	−30 (−35)
SA-516, Grade 70	Q & T	−10 (−25)
SA-516, Grade 70	N	0 (−20)
SA-508, Class 1	Q & T	+10 (−10)
SA-533, Grade B	Q & T	+10 (−10)
SA-299 [Note (5)]	N	+20 (−7)
SA-216, Grades WCB and WCC	Q & T	+30 (0)
SA-36 (Plate)	HR	+40 (+5)
SA-508, Class 2	Q & T	+40 (+5)

NOTES:
(1) These materials are exempt from toughness testing when LST − T_{NDT} is satisfied in accordance with the rules established in Section III Appendices, Nonmandatory Appendix R.
(2) Material Condition letters refer to:
N = normalize
Q & T = quench and temper
HR = hot rolled
(3) These values for T_{NDT} were established from data on heavy section steel [thickness greater than 2$^1/_2$ in. (64 mm)]. Values for sections less than 2$^1/_2$ in. (64 mm) thick are held constant until additional data are obtained.
(4) T_{NDT} = temperature at or above nil-ductility transition temperature NDT (ASTM E208); T_{NDT} is 10°F (5°C) below the temperature at which at least two specimens show no-break performance.
(5) Materials made to a fine grain melting practice.

(b) The Design Specification shall state the Lowest Service Temperature for the component.

(c) Drop weight tests are not required for the martensitic high alloy chromium (Series 4XX) steels and precipitation-hardening steels listed in Section II, Part D, Subpart 1, Table 1A. The other requirements of NC-2331 and NC-2332 apply for these steels. For nominal wall thicknesses greater than 2$^1/_2$ in. (64 mm), the required C_v values shall be 40 mils (1.0 mm) lateral expansion.

NC-2320 IMPACT TEST PROCEDURES

NC-2321 Types of Tests

NC-2321.1 Drop Weight Tests. The drop weight test, when required, shall be performed in accordance with ASTM E208. Specimen types P-1, P-2, or P-3 may be used. When drop weight tests are performed to meet the requirements of NC-2300, the test temperature and the results shall be reported on the Certified Material Test Report.

NC-2321.2 Charpy V-Notch Tests. The Charpy V-notch test (C_v), when required, shall be performed in accordance with SA-370. Specimens shall be in accordance with SA-370, Figure 11, Type A. A test shall consist of a set of three full-size 10 mm × 10 mm specimens. The lateral expansion and absorbed energy, as applicable, and the test temperature, as well as the orientation and location of all tests performed to meet the requirements of NC-2330 shall be reported in the Certified Material Test Report.

NC-2322 Test Specimens

NC-2322.1 Location of Test Specimens. Impact test specimens shall be removed from a depth within the material that is at least as far from the material surface as that specified for tensile test specimens in the material specification. For bolting, the C_v impact test specimens shall be taken with the longitudinal axis of the specimen located at least one-half radius or 1 in. (25 mm) below the surface plus the machining allowance per side, whichever is less. The fracture plane of the specimen shall be at least one diameter or thickness from the heat treated end. When the studs, nuts, or bolts are not of sufficient length, the midlength of the specimen shall be at the midlength of the studs, nuts, or bolts. The studs, nuts, or bolts selected to provide test coupon material shall be identical with respect to the quenched contour and size except for length, which shall equal or exceed the length of the represented studs, nuts, or bolts.

NC-2322.2 Orientation of Impact Test Specimens.

(a) Specimens for C_v impact tests shall be oriented as required in NC-2200 for the tensile test specimen or, alternatively, the orientation may be in the direction of maximum stress. The notch of the C_v specimen shall be normal to the surface of the material.

(b) Specimens for drop weight tests may have their axes oriented in any direction.

NC-2330 TEST REQUIREMENTS AND ACCEPTANCE STANDARDS

NC-2331 Pressure-Retaining Material Test Methods and Temperature

Pressure-retaining material shall be impact tested in accordance with one of the test methods indicated below:

(a) Charpy V-notch testing at or below the Lowest Service Metal Temperature[5, 6]

(b) drop weight testing to show that the Lowest Service Metal Temperature[5] (LST $- T_{NDT}$[3]) is satisfied in accordance with the rules established in Section III Appendices, Nonmandatory Appendix R.

NC-2332 Specific Test Methods and Acceptance Standards for Pressure-Retaining Material for Tests Based on Lowest Service Metal Temperatures

NC-2332.1 Pressure-Retaining Material Other Than Bolting With 2½ in. (64 mm) Maximum Thickness.[7] Except as limited in NC-4335, apply one of the methods of NC-2331 to test: base material; the base material, the heat affected zone, and weld metal for the weld procedure qualification tests of NC-4335; and the weld metal for NC-2431. The impact test results shall meet one of the acceptance standards applicable to the specified test method.

(a) Charpy V-Notch Testing for Lateral Expansion Values. The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NC-2332.1-1.

(b) Charpy V-Notch Testing for Absorbed Energy Values. The test results of the three specimens, collectively and singly, shall meet the respective requirements of Table NC-2332.1-2.

(c) Drop Weight Testing. An acceptance test shall consist of at least two no-break specimens as described in ASTM E208.

NC-2332.2 Pressure-Retaining Material Other Than Bolting With Thickness[7] Exceeding 2½ in. (64 mm).

(a) The base material, and the weld procedure qualification weld metal tests of NC-4335, shall be tested by the drop weight method as specified in NC-2321.1 and NC-2331(b).

(b) Except as limited in NC-4335, apply one of the methods of NC-2331 to test: the base material and the heat affected zone of the weld procedure qualification tests for NC-4335; and the weld metal for NC-2431.

(c) The acceptance standards shall be as given in NC-2332.1(a), NC-2332.1(b), or NC-2332.1(c), as applicable.

NC-2332.3 Bolting Material. For bolting material, including nuts, studs, and bolts, a Charpy V-notch test shall be performed. The tests shall be performed at or below the Lowest Service Metal Temperature, and all three specimens shall meet the requirements of Table NC-2332.3-1.

Table NC-2332.1-1
Required C_v Lateral Expansion Values for Pressure-Retaining Material Other Than Bolting

Nominal Wall Thickness, in. (mm) [Note (1)]	Lateral Expansion, mils (mm) Average of 3	Lowest 1 of 3
⅝ (16) or less [Note (2)]	...	...
Over ⅝ to 1 (16 to 25), incl.	20 (0.50)	15 (0.38)
Over 1 to 1½ (25 to 38), incl.	25 (0.64)	20 (0.50)
Over 1½ to 2½ (38 to 64), incl.	35 (0.89)	30 (0.75)
Over 2½ (64) [Note (3)]	45 (1.14)	40 (1.0)

GENERAL NOTES:

(a) Where weld metal tests of NC-2400 are made to these requirements, the impact lateral expansion shall conform to the requirements of either of the base materials being joined.

(b) Where two base materials having different required lateral expansion values are joined, the weld metal lateral expansion requirements of NC-4330 shall conform to the requirements of either of the base materials.

NOTES:

(1) For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting pipe. For vessels use the least of:

(a) the maximum radial thickness of the item exclusive of integral butt welded projections;

(b) the vessel shell thickness to which the item is welded;

(c) the maximum shell thickness associated with the item for flat heads, tubesheets, or flanges.

(2) No test required.

(3) For use with NC-2332.2(b).

NC-2340 NUMBER OF IMPACT TESTS REQUIRED

NC-2341 Plates

One test shall be made from each plate as heat treated. Where plates are furnished in the non-heattreated condition and qualified by heat treated test specimens, one test shall be made for each plate as rolled. The term *as-rolled* refers to the plate rolled from a slab or directly from an ingot, not to its heat treated condition.

NC-2342 Forgings and Castings

(a) Where an individual forging or casting is less than 1,000 lb (450 kg), one test shall be made to represent each heat in each heat treatment charge.

(b) When heat treatment is performed in a continuous-type furnace with suitable temperature controls and equipped with recording pyrometers so that complete heat treatment records are available, a heat treatment charge shall be considered as the lesser of a continuous run not exceeding 8 hr duration or a total weight, so treated, not exceeding 2,000 lb (900 kg).

Table NC-2332.1-2
Required C_v Energy Values for Pressure-Retaining Material Other Than Bolting

Nominal Wall Thickness, in. (mm) [Note (2)]	Energy, ft-lb (J) for Base Materials [Note (1)] of Specified Minimum Yield Strength, ksi (MPa)					
	55 ksi (380 MPa) or Below		Over 55 ksi to 75 ksi (380 MPa to 515 MPa), Incl.		Over 75 ksi to 105 ksi (515 MPa to 725 MPa), Incl.	
	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3	Average of 3	Lowest 1 of 3
$^5/_8$ (16) or less [Note (3)]	...	...	...	...	...	...
Over $^5/_8$ to 1 (16 to 25), incl.	20 (27)	15 (20)	25 (34)	20 (27)	30 (41)	25 (34)
Over 1 to $1^1/_2$ (25 to 38), incl.	25 (34)	20 (27)	30 (41)	25 (34)	35 (47)	30 (41)
Over $1^1/_2$ to $2^1/_2$ (38 to 64), incl.	35 (47)	30 (41)	40 (54)	35 (47)	45 (61)	40 (54)
Over $2^1/_2$ (64) [Note (4)]	45 (61)	40 (54)	50 (68)	45 (61)	55 (75)	50 (68)

GENERAL NOTE: Where weld metal tests of NC-2400 are made to these requirements, the impact energy shall conform to the requirements of either of the base materials being joined.

NOTES:
(1) Where two base materials having different required energy values are joined, the weld metal impact energy requirements of the procedure qualification tests of NC-4330 shall conform to the requirements of either of the base materials.
(2) For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting pipe. For vessels use the least of:
    (a) the maximum radial thickness of the item exclusive of integral butt welded projections;
    (b) the vessel shell thickness to which the item is welded;
    (c) the maximum shell thickness associated with the item for flat heads, tubesheets, or flanges.
(3) No test required.
(4) For use with NC-2332.2(b).

(c) One test shall be made for each forging or casting of 1,000 lb to 10,000 lb (450 kg to 4 500 kg).

(d) As an alternative to (c), a separate test forging or casting may be used to represent forgings or castings of different sizes in one heat and heat treat lot, provided the test piece is a representation of the greatest thickness in the heat treat lot. In addition, test forgings shall have been subjected to substantially the same reduction and working as the forgings represented.

(e) Forgings or castings larger than 10,000 lb (4 500 kg) shall have two tests per part for Charpy V-notch and one test for drop weights. The location of drop weight or C_v test specimens shall be selected so that an equal number of specimens is obtained from positions in the forging or casting 180 deg apart.

Table NC-2332.3-1
Required C_v Values for Bolting Material Tested in Accordance With NC-2332.3

Nominal Diameter, in. (mm)	Lateral Expansion, mils (mm)	Absorbed Energy, ft-lb (J)
1 (25) or less	No test required	No test required
Over 1 through 4 (25 through 100)	25 (0.64)	No requirements
Over 4 (100)	25 (0.64)	45 (61)

(f) As an alternative to (e) for static castings, a separately cast coupon [NC-2226(b)(2)] may be used; one test shall be made for Charpy V-notch and one test for drop weight.

NC-2343 Bars

One test shall be made for each lot of bars with a cross-sectional area greater than 1 in.^{2} (650 mm^2) where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed 6,000 lb (2 700 kg).

NC-2344 Tubular Products and Fittings

On products which are seamless or welded without filler metal, one test shall be made from each lot. On products which are welded with filler metal, one additional test with the specimens taken from the weld area shall also be made on each lot. A lot shall be defined as stated in the applicable material specification, but in no case shall a lot consist of products from more than one heat of material and of more than one diameter, with the nominal thickness of any product included not exceeding that to be impact tested by more than $^1/_4$ in. (6 mm); such a lot shall be in a single heat treatment load or in the same continuous run in a continuous furnace controlled within a 50°F (28°C) range and equipped with recording pyrometers.

NC-2345 Bolting Material

One test shall be made for each lot of material where a lot is defined as one heat of material heat treated in one charge or as one continuous operation, not to exceed the following:

Diameter	Weight
$1^3/_4$ in. (44 mm) and less	1,500 lb (680 kg)
Over $1^3/_4$ in. to $2^1/_2$ in. (44 mm to 64 mm)	3,000 lb (1 350 kg)
Over $2^1/_2$ in. to 5 in. (64 mm to 125 mm)	6,000 lb (2 700 kg)
Over 5 in. (125 mm)	10,000 lb (4 500 kg)

NC-2350 RETESTS

NC-2351 Retests for Material Other Than Bolting

(a) For Charpy V-notch tests required by NC-2330, one retest at the same temperature may be conducted, provided:

(1) the average value of the test results meets the average of three requirements specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable;

(2) not more than one specimen per test is below the lowest one of three requirements specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable;

(3) the specimen not meeting the requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the lowest one of three requirements specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall be equal to or greater than the average of three requirements specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable.

NC-2352 Retests for Bolting Material

(a) For Charpy V-notch tests required by NC-2330, one retest at the same temperature may be conducted, provided:

(1) not more than one specimen per test is below the acceptance requirements;

(2) the specimen not meeting the acceptance requirements is not lower than 5 ft-lb (6.8 J) or 5 mils (0.13 mm) below the acceptance requirements.

(b) A retest consists of two additional specimens taken as near as practicable to the failed specimens. For acceptance of the retests, both specimens shall meet the specified acceptance requirements.

NC-2360 CALIBRATION OF INSTRUMENTS AND EQUIPMENT

Calibration of temperature instruments and C_v impact test machines used in impact testing shall be performed at the frequency specified in (a) or (b) below.

(a) Temperature instruments used to control test temperature of specimens shall be calibrated and the results recorded to meet the requirements of NCA-3858.2 at least once in each 3-month interval.

(b) C_v impact test machines shall be calibrated and the results recorded to meet the requirements of NCA-3858.2. The calibrations shall be performed using the frequency and methods outlined in ASTM E23 and employing standard specimens obtained from the National Institute of Standards and Technology, or any supplier of subcontracted calibration services accredited in accordance with the requirements of NCA-3126 and NCA-3855.3(c).

NC-2400 WELDING MATERIAL

NC-2410 GENERAL REQUIREMENTS

(a) All welding material used in the construction and repair of components or material, except welding material used for cladding or hard surfacing, shall conform to the requirements of the welding material specification or to the requirements for other welding material as permitted in Section IX. In addition, welding material shall conform to the requirements stated in this subarticle and to the rules covering identification in NC-2150.

(b) The Certificate Holder shall provide the organization performing the testing with the information listed below, as applicable:

(1) welding process;

(2) SFA specification and classification;

(3) other identification if no SFA specification applies;

(4) minimum tensile strength [NC-2431.1(e)] in either the as-welded or heat treated condition, or both [NC-2431.1(c)];

(5) drop weight test for material in either the as-welded or heat treated condition, or both (NC-2332);

(6) Charpy V-notch test for material as-welded, or heat treated, or both (NC-2331); the test temperature and the lateral expansion or the absorbed energy shall be provided;

(7) the preheat and interpass temperatures to be used during welding of the test coupon [NC-2431.1(c)];

(8) postweld heat treatment time, temperature range, and maximum cooling rate, if the production weld will be heat treated [NC-2431.1(c)];

(9) elements for which chemical analysis is required per the SFA specification or WPS, and NC-2432;

(10) minimum delta ferrite (NC-2433).

NC-2420 REQUIRED TESTS (15)

The required tests shall be conducted for each lot of covered, flux cored, or fabricated electrodes; for each heat of bare electrodes, rod, or wire for use with the OFW, GMAW, GTAW, PAW, and EGW (electrogas welding) processes (Section IX, QG-109); for each heat of consumable inserts; for each combination of heat of bare electrodes and lot of submerged arc flux; for each combination of lot of fabricated electrodes and lot of submerged arc flux; for each combination of heat of bare electrodes or lot of fabricated electrodes and dry blend of supplementary powdered filler metal and lot of submerged arc flux; or for each combination of heat of bare electrodes and lot of electroslag flux. Tests performed on welding material in the qualification of weld procedures will satisfy the testing requirements for the lot, heat, or combination of heat and batch of welding material used, provided the tests required by Article NC-4000 and this subarticle are made and the results conform to the requirements of this Article. The definitions in (a) through (h) below apply.

(a) A *dry batch of covering mixture* is defined as the quantity of dry covering ingredients mixed at one time in one mixing vessel; a dry batch may be used singly or may be subsequently subdivided into quantities to which the liquid binders may be added to produce a number of wet mixes.

(b) A *dry blend* is defined as one or more dry batches mixed in a mixing vessel and combined proportionately to produce a uniformity of mixed ingredients equal to that obtained by mixing the same total amount of dry ingredients at one time in one mixing vessel.

(c) A *wet mix* is defined as the combination of a dry batch (a) or dry blend (b) and liquid binder ingredients at one time in one mixing vessel.

(d) A *lot of covered, flux cored, or fabricated electrodes* is defined as the quantity of electrodes produced from the same combination of heat of metal and dry batch, dry blend, or chemically controlled mixes of flux or core materials. Alternatively, a lot of covered, flux cored, or fabricated electrodes may be considered one type and size of electrode, produced in a continuous period, not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg), from chemically controlled tube, wire, or strip and a dry batch, a dry blend, or chemically controlled mixes of flux, provided each container of welding materials is coded for identification and traceable to the production period, the shift, line, and the analysis range of both the mix and the rod, tube, or strip used to make the electrode.

(1) Chemically controlled tube, wire, or strip is defined as consumable tube, wire, or strip material supplied on coils with a maximum of one splice per coil that has been chemically analyzed to assure that the material conforms to the electrode manufacturer's chemical control limits for the specific type of electrode. Both ends of each coil shall be chemically analyzed except that those coils which are splice free need only be analyzed on one end of the coil.

(2) Chemically controlled mixes of flux are defined as flux material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the electrode manufacturer's standard for each chemical element for that type electrode. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending.

(e) A *heat of bare electrode, rod, wire, or consumable insert* is defined as the material produced from the same melt of metal.

(f) Alternatively, for carbon and low alloy steel bare electrode, rod, wire, or consumable inserts for use with of SAW, OFW, GMAW, GTAW, PAW, and EGW processes, a heat may be defined as either the material produced from the same melt of metal or the material produced from one type and size of wire when produced in a continuous period [not to exceed 24 hr and not to exceed 100,000 lb (45 000 kg)] from chemically controlled wire, subject to requirements of (1), (2), and (3) below.

(1) For the chemical control of the product of the rod mill, coils shall be limited to a maximum of one splice prior to processing the wire. Chemical analysis shall be made from a sample taken from both ends of each coil of mill coiled rod furnished by mills permitting spliced coil practice of one splice maximum per coil. A chemical analysis need be taken from only one end of rod coils furnished by mills prohibiting spliced coil practice.

(2) Carbon, manganese, silicon, and other intentionally added elements shall be identified to ensure that the material conforms to the SFA or user's material specification.

(3) Each container of wire shall be coded for identification and traceability to the lot, production period, shift, line, and analysis of rod used to make the wire.

(g) A *lot of submerged arc or electroslag flux* is defined as the quantity of flux produced from the same combination of raw materials under one production schedule.

(h) A *dry blend of supplementary powdered filler metal* is defined as one or more mixes of material produced in a continuous period, not to exceed 24 hr and not to exceed 20,000 lb (9 000 kg) from chemically controlled mixes of powdered filler metal, provided each container of powdered metal is coded for identification and traceable to the production period, the shift, and the mixing vessel. A chemically controlled mix of powdered filler metal is defined as powdered filler metal material that has been chemically analyzed to assure that it conforms to the percent allowable variation from the powdered filler metal manufacturer's standard, for each chemical element, for that type of powdered filler metal. A chemical analysis shall be made on each mix made in an individual mixing vessel after blending. The chemical analysis range of the supplemental powdered filler shall be the same as that of the welding electrode, and the ratio of powder to electrode used to make the test coupon shall be the maximum permitted for production welding.

NC-2430 WELD METAL TESTS

NC-2431 Mechanical Properties Test

Tensile and impact tests shall be made in accordance with this paragraph, of welding materials which are used to join P-Nos. 1, 3, 4, 5, 6, 7, 9, and 11 base materials in any combination, with the exceptions listed in (a) through (d) below.

(a) austenitic stainless steel and nonferrous welding material used to join the listed P-Numbers;

(b) consumable inserts (backing filler material);

(c) welding material used for GTAW root deposits with a maximum of two layers;

(d) welding material to be used for the welding of base materials exempted from impact testing by NC-2311(a)(1) through NC-2311(a)(7) or NC-2311(a)(9) shall also be exempted from the impact testing required by this paragraph.

NC-2431.1 General Test Requirements. The welding test coupon shall be made in accordance with (a) through (f) below, using each process with which the weld material will be used in production welding.

(a) Test coupons shall be of sufficient size and thickness such that the test specimens required herein can be removed.

(b) The weld metal to be tested for all processes except electroslag welding shall be deposited in such a manner as to substantially eliminate the influence of the base material on the results of the tests. Weld metal to be used with the electroslag process shall be deposited in such a manner as to conform to one of the applicable Welding Procedure Specifications (WPS) for production welding. The base material shall conform to the requirements of Section IX, QW-403.1 or QW-403.4, as applicable.

(c) The welding of the test coupon shall be performed within the range of preheat and interpass temperatures that will be used in production welding. Coupons shall be tested in the as-welded condition, or they shall be tested in the applicable postweld heat treated condition when the production welds are to be postweld heat treated. The postweld heat treatment holding time[2] shall be at least 80% of the maximum time to be applied to the weld metal in production application. The total time for postweld heat treatment of the test coupon may be applied in one heating cycle. The cooling rate from the postweld heat treatment temperature shall be of the same order as that applicable to the weld metal in the component. In addition, weld coupons for weld metal to be used with the electroslag process, which are tested in the as-welded condition or following a postweld heat treatment within the holding temperature ranges of Table NC-4622.1-1 or Table NC-4622.4(c)-1, shall have a thickness within the range of 0.5 to 1.1 times the thickness of the welds to be made in production. Electroslag weld coupons to be tested following a postweld heat treatment, which will include heating the coupon to a temperature above the Holding Temperature Range of Table NC-4622.1-1 for the type of material being tested, shall have a thickness within the range of 0.9 to 1.1 times the thickness of the welds to be made in production.

(d) The tensile specimens, and the C_v impact specimens when required, shall be located and prepared in accordance with the requirements of SFA-5.1 or the applicable SFA Specification. Drop weight impact test specimens, where required, shall be oriented so that the longitudinal axis is transverse to the weld, with the notch in the weld face or in a plane parallel to the weld face. For impact specimen preparation and testing, the applicable parts of NC-2321.1 and NC-2321.2 shall apply. The longitudinal axis of the specimen shall be at a minimum depth of $^1/_4t$ from a surface, where t is the thickness of the test weld.

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirements of the base material specification. Where base materials of different specifications are to be welded, the tensile strength requirements shall conform to the specified minimum tensile strength requirement of either of the base material specifications.

(f) Impact specimens of the weld metal shall be tested where impact tests are required for either of the base materials of the production weld. The weld metal shall conform to the parts of NC-2331 or NC-2332 applicable to the base material. Where different requirements exist for the two base materials, the weld metal may conform to either of the requirements for either base material.

NC-2431.2 Standard Test Requirements. In lieu of the use of the General Test Requirements specified in NC-2431.1, tensile and impact tests may be made in accordance with this subparagraph where they are required for mild and low alloy steel covered electrodes. The material combinations to require weld material testing, as listed in NC-2431, shall apply for this option. The limitations and testing under this option shall be in accordance with (a) through (f) below.

(a) Testing to the requirements of this subparagraph shall be limited to electrode classifications included in SFA-5.1 or SFA-5.5.

(b) The assembly required by SFA-5.1 or SFA-5.5, as applicable, shall be used for test coupon preparation, except that it shall be increased in size to obtain the number of impact specimens required by NC-2331 or NC-2332, as applicable.

(c) The welding of the test coupon shall conform to the requirements of the SFA specification for the classification of electrode being tested. Coupons shall be tested in the as-welded condition and also the postweld heat treated condition. The postweld heat treatment temperatures shall be in accordance with Table NC-4622.1-1 for the applicable P-Number equivalent. The time at postweld heat treatment temperature shall be 8 hr (this qualifies postweld heat treatments of 10 hr or less). When the

postweld heat treatment of the production weld exceeds 10 hr or the PWHT temperature is other than that required, the general test of NC-2431.1 shall be used.

(d) The tensile and C_v specimens shall be located and prepared in accordance with the requirements of SFA-5.1 or SFA-5.5, as applicable. Drop weight impact test specimens, where required, shall be located and oriented as specified in NC-2431.1(d).

(e) One all-weld-metal tensile specimen shall be tested and shall meet the specified minimum tensile strength requirement of the SFA specification for the applicable electrode classification.

(f) The requirements of NC-2431.1(f) shall be applicable to the impact testing.

NC-2432 Chemical Analysis Test

Chemical analysis of filler metal or weld deposits shall be made in accordance with NC-2420 and as required by the following subparagraphs.

(15) **NC-2432.1 Test Method.** The chemical analysis test shall be performed in accordance with this subparagraph and Table NC-2432.1-1, and the results shall conform to NC-2432.2.

(a) A-No. 8 welding material to be used with GTAW and PAW processes and any other welding material to be used with any GTAW, PAW, or GMAW process shall have chemical analysis performed either on the filler metal or on a weld deposit made with the filler metal in accordance with (c) or (d) below.

(b) A-No. 8 welding material to be used with other than the GTAW and PAW processes and other welding material to be used with other than the GTAW, PAW, or GMAW process shall have chemical analysis performed on a weld deposit of the material or combination of materials being certified in accordance with (c) or (d) below. The removal of chemical analysis samples shall be from an undiluted weld deposit made in accordance with (c) below. As an alternative, the deposit shall be made in accordance with (d) below for material that will be used for corrosion resistant overlay cladding. Where the Welding Procedure Specification or the welding material specification specifies percentage composition limits for analysis, it shall state that the specified limits apply for the filler metal analysis, the undiluted weld deposit analysis, or the *in situ* cladding deposit analysis in conformance with the above required certification testing.

(c) The preparation of samples for chemical analysis of undiluted weld deposits shall comply with the method given in the applicable SFA specification. Where a weld deposit method is not provided by the SFA specification, the sample shall be removed from a weld pad, groove, or other test weld[8] made using the welding process that will be followed when the welding material or combination of welding materials being certified is consumed. The weld for A-No. 8 material to be used with the GMAW or EGW process shall be made using the shielding gas composition specified in the Welding Procedure Specifications that will be followed when the material is consumed. The test sample for ESW shall be removed from the weld metal of the mechanical properties test coupon. Where a chemical analysis is required for a welding material which does not have a mechanical properties test requirement, a chemical analysis test coupon shall be prepared as required by NC-2431.1(c), except that heat treatment of the coupon is not required and the weld coupon thickness requirements of NC-2431.1(c) do not apply.

(d) The alternate method provided in (b) above for the preparation of samples for chemical analysis of welding material to be used for corrosion resistant overlay cladding shall require a test weld made in accordance with the essential variables of the welding procedure specification that will be followed when the welding material is consumed. The test weld shall be made in conformance with the requirements of Section IX, QW-214.1. The removal of chemical analysis samples shall conform with Section IX, QW-453 for the minimum thickness for which the Welding Procedure Specification is qualified.

NC-2432.2 Requirements for Chemical Analysis. The chemical elements to be determined, the composition requirements of the weld metal, and the recording of results of the chemical analysis shall be in accordance with (a), (b), and (c) below.

(a) Welding material of ferrous alloy A-No. 8 (Section IX, Table QW-442) shall be analyzed for the elements listed in Table NC-2432.2-1 and for any other elements specified either in the welding material specification referenced by the Welding Procedure Specification or in the Welding Procedure Specification.

Table NC-2432.1-1
Sampling of Welding Materials for Chemical Analysis

	GTAW/PAW	GMAW	All Other Processes
A-No. 8 filler metal	Filler metal or weld deposit	Weld deposit	Weld deposit
All other filler metal	Filler metal or weld deposit	Filler metal or weld deposit	Weld deposit

Table NC-2432.2-1
Welding Material Chemical Analysis

Materials	Elements
Cr–Ni stainless materials	C, Cr, Mo, Ni, Mn, Si, Cb

(b) The chemical composition of the weld metal or filler metal shall conform to the welding material specification for elements having specified percentage composition limits. Where the Welding Procedure Specification contains a modification of the composition limits of SFA or other referenced welding material specifications, or provides limits for additional elements, these composition limits of the Welding Procedure Specification shall apply for acceptability.

(c) The results of the chemical analysis shall be reported in accordance with NCA-3862.1. Elements listed in Table NC-2432.2-1 but not specified in the welding material specification or Welding Procedure Specification shall be reported for information only.

NC-2433 Delta Ferrite Determination

A determination of delta ferrite shall be performed on A-No. 8 weld material (Section IX, Table QW-442) backing filler metal (consumable inserts); bare electrode, rod, or wire filler metal; or weld metal, except that delta ferrite determinations are not required for SFA-5.4 Type 16-8-2 or A-No. 8 weld filler metal to be used for weld metal cladding.

NC-2433.1 Method. Delta ferrite determinations of welding material, including consumable insert material, shall be made using a magnetic measuring instrument and weld deposits made in accordance with (b) below. Alternatively, the delta ferrite determinations for welding materials may be performed by the use of the chemical analysis of NC-2432 in conjunction with Figure NC-2433.1-1.

(a) Calibration of magnetic instruments shall conform to AWS-A 4.2.

(b) The weld deposit for magnetic delta ferrite determination shall be made in accordance with NC-2432.1(c).

(c) A minimum of six ferrite readings shall be taken on the surface of the weld deposit. The readings obtained shall be averaged to a single Ferrite Number.

NC-2433.2 Acceptance Standards. The minimum acceptable delta ferrite shall be 5FN (Ferrite Number). The results of the delta ferrite determination shall be included in the Certified Material Test Report of NC-2130 or NC-4120.

NC-2440 STORAGE AND HANDLING OF WELDING MATERIAL

Suitable storage and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by fluxes and cored, fabricated, and coated electrodes.

NC-2500 EXAMINATION AND REPAIR OF PRESSURE-RETAINING MATERIAL

NC-2510 PRESSURE-RETAINING MATERIAL

Pressure-retaining material shall be examined and repaired in accordance with the material specification and as otherwise required by this subarticle. Pressure-retaining material for ASME B16.34 Special Class category valves (NC-3513) shall be examined and repaired in accordance with the requirements therein and as otherwise required by this subarticle. If the examination and repair requirements of this subarticle either duplicate or exceed the ASME B16.34 requirements, then only the requirements of this subarticle need to be met. Size exclusions or quality factor pressure ratings of this subarticle shall not be applied so as to reduce the examination requirements of ASME B16.34 for Special Class category valves.

NC-2530 EXAMINATION AND REPAIR OF PLATE

NC-2531 Required Examination

Plates shall be examined in accordance with the requirements of the material specification.

NC-2537 Time of Examination

Acceptance examinations shall be performed at the time of manufacture as required in (a) through (c) below.

(a) Examinations required by the material specification shall be performed at the time of manufacture as specified in the material specification.

(b) Radiographic examination of repair welds, when required, may be performed prior to any required postweld heat treatment.

(c) Magnetic particle or liquid penetrant examination of repair welds shall be performed after any required postweld heat treatment, except for P-No. 1 material, which may be examined before or after any required postweld heat treatment.

NC-2538 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) and (b) below are met:

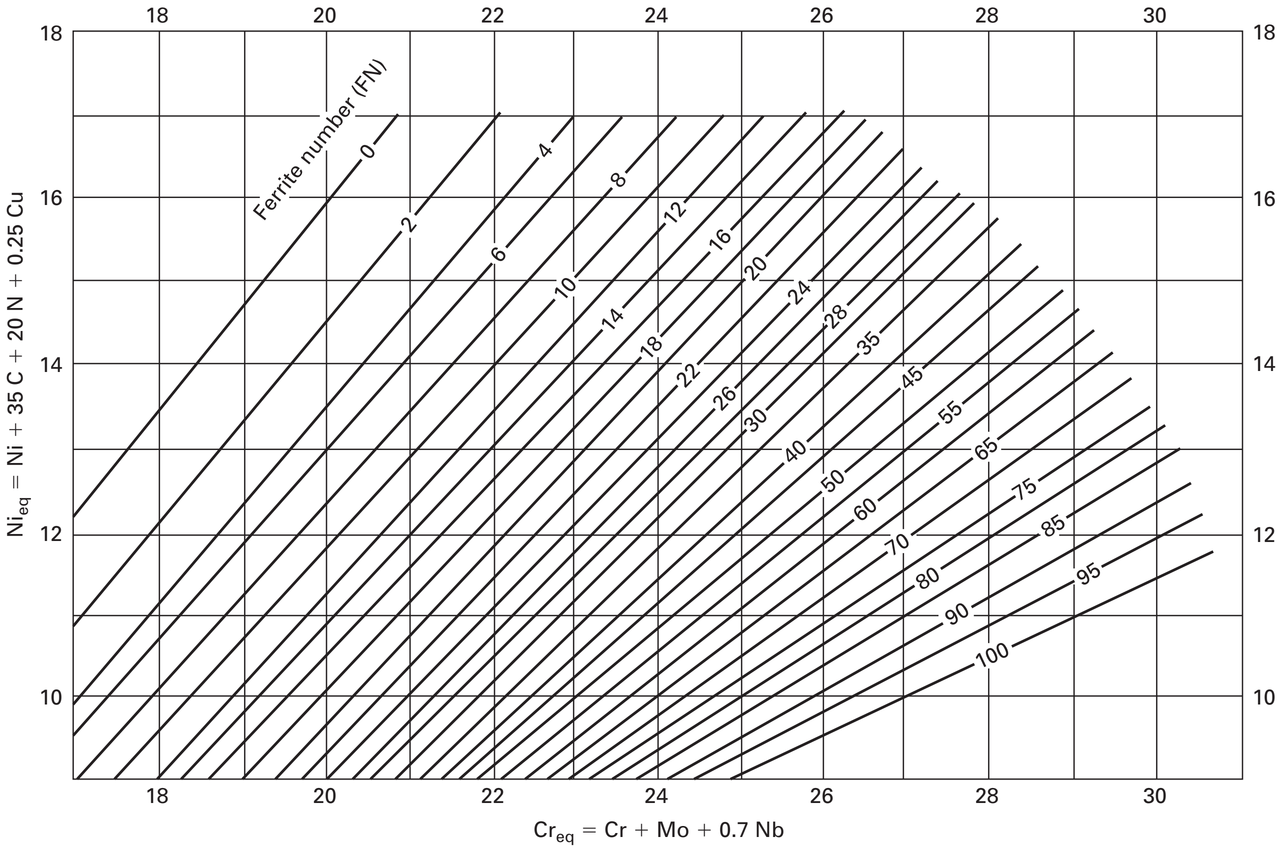
(a) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(b) When the elimination of the defect reduces the thickness of the section below the minimum required by the design, the material shall be repaired in accordance with NC-2539.

NC-2539 Repair by Welding

The Material Organization may repair by welding materials from which defects have been removed, provided the depth of the repair cavity does not exceed one-third of the nominal thickness and the requirements of the following

Figure NC-2433.1-1
Weld Metal Delta Ferrite Content



GENERAL NOTES:

(a) The actual nitrogen content is preferred. If this is not available, the following applicable nitrogen value shall be used:

(1) GMAW welds — 0.08%, except that when self-shielding flux-cored electrodes are used — 0.12%.

(2) Welds made using other processes — 0.06%.

(b) This diagram is identical to the WRC-1992 Diagram, except that the solidification mode lines have been removed for ease of use.

subparagraphs are met. Prior approval of the Certificate Holder shall be obtained for the repair of plates to be used in the manufacture of vessels.

NC-2539.1 Defect Removal. The defect shall be removed or reduced to an imperfection of acceptable limit by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair (NC-4211.1).

NC-2539.2 Qualification of Welding Procedures and Welders. The welding procedure and welders or welding operators shall be qualified in accordance with Article NC-4000 and Section IX.

NC-2539.3 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

NC-2539.4 Examination of Repair Welds. Each repair weld shall be examined by the magnetic particle method (NC-2545) or by the liquid penetrant method (NC-2546). In addition, when the depth of the repair cavity exceeds the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness, the repair weld shall be radiographed in accordance with and to the applicable acceptance standards of NC-5320. The image quality indicator (IQI) shall be based upon the section thickness of the repaired area.

NC-2539.5 Heat Treatment After Repairs. The product shall be heat treated after repair in accordance with the requirements of NC-4620.

NC-2539.6 Material Report Describing Defects and Repair. Each defect repair that is required to be radiographed shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart which shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and a report of the results of the examinations, including radiographs.

NC-2540 EXAMINATION AND REPAIR OF FORGINGS AND BARS

NC-2541 Required Examinations

Forgings and bars shall be examined in accordance with the requirements of the material specification, except when magnetic particle or liquid penetrant examination is specifically required by the rules of this Subsection, in which case the examination shall conform to the requirements of NC-2545 or NC-2546, as applicable.

NC-2545 Magnetic Particle Examination

NC-2545.1 Examination Procedure. The procedure for magnetic particle examination shall be in accordance with the methods of Section V, Article 7.

NC-2545.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication in excess of the NC-2545.3 acceptance standards which is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width. Indications resulting from nonmetallic inclusions are not considered relevant indications.

NC-2545.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $^1/_{16}$ in. (1.5 mm) long for material less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for material from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm) and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NC-2546 Liquid Penetrant Examinations

NC-2546.1 Examination Procedure. The procedure for liquid penetrant examination shall be in accordance with the methods of Section V, Article 6.

NC-2546.2 Evaluation of Indications.

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities, such as may occur from machining marks or surface conditions, may produce similar indications which are not relevant.

(b) Any indication in excess of the NC-2546.3 acceptance standards, which is believed to be nonrelevant, shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation which would mask defects are unacceptable.

(c) Relevant indications are those which result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length equal to or less than three times the width.

NC-2546.3 Acceptance Standards.

(a) Only imperfections producing indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant.

(b) Imperfections producing the following relevant indications are unacceptable:

(1) any linear indications greater than $^1/_{16}$ in. (1.5 mm) long for material less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for material from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for material 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm) and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) of area whose major dimension is no more than 6 in. (150 mm) with the dimensions taken in the most unfavorable location relative to the indications being evaluated.

NC-2547 Time of Examination

The requirements for time of examination shall be the same as stated in NC-2537.

NC-2548 Elimination of Surface Defects

Elimination of surface defects shall be made in accordance with NC-2538.

NC-2549 Repair by Welding

Repair by welding shall be performed in accordance with NC-2539, except that the depth of repair that is permitted is not limited.

NC-2550 EXAMINATION AND REPAIR OF SEAMLESS AND WELDED (WITHOUT FILLER METAL) TUBULAR PRODUCTS AND FITTINGS

NC-2551 Required Examination

(a) All seam welds in welded (without filler metal) tubular products shall be examined by one of the following methods:

(1) ultrasonic examination in accordance with NC-2552;

(2) radiographic examination in accordance with NC-2553;

(3) eddy current examination in accordance with NC-2554.

(b) Wrought seamless and welded (without filler metal) tubular products and fittings, except copper alloy and nickel alloy tubular products and fittings, shall comply with the requirements of NC-2557, NC-2558, and NC-2559, in addition to the basic material specification.

(c) Copper alloy and nickel alloy wrought seamless and welded (without filler metal) tubular products and fittings shall comply with the requirements of NC-2558, in addition to the basic material specification.

NC-2552 Ultrasonic Examination[9]

NC-2552.1 Examination Procedure for Welds in Pipe and Tubing.

(a) Circumferential Direction — 6¾ in. (170 mm) O.D. and Smaller. The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing in the circumferential direction shall be in accordance with SE-213, Standard Method for Ultrasonic Examination of Pipe and Tubing for Longitudinal Discontinuities, and the requirements of this paragraph. The procedure shall provide a sensitivity which will consistently detect defects that produce indications equal to or greater than the indications produced by standard defects included in the reference specimens specified in NC-2552.3.

(b) Pipe and Tubing Larger Than 6¾ in. (170 mm) O.D. The welds in pipe and tubing shall be examined in two circumferential directions. The procedure for ultrasonic examination of pipe and tubing larger than 6¾ in. (170 mm) O.D. shall be in accordance either with the requirements of SA-388 for angle beam scanning in the circumferential direction, or with the requirements of SE-213. The reference standard shall be in accordance with NC-2552.3 below.

(c) Acceptance Standard. Products with defects that produce indications in excess of the indications produced by the standard defects in the reference specimen are unacceptable unless the defects are eliminated or repaired in accordance with NC-2558 or NC-2559.

NC-2552.2 Examination Procedure for Welds in Fittings.

(a) Procedure. The procedure for ultrasonic examination of welds in fittings shall be in accordance with the requirements of Recommended Practice SA-388 for angle beam examination in two circumferential directions.

(b) Acceptance Standard. Fittings shall be unacceptable if angle beam examination results show one or more reflectors which produce indications exceeding in amplitude the indications from the calibrated notch.

NC-2552.3 Reference Specimens.

(a) The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat treated condition as the product which is being examined. For circumferential scanning, the standard defects shall be axial notches or grooves on the outside and inside surfaces of the reference specimen and shall have a length of approximately 1 in. (25 mm) or less, a width not to exceed $^1/_{16}$ in. (1.5 mm) for a square notch or U-notch, a width proportional to the depth for a V-notch, and a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the nominal wall thickness.

(b) The reference specimen shall be long enough to simulate the handling of the product being examined through the examination equipment. When more than one standard defect is placed in a reference specimen, the defects shall be located so that indications from each defect are separate and distinct without mutual interference or amplification. All upset metal and burrs adjacent to the reference notches shall be removed.

NC-2552.4 Checking and Calibration of Equipment. The proper functioning of the examination equipment shall be checked, and the equipment shall be calibrated by the use of the reference specimens, as a minimum:

(a) at the beginning of each production run of a given size and thickness of a given material;

(b) after each 4 hr or less during the production run;

(c) at the end of the production run;

(d) at any time that malfunctioning is suspected.

If, during any check, it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last valid equipment calibration shall be reexamined.

NC-2553 Radiographic Examination

(a) General. When radiographic examination is performed as an alternative to ultrasonic examination of the entire volume of the material, it shall apply to the entire volume of the pipe, tube, or fitting material. Acceptance standards specified for welds shall apply to the entire volume of material examined.

(b) Examination Procedure. The radiographic examination shall be performed in accordance with Section V, Article 2, as modified by NC-5111.

(c) Acceptance Standard. Welds that are shown by radiography to have any of the following types of discontinuities are unacceptable:

(1) any type of crack or zone of incomplete fusion or penetration;

(2) any other elongated indication which has a length greater than:

(-a) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm), inclusive

(-b) $^1/_3t$ for t from $^3/_4$ in. (19 mm) to $2^1/_4$ in. (57 mm), inclusive

(-c) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm)

where t is the thickness of the thinner portion of the weld;

(3) any group of aligned indications having an aggregate length greater than t in a length of $12t$, unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(4) rounded indications in excess of that shown as acceptable in Section III Appendices, Mandatory Appendix VI.

NC-2554 Eddy Current Examination

This examination method is restricted to materials with uniform magnetic properties and of sizes for which meaningful results can be obtained.

NC-2554.1 Examination Procedure. The procedure for eddy current examination shall provide a sensitivity that will consistently detect defects by comparison with the standard defects included in the reference specimen specified in NC-2552.3. Products with defects that produce indications in excess of the reference standards are unacceptable unless the defects are eliminated or repaired in accordance with NC-2558 or NC-2559 as applicable.

NC-2554.2 Reference Specimens. The reference specimen shall be of the same nominal diameter and thickness and of the same nominal composition and heat treated condition as the product that is being examined. The standard shall contain tangential or circumferential notches on the outside surface plus a $^1/_{16}$ in. (1.5 mm) diameter hole drilled through the wall. These shall be used to establish the rejection level for the product to be tested. The reference notches shall have a depth not greater than the larger of 0.004 in. (0.10 mm) or 5% of the wall thickness. The width of the notch shall not exceed $^1/_{16}$ in. (1.5 mm). The length shall be approximately 1 in. (25 mm) or less. The size of reference specimens shall be as specified in NC-2552.3.

NC-2554.3 Checking and Calibration of Equipment. The checking and calibration of examination equipment shall be the same as in NC-2552.4.

NC-2557 Time of Examination

(a) Products that are quenched and tempered shall be examined, as required, after the quenching and tempering heat treatment.

(b) Products that are not quenched and tempered shall receive the required examinations as follows:

(1) ultrasonic or eddy current examination, when required, shall be performed after final heat treatment, except postweld heat treatment;

(2) radiographic examination, when required, may be performed prior to any required postweld heat treatment;

(3) magnetic particle or liquid penetrant examination of welds, including repair welds, shall be performed after final heat treatment, except that the examination may be performed prior to postweld heat treatment for P-No. 1 (Section IX of the Code) materials of 2 in. (50 mm) and less nominal thickness;

(4) forgings and rolled bars which are to be bored and/or turned to form tubular parts or fittings shall be examined after boring and/or turning, except for threading; fittings shall be examined after final forming;

(5) when surface examination is required, all external surfaces and all accessible internal surfaces shall be examined, except for bolt holes and threads.

NC-2558 Elimination of Surface Defects

Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is examined by the method which originally disclosed the defect to assure that the defect has been removed or reduced to an imperfection of acceptable size;

(c) if the elimination of the defect reduces the thickness of the section below the minimum required to satisfy the rules of Article NC-3000, the product shall be repaired in accordance with NC-2559.

NC-2559 Repair by Welding

Repair of defects shall be in accordance with NC-2539, except repair by welding is not permitted on copper alloy and nickel alloy heat exchanger tubes.

NC-2560 EXAMINATION AND REPAIR OF TUBULAR PRODUCTS AND FITTINGS WELDED WITH FILLER METAL

NC-2561 Required Examination

(a) Welded (with filler metal) tubular products, such as pipe made in accordance with SA-358, SA-409, SA-671, SA-672, and SA-691 and fittings made in accordance with the WPW grades of SA-234, SA-403, and SA-420, which are made by welding with filler metal, shall be treated as material; however, inspection by an Inspector and stamping with the Certification Mark with NPT Designator shall be in accordance with Section III requirements. In addition to the Certification Mark with NPT Designator, a numeral 2 shall be stamped below and outside the official Certification Mark.

(b) In addition to the requirements of the material specification and of this Article, all welds shall be examined 100% by radiography in accordance with the basic material specification. When radiographic examination is not specified in the basic material specification, the welds shall be examined in accordance with NC-2563.

(c) Tubular products and fittings which have been radiographed shall be marked to indicate that radiography has been performed. The radiographs and a radiographic report showing exposure locations shall be provided with the Certified Material Test Report.

(d) The Authorized Inspector shall certify by signing the Partial Data Report Form NM-1 (see Section III Appendices, Mandatory Appendix V) in accordance with NCA-5290.

NC-2563 Radiographic Examination

The radiographic examination shall be performed in accordance with the requirements of NC-2553.

NC-2567 Time of Examination

The time of examination shall be in accordance with the requirements of NC-2557.

NC-2568 Elimination of Surface Defects

Unacceptable surface defects shall be removed in accordance with the requirements of NC-2558.

NC-2569 Repair by Welding

When permitted by the basic material specification, base material defects shall be repair welded in accordance to the requirements of NC-2559. Repair welding of weld seam defects shall be in accordance with NC-4450.

NC-2570 EXAMINATION AND REPAIR OF STATICALLY AND CENTRIFUGALLY CAST PRODUCTS

In addition to the requirements of the material specification and of this Article NC-2000, statically and centrifugally cast products shall comply with the following paragraphs.

NC-2571 Required Examination

(a) Cast products shall be examined by volumetric and/or surface methods, including repairs, as required for the product form by Table NC-2571-1 Class 2 castings.

(b) For cast valves furnished to ASME B16.34 Special Class category, neither the size exclusions nor the quality factor pressure ratings of Table NC-2571-1 shall be applied so as to reduce the required examinations of that Standard. The required examinations by ASME B16.34 for Special Class category valves shall be performed in accordance with the procedures and acceptance standards of this Subsection.

NC-2572 Time of Nondestructive Examination

NC-2572.1 Acceptance Examinations. Acceptance examinations shall be performed at the time of manufacture as stipulated in the following and Table NC-2571-1.

(a) Ultrasonic Examination. Ultrasonic examination, if required, shall be performed at the same stage of manufacture as required for radiography.

(b) Radiographic Examination. Radiography may be performed prior to heat treatment and may be performed prior to or after finish machining at the following limiting thicknesses.

(1) For finished thicknesses under $2\frac{1}{2}$ in. (64 mm), castings shall be radiographed within $\frac{1}{2}$ in. (13 mm) or 20% of the finished thickness, whichever is greater. The IQI and reference radiographs shall be based on the finished thickness.

(2) For finished thickness from $2\frac{1}{2}$ in. (64 mm) up to 6 in. (150 mm), castings shall be radiographed within 20% of the finished thickness. The IQI and the acceptance reference radiographs shall be based on the finished thickness.

(3) For finished thicknesses over 6 in. (150 mm), castings shall be radiographed within $\frac{1}{2}$ in. (13 mm) or 15% of the finished thickness, whichever is greater. The IQI and the acceptance reference radiographs shall be based on the finished thickness.

(c) Radiography of castings for pumps and valves may be performed in as-cast or rough machined thickness exceeding the limits of (b)(1), (b)(2), or (b)(3) subject to the following conditions.

(1) When the thickness of the as-cast or rough machined section exceeds 2 in. (50 mm) acceptance shall be based on reference radiographs for the next lesser thickness; e.g., if the section being radiographed exceeds

Table NC-2571-1 Required Examinations

(15)

Nominal Pipe Size	Item	Applicable Special Requirements for Class 2 Castings
Inlet piping connections of NPS 2 (DN 50) and less	Cast pipe fittings, pumps, and valves	None, except for ASME B16.34 Special Class category valves which shall be in accordance with NC-2571(b).
	Cast pressure-retaining material other than pipe fittings, pumps, and valves	Cast pressure-retaining materials shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods (NC-2575).
	Repair welds in pumps and valves of P-No. 1 or P-No. 8 material	None
	Repair welds in cast pressure-retaining material other than pumps and valves of P-No. 1 or P-No. 8 material	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, when radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness, shall be radiographed in accordance with NC-2575.
Inlet piping connections over NPS 2 (DN 50) up to and including NPS 4 (DN 100)	Cast pumps and valves with a quality factor of 1.00	Magnetic particle or liquid penetrant examination may be performed on all external surfaces and on all accessible internal surfaces, in lieu of volumetric examination, except the weld ends of cast pumps and valves shall be radiographed for a minimum distance of t (where t is the design section thickness of the weld) from the final weld end. For ASME B16.34 Special Class category valves, see NC-2571(b).
	Cast pumps and valves with a quality factor of 0.70	None
	Cast pressure-retaining material other than cast pumps and valves	Cast pressure-retaining materials shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods.
	Repair welds in pumps and valves of P-No. 1 or P-No. 8 material with a quality factor of 0.70	None
	Repair welds in cast pressure-retaining material other than pumps and valves of P-No. 1 or P-No. 8 material with a quality factor of 0.70	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, when radiography of the casting is required, repair welds in cavities, the depth of which exceeds the lesser of $^3/_8$ in. (10 mm) or 10% of the section thickness, shall be radiographed in accordance with NC-2575.
Inlet piping connections over NPS 4 (DN 100)	Cast pressure-retaining materials	Cast pressure-retaining materials shall be examined by either radiographic or ultrasonic methods, or a combination of the two methods. Castings or sections of castings, which have coarse grains or configurations which do not yield meaningful results by ultrasonic examination, shall be examined by radiographic methods. For ASME B16.34 Special Class category valves, see NC-2571(b).
	Repair welds	Each repair weld shall be examined by the magnetic particle method or by the liquid penetrant method. In addition, when radiography of the casting is required, repair welds in cavities, the depth of which exceeds the less of $^3/_8$ in. (10 mm) or 10% of the section thickness, shall be radiographed in accordance with NC-2575.

$4^1/_2$ in. (114 mm), use reference radiographs of ASTM E186. The IQI shall be based on the thickness of the section being radiographed.

(2) When the thickness of the as-cast or rough machined section is 2 in. (50 mm) or less, the reference radiographs of ASTM E446 shall be used, and the IQI shall be based on the final section thickness.

(3) Weld ends for a minimum distance of t or $^1/_2$ in. (13 mm), whichever is less (where t is the design section thickness of the weld), from the final welding end shall be radiographed at a thickness within the limits given in (b)(1), (b)(2), or (b)(3) as applicable. As an alternative, the weld ends may be radiographed in the as-cast or rough machined thickness in accordance with (1) and (2) above, and the IQI shall be based on the final section thickness.

(d) Magnetic Particle or Liquid Penetrant Examination. Magnetic particle or liquid penetrant examination shall be performed after the final heat treatment required by the material specification. Repair weld areas shall be examined after postweld heat treatment when a postweld heat treatment is performed, except that repair welds in P-No. 1 (see Section IX of the Code) material 2 in. (50 mm) nominal thickness and less may be examined prior to postweld heat treatment. For cast products with machined surfaces, all finished machine surfaces, except threaded surfaces and small deep holes, shall also be examined by magnetic particle or liquid penetrant methods.

NC-2573 Provisions for Repair of Base Material by Welding

The Material Manufacturer may repair, by welding, products from which defects have been removed, provided the requirements of this Article are met.

NC-2573.1 Defect Removal. The defects shall be removed or reduced to an imperfection of acceptable size by suitable mechanical or thermal cutting or gouging methods and the cavity prepared for repair. When thermal cutting is performed, consideration shall be given to preheating the material.

NC-2573.2 Repair by Welding. The Material Manufacturer may repair castings by welding after removing the material containing unacceptable defects. The depth of the repair is not limited. A cored hole or access hole may be closed by the Material Manufacturer by welding in accordance with the requirements of this subparagraph, provided the hole is closed by filler metal only. If the hole is closed by welding in a metal insert, the welding shall be performed by a holder of a Certificate of Authorization in accordance with the requirements of the Code.

NC-2573.3 Qualification of Welding Procedures and Welders. Each manufacturer is responsible for the welding done by his organization and shall establish the procedures and conduct the tests required by Article NC-4000 and by Section IX of the Code in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures. He is also responsible for the welding performed by his subcontractors and shall assure himself that the subcontractors conduct the tests required by Article NC-4000 and by Section IX of the Code in order to qualify their welding procedures and the performance of their welders and welding operators.

NC-2573.4 Blending of Repaired Areas. After repair, the surface shall be blended uniformly into the surrounding surface.

NC-2573.5 Examination of Repair Welds.

(a) Each repair weld shall be examined by the magnetic particle method in accordance with the requirements of NC-2577, or by the liquid penetrant method in accordance with the requirements of NC-2576. In addition, when radiography is specified in the order for the original casting, repair cavities, the depth of which exceeds the lesser of $^3/_8$ in. (10 mm) or 10% of the nominal wall thickness, shall be radiographed after repair except that weld slag, including elongated slag, shall be considered as inclusions under Category B of the applicable reference radiographs. The total area of all inclusions, including slag inclusions, shall not exceed the limits of the applicable severity level of Category B of the reference radiographs. The IQI and the acceptance standards for radiographic examination of repair welds shall be based on the actual section thickness at the repair area.

(b) Examination of repair welds in P-No. 1 and P-No. 8 materials is not required for pumps and valves with inlet piping connections NPS 2 (DN 50) and less.

NC-2573.6 Heat Treatment After Repairs. The material shall be heat treated after repair in accordance with the heat treatment requirements of NC-4620, except that the heating and cooling rate limitations of NC-4623 do not apply.

NC-2573.7 Elimination of Surface Defects. Surface defects shall be removed by grinding or machining, provided the requirements of (a) through (c) below are met:

(a) the depression, after defect elimination, is blended uniformly into the surrounding surface;

(b) after defect elimination, the area is reexamined by the magnetic particle method in accordance with NC-2577, or the liquid penetrant method in accordance with NC-2576, to assure that the defect has been removed or reduced to an imperfection of acceptable size;

(c) if the elimination of the defect reduces the section thickness below the minimum required by the specification or drawing, the casting shall be repaired in accordance with NC-2539.

NC-2573.8 Material Report Describing Defects and Repairs. Each defect repair exceeding in depth the lesser of $^3/_8$ in. (10 mm) or 10% of the nominal wall thickness shall be described in the Certified Material Test Report. The Certified Material Test Report for each piece shall include a chart that shows the location and size of the prepared cavity, the welding material identification, the welding procedure, the heat treatment, and the examination results, including radiographs, when radiographs are specified in the order for the original casting.

NC-2574 Ultrasonic Examination of Ferritic Steel Castings

Ultrasonic examination shall be performed in accordance with Section V, Article 5, T-571.4. Each manufacturer shall certify that the procedure is in accordance with the requirements of NC-2574 and shall make the procedure available for approval upon request.

NC-2574.1 Acceptance Standards.

(a) The Quality Levels of SA-609 as shown in Section V shall apply for the casting thicknesses indicated.

(1) Quality Level 1 for thicknesses up to 2 in. (50 mm);

(2) Quality Level 3 for thicknesses 2 in. to 4 in. (50 mm to 100 mm);

(3) Quality Level 4 for thicknesses greater than 4 in. (100 mm).

(b) In addition to the Quality Level requirements stated in (a) above, the requirements in (1) through (5) below shall apply for both straight beam and angle beam examination.

(1) Areas giving indications exceeding the Amplitude Reference Line with any dimension longer than those specified in the following tabulation are unacceptable.

UT Quality Level	Longest Dimension of Area, in. (mm) [Note (1)], [Note (2)], [Note (3)]
1	1.5 (38)
2	2.0 (50)
3	2.5 (64)
4	3.0 (75)

NOTES:
(1) The areas for the Ultrasonic Quality Levels in SA-609 refer to the surface area on the casting over which a continuous indication exceeding the transfer corrected distance amplitude curve is maintained.
(2) Areas are to be measured from dimensions of the movement of the search unit, using the center of the search unit as the reference point.
(3) In certain castings, because of very long metal path distances or curvature of the examination surfaces, the surface area over which a given discontinuity is detected may be considerably larger or smaller than the actual area of the discontinuity in the casting. In such cases, other criteria that incorporate a consideration of beam angles or beam spread must be used for realistic evaluation of the discontinuity.

(2) Quality Level 1 shall apply for the volume of castings within 1 in. (25 mm) of the surface regardless of the overall thickness.

(3) Discontinuities indicated to have a change in depth equal to or greater than $^1/_2$ the wall thickness or 1 in. (25 mm) (whichever is less) are unacceptable.

(4) Two or more imperfections producing indications in the same plane with amplitudes exceeding the Amplitude Reference Line and separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable if they cannot be encompassed within an area less than that of the quality level specified in (1) above.

(5) Two or more imperfections producing indications greater than permitted for Quality Level 1 for castings less than 2 in. (50 mm) in thickness, greater than permitted for Quality Level 2 for thicknesses 2 in. (50 mm) through 4 in. (100 mm), and greater than permitted for Level 3 for thicknesses greater than 4 in. (100 mm), separated by a distance less than the longest dimension of the larger of the adjacent indications are unacceptable, if they cannot be encompassed in an area less than that of the Quality Level requirements stated in (a) above.

NC-2575 Radiographic Examination

NC-2575.1 Examination. Cast pressure-retaining materials shall be examined by radiographic methods when specified in the order for the original castings, except that cast ferritic steels may be examined by either radiographic or ultrasonic methods, or a combination of both methods. Castings or sections of castings that have coarse grains or configurations that do not yield meaningful examination results by ultrasonic methods shall be examined by radiographic methods.

NC-2575.2 Extent. Radiographic examination shall be performed on pressure-retaining castings such as vessel heads and flanges, valve bodies, bonnets and disks, pump casings and covers, and piping and fittings. The extent of radiographic coverage shall be of the maximum feasible volume and, when the shape of the casting precludes complete coverage, the coverage shall be at least as exemplified in the typical sketches as shown in Figure NC-2575.2-1.

NC-2575.3 Examination Requirements. Radiographic examination shall be performed in accordance with Section V, Article 2, Mandatory Appendix VII, Radiographic Examination of Metallic Castings, with the following modifications:

(a) The geometric unsharpness limitations of Section V, Article 2, T-274.2 need not be met.

(b) The examination procedure or report shall also address the following:

(1) type and thickness of filters, if used

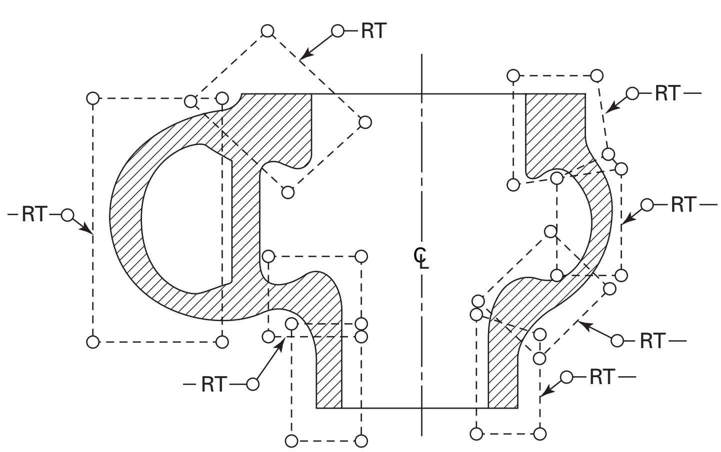
(2) for multiple film techniques, whether viewing is to be single or superimposed, if used

(3) blocking or masking technique, if used

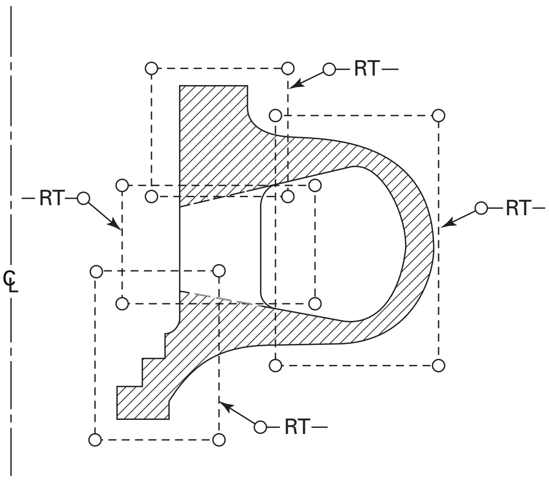
(4) orientation of location markers

(5) description of how internal markers, when used, locate the area of interest

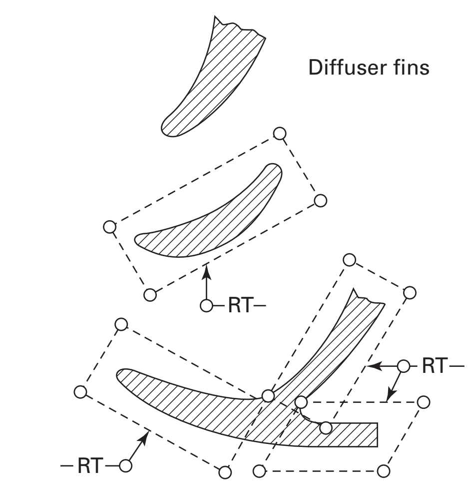
Figure NC-2575.2-1
Typical Pressure-Retaining Parts of Pumps and Valves



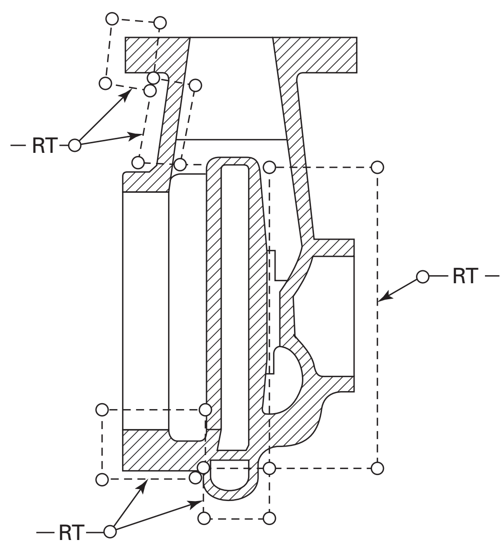
(a) Typical Volute-Type Pump Case



(b) Typical Diffuser-Type Pump Case

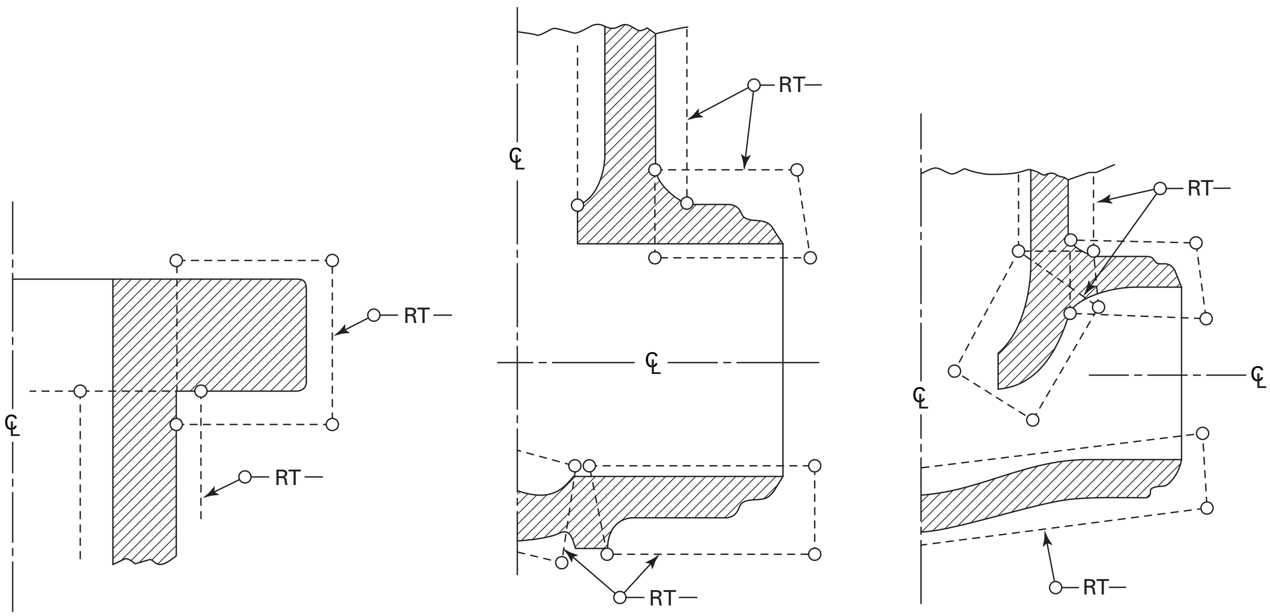


(c) Typical Difusser-Type Pump Case Detail



(d) Typical Single Stage Pump Case

Figure NC-2575.2-1
Typical Pressure-Retaining Parts of Pumps and Valves (Cont'd)



(e) Typical Flange **(f) Typical Gate Valve** **(g) Typical Globe Valve**

GENERAL NOTES:
(a) Radiographic examination areas shall be indicated by a circle at each change of direction. The examination symbol for radiography shall be indicated as RT.
(b) For nondestructive examination areas of revolution, the area shall be indicated by the examine-all-around symbol: – RT – ♂.
(c) The sketches are typical and are to be used as a guide for minimum required coverage. Even though a sketch may be titled "pump" or "valve," the coverage shown by the configurations may be applied interchangeably.

(c) The location of location markers (e.g., lead numbers or letters) shall be permanently stamped on the surface of the casting in a manner permitting the area of interest on a radiograph to be accurately located on the casting and providing evidence on the radiograph that the extent of coverage required by NC-2575.2 has been obtained. For castings or sections of castings where stamping is not feasible, the radiographic procedure shall so state, and a radiographic exposure map shall be provided.

NC-2575.6 Acceptance Criteria. Castings shall meet the acceptance requirements of Severity Level 2 of ASTM E446, Reference Radiographs for Steel Castings up to 2 in. (50 mm) in Thickness, ASTM E186, Reference Radiographs for Heavy-Walled [2 in. to $4^1/_2$ in. (51 mm to 114 mm)] Steel Castings, or ASTM E280, Reference Radiographs for Heavy Walled [$4^1/_2$ in. to 12 in. (114 mm to 305 mm)] Steel Castings, as applicable for the thickness being radiographed, except Category D, E, F, or G defects are not acceptable. The requirements of ASTM E280 shall apply for castings over 12 in. (300 mm) in thickness.

NC-2576 Liquid Penetrant Examination

(a) Castings shall be examined, if required, on all accessible surfaces by liquid penetrant method in accordance with Section V of the Code.

(b) Evaluation of Indications. All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by bleeding out of the penetrant; however, localized surface discontinuities, as may occur from machining marks, scale, or dents, may produce indications which are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask indications of defects are unacceptable. Relevant indications are those which result from imperfections and have a major dimension greater than $^1/_{16}$ in. (1.5 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) Acceptance Standards. The following relevant indications are unacceptable:

(1) linear indications greater than $^1/_{16}$ in. (1.5 mm) long for materials less than $^5/_8$ in. (16 mm) thick, greater than $^1/_8$ in. (3 mm) long for materials from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick, and $^3/_{16}$ in. (5 mm) long for materials 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm), and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater;

(3) four or more indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more indications in any 6 in.^{2} (4 000 mm^2) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NC-2577 Magnetic Particle Examination (for Ferritic Steel Products Only)

(a) Castings of magnetic material shall be examined, if required, on all accessible surfaces by a magnetic particle method in accordance with Section V of the Code.

(b) Evaluation of Indications. All indications shall be evaluated in terms of the acceptance standards. Mechanical discontinuities intersecting the surface are indicated by retention of the examination medium. All indications are not necessarily defects since certain metallurgical discontinuities and magnetic permeability variations may produce indications that are not relevant. Any indication in excess of the acceptance standards believed to be nonrelevant shall be reexamined to verify whether actual defects are present. Nonrelevant indications which would mask indications of defects are unacceptable. Surface conditioning may precede the reexamination. Relevant indications are those which result from imperfections and have a major dimension greater than $^1/_{16}$ in. (1.5 mm). Linear indications are those whose length is more than three times the width. Rounded indications are those which are circular or elliptical with the length less than three times the width.

(c) Acceptance Standards. The following relevant indications are unacceptable:

(1) linear indications greater than $^1/_{16}$ in. (1.5 mm) long for materials less than $^5/_8$ in. (16 mm) thick; greater than $^1/_8$ in. (3 mm) long for materials from $^5/_8$ in. (16 mm) thick to under 2 in. (50 mm) thick; and $^3/_{16}$ in. (5 mm) long for materials 2 in. (50 mm) thick and greater;

(2) rounded indications with dimensions greater than $^1/_8$ in. (3 mm) for thicknesses less than $^5/_8$ in. (16 mm), and greater than $^3/_{16}$ in. (5 mm) for thicknesses $^5/_8$ in. (16 mm) and greater;

(3) four or more relevant indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more relevant indications in any 6 in.^{2} (4 000 mm^2) of surface with the major dimension of this area not to exceed 6 in. (150 mm) taken in the most unfavorable orientation relative to the indications being evaluated.

NC-2580 EXAMINATION OF BOLTS, STUDS, AND NUTS

NC-2581 Requirements

All bolting material shall be visually examined in accordance with NC-2582.

NC-2582 Visual Examination

Visual examination shall be applied to the areas of threads, shanks, and heads of final machined parts. Harmful discontinuities such as laps, seams, or cracks that would be detrimental to the intended service are unacceptable.

NC-2600 MATERIAL ORGANIZATIONS' QUALITY SYSTEM PROGRAMS

NC-2610 DOCUMENTATION AND MAINTENANCE OF QUALITY SYSTEM PROGRAMS

(a) Except as provided in (b) below, Material Organizations shall have a Quality System Program that meets the requirements of NCA-3800.

(b) The requirements of NCA-3862 shall be met as required by NC-2130. The other requirements of NCA-3800 need not be used by Material Organizations for small products, as defined in (c) below, for brazing material, and for material which is allowed by this Subsection to be furnished with a Certificate of Compliance. For these products, the Certificate Holder's Quality Assurance Program (Article NCA-4000) shall include measures to provide assurance that the material is furnished in accordance with the material specification and with the applicable requirements of this Subsection.

(c) For the purpose of this paragraph, small products are defined as given in (1) through (4) below:

(1) pipe, tube (except heat exchanger tube), pipe fittings, and flanges NPS 2 (DN 50) and less;

(2) bolting materials, including studs, nuts, and bolts of 1 in. (25 mm) nominal diameter and less;

(3) bars with a nominal cross-sectional area of 1 in.^{2} (650 mm^2) and less;

(4) material for pumps and valves with inlet pipe connections of NPS 2 (DN 50) and less;

(5) materials exempted by NC-2121(c).

NC-2700 DIMENSIONAL STANDARDS

Dimensions of standard items shall comply with the standards and specifications of Table NCA-7100-1.

ARTICLE NC-3000
DESIGN

NC-3100 GENERAL DESIGN

NC-3110 LOADING CRITERIA

NC-3111 Loading Conditions

The loadings that shall be taken into account in designing a component shall include, but are not limited to, those in (a) through (g) below:

(a) internal and external pressure;

(b) impact loads, including rapidly fluctuating pressures;

(c) weight of the component and normal contents under operating or test conditions, including additional pressure due to static and dynamic head of liquids;

(d) superimposed loads such as other components, operating equipment, insulation, corrosion resistant or erosion resistant linings, and piping;

(e) wind loads, snow loads, vibrations, and earthquake loads, where specified;

(f) reactions of supporting lugs, rings, saddles, or other types of supports;

(g) temperature effects.

NC-3112 Design Loadings

The Design Loadings shall be established in accordance with NCA-2142.1 and the following subparagraphs.

NC-3112.1 Design Pressure. The specified internal and external Design Pressures to be used in this Subsection shall be established in accordance with NCA-2142.1(a).

NC-3112.2 Design Temperature. The specified Design Temperature shall be established in accordance with NCA-2142.1(b). It shall be used in conjunction with the Design Pressure. If necessary, the metal temperature shall be determined by computation using accepted heat transfer procedures or by measurement from equipment in service under equivalent operating conditions. In no case shall the temperature at the surface of the metal exceed the maximum temperature listed in the applicability column of Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, nor exceed the maximum temperature limitations specified elsewhere in this Subsection.

NC-3112.3 Design Mechanical Loads. The specified Design Mechanical Loads shall be established in accordance with NCA-2142.1(c). They shall be used in conjunction with the Design Pressure.

NC-3112.4 Design Allowable Stress Values.

(a) Allowable stresses for design for materials are listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, except for vessels designed to the requirements of NC-3200, for which the design stress intensity values are listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. The materials shall not be used at metal and design temperatures that exceed the temperature limit in the applicability column for which stress or stress intensity values are given. The values in the Tables may be interpolated for intermediate temperatures.

(b) The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loadings that produce longitudinal compressive stress in the shell shall be the smaller of the following values:

(1) the maximum allowable tensile stress value permitted in (a) above;

(2) the value of the factor B determined from NC-3133.6(b).

(c) The wall thickness of a component computed by the rules of this Subsection shall be determined so that the general membrane stress due to any combination of mechanical loadings listed in NC-3111 which are expected to occur simultaneously during a condition of loading for which service Level A is designated for the component does not exceed[10] the maximum allowable stress value permitted at the Design Temperature unless specifically permitted in other paragraphs of this Subsection. These allowable stress values may be interpolated for intermediate Design Temperature.

NC-3113 Service Conditions

(a) Each service condition to which the components may be subjected shall be classified in accordance with NCA-2142, and Service Limits [NCA-2142.4(b)] shall be designated in the Design Specifications in such detail as will provide a complete basis for design in accordance with this Article.

(b) When any loadings for which Level B, C, or D Service Limits are designated are specified in the Design Specifications, they shall be evaluated in accordance with NCA-2140 and in compliance with the applicable design and stress limits of this Article.

NC-3120 SPECIAL CONSIDERATIONS

NC-3121 Corrosion

Materials subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made in the Design Specifications for these effects by indicating the increase in the thickness of the base metal over that determined by the design equations (NC-2160). Other suitable methods of protection may be used. Material added or included for these purposes need not be of the same thickness for all areas of the component if different rates of attack are expected for the various areas.

NC-3122 Cladding

The rules of this paragraph apply to the design of clad components constructed of material permitted in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NC-3122.1 Stresses. Except as permitted by NC-3214, no structural strength shall be attributed to the cladding.

NC-3122.2 Design Dimensions. The dimensions given in (a) and (b) below shall be used in the design of the component:

(a) for components subjected to internal pressure, the inside diameter shall be taken at the nominal inner face of the cladding;

(b) for components subjected to external pressure, the outside diameter shall be taken at the outer face of the base metal.

NC-3123 Welds Between Dissimilar Metals

In satisfying the requirements of this subarticle, caution shall be exercised in construction involving dissimilar metals having different chemical compositions, mechanical properties, and coefficients of thermal expansion in order to avoid difficulties in service.

NC-3124 Ductile Behavior Evaluation

The use of material below the temperature established by the methods of NC-2331(a) may be justified by methods equivalent to those contained in Section III Appendices, Nonmandatory Appendix G.

NC-3125 Configuration

Accessibility to permit the examinations required by the Edition and Addenda of Section XI as specified in the Design Specification for the component shall be provided in the design of the component.

NC-3130 GENERAL DESIGN RULES

NC-3131 General Requirements

The design shall be such that the rules of this Article are satisfied for all configurations and loadings, using the maximum allowable stress values S of Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 in the various equations and including the use of the standard products listed in Table NCA-7100-1. Use of the maximum allowable stress values of Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 does not apply to vessels designed to the rules of NC-3200.

NC-3131.1 Design Reports.

(a) The N Certificate Holder is required to provide a Design Report as part of the responsibility for achieving structural integrity of the component. The Design Report shall be certified when required by NCA-3550.

(b) The Certificate Holder for construction of a vessel conforming to the design requirements of NC-3200 shall provide a Design Report conforming to the requirements of NC-3211 and NC-3223.2.

NC-3131.2 Proof Test to Establish Maximum Design Pressure. When the configuration of a component is such that the stresses resulting from internal or external pressure cannot be determined with adequate accuracy by the rules of this Article, the maximum Design Pressure shall be determined by proof testing in accordance with the rules of NC-6900 except for piping as otherwise provided in this Article. This procedure does not apply to vessels designed to the requirements of NC-3200.

NC-3132 Dimensional Standards for Standard Products

Dimensions of standard products shall comply with the standards and specifications listed in Table NCA-7100-1 when the standard or specification is referenced in the specific design subarticle. However, compliance with these standards does not replace or eliminate the requirements for stress analysis when called for by the design subarticle for a specific component.

NC-3133 Components Under External Pressure

NC-3133.1 General. Rules are given in this paragraph for determining the thickness under external pressure loading in spherical shells, cylindrical shells with or without stiffening rings, and tubular products consisting of pipes, tubes, and fittings. Charts for determining the stresses in shells and hemispherical heads are given in Section II, Part D, Subpart 3. For vessels designed to NC-3200, see NC-3240.

NC-3133.2 Nomenclature. The symbols used in this paragraph are defined as follows:

A = factor determined from Section II, Part D, Subpart 3, Figure G and used to enter the applicable material chart in Section II, Part D, Subpart 3. For the case of cylinders having D_o/T values less than 10, see NC-3133.3(b).

= factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration

A_s = cross-sectional area of a stiffening ring

B = factor determined from the applicable chart in Section II, Part D, Subpart 3 for the material used in a shell or stiffening ring at the design metal temperature, psi (MPa)

D_o = outside diameter of the cylindrical shell course or tube under consideration

E = modulus of elasticity of material at Design Temperature, psi (MPa). For external pressure and axial compression design in accordance with this Section the modulus of elasticity to be used shall be taken from the applicable materials chart in Section II, Part D, Subpart 3. (Interpolation may be made between lines for intermediate temperatures.) The modulus of elasticity values shown in Section II, Part D, Subpart 3 for material groups may differ from those values listed in Section II, Part D, Subpart 2, Tables TM for specific materials. Section II, Part D, Subpart 3 values shall be applied only to external pressure and axial compression design.

I = available moment of inertia of the stiffening ring about its neutral axis, parallel to the axis of the shell

I' = available moment of inertia of the combined ring-shell cross section about its neutral axis, parallel to the shell. The width of the shell, which is taken as contributing to the combined moment of inertia, shall not be greater than 1.10 $\sqrt{D_o T_n}$ and shall be taken as lying one half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing to more than one stiffening ring.

I_s = required moment of inertia of the stiffening ring about its neutral axis parallel to the axis of the shell

I'_s = required moment of inertia of the combined ring-shell section about its neutral axis parallel to the axis of the shell

L = total length of a tube between tubesheets, or the design length of a vessel section, taken as the largest of the following:

(a) the distance between head tangent lines plus one-third of the depth of each head if there are no stiffening rings

(b) the greatest center-to-center distance between any two adjacent stiffening rings

(c) the distance from the center of the first stiffening ring to the head tangent line plus one-third of the depth of the head, all measured parallel to the axis of the vessel

L_s = one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the center line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component. A line of support is

(a) a stiffening ring that meets the requirements of this paragraph

(b) a circumferential line on a head at one-third the depth of the head from the head tangent line

(c) a circumferential connection to a jacket for a jacketed section of a cylindrical shell

P = external Design Pressure, psi (MPa) (gage or absolute, as required)

P_a = allowable external pressure, psi (MPa) (gage or absolute, as required)

R = inside radius of spherical shell

S = the lesser of twice the allowable stress at design metal temperature from Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 or 0.9 times the tabulated yield strength at design metal temperature from Section II, Part D, Subpart 1, Table Y-1, psi (MPa)

T = minimum required thickness of cylindrical shell or tube or spherical shell

T_n = nominal thickness used, less corrosion allowance, of a cylindrical shell or tube

NC-3133.3 Cylindrical Shells and Tubular Products. The thickness of cylinders under external pressure shall be determined by the procedure given in (a) or (b) below.

(a) Cylinders having D_o/T values ≥ 10:

Step 1. Assume a value for T and determine the ratios L/D_o and D_o/T.

Step 2. Enter Section II, Part D, Subpart 3, Figure G at the value of L/D_o determined in Step 1. For values of L/D_o greater than 50, enter the chart at a value of L/D_o = 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o of 0.05.

Step 3. Move horizontally to the line for the value of D_o/T determined in Step 1. Interpolation may be made for immediate values of D_o/T. From this point of intersection move vertically downward to determine the value of factor A.

Step 4. Using the value of A calculated in Step 3, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 7.

Step 5. From the intersection obtained in Step 4, move horizontally to the right and read the value of B.

Step 6. Using this value of B, calculate the value of the maximum allowable external pressure P_a using the following equation:

$$P_a = \frac{4B}{3(D_o / T)}$$

Step 7. For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following equation:

$$P_a = \frac{2AE}{3(D_o / T)}$$

Step 8. Compare P_a with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value of P_a is obtained that is equal to or greater than P.

(b) Cylinders having D_o/T values < 10:

Step 1. Using the same procedure as given in (a) above, obtain the value of B. For values of D_o/T less than 4, the value of factor A can be calculated using the following equation:

$$A = \frac{1.1}{(D_o / T)^2}$$

For values of A greater than 0.10, use a value of 0.10.

Step 2. Using the value of B obtained in Step 1, calculate a value P_{a1} using the following equation:

$$P_{a1} = \left[\frac{2.167}{(D_o / T)} - 0.0833\right]B$$

Step 3. Calculate a value P_{a2} using the following equation:

$$P_{a2} = \frac{2S}{(D_o / T)}\left[1 - \frac{1}{(D_o / T)}\right]$$

Step 4. The smaller of the values of P_{a1} calculated in Step 2, or P_{a2} calculated in Step 3 shall be used for the maximum allowable external pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

NC-3133.4 Spherical Shells and Formed Heads.

(a) Spherical Shells. The minimum required thickness of a spherical shell under external pressure, either seamless or of built-up construction with butt joints, shall be determined by the procedure given in Steps 1 through 6.

Step 1. Assume a value for T and calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R / T)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 5.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B.

Step 4. Using the value of B obtained in Step 3, calculate the value of the maximum allowable external pressure P_a using the following equation:

$$P_a = \frac{B}{(R / T)}$$

Step 5. For values of A falling to the left of the applicable material/temperature line for the Design Temperature, the value of P_a can be calculated using the following equation:

$$P_a = \frac{0.0625E}{(R / T)^2}$$

Step 6. Compare P_a obtained in Step 4 or Step 5 with P. If P_a is smaller than P, select a larger value for T and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

(b) The nomenclature defined below is used in the equations of (c) through (e) below.

D_o = outside diameter of the head skirt or the outside diameter of a cone head at the point under consideration, measured perpendicular to the longitudinal axis of the cone, in. (mm)

K_1 = a factor depending on the ellipsoidal head proportions, given in Table NC-3332.2-1

R = for hemispherical heads, the inside radius in the corroded condition, in. (mm)
= for ellipsoidal heads, the equivalent inside spherical radius taken as $K_1 D_o$ in the corroded condition, in. (mm)
= for torispherical heads, the inside radius of the crown portion of the head in the corroded condition, in. (mm)

T = minimum required thickness of head after forming, exclusive of corrosion allowance, in. (mm) *(c) Hemispherical Heads*. The required thickness of a hemispherical head having pressure on the convex side shall be determined in the same manner as outlined in (a) above for determining the thickness for a spherical shell.

(d) Ellipsoidal Heads. The required thickness of an ellipsoidal head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the following procedure.

Step 1. Assume a value for T and calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R/T)}$$

Step 2. Using the value of A calculated in Step 1, follow the same procedure as that given for spherical shells in (a) above, Steps 2 through 6.

(e) Torispherical Heads. The required thickness of a torispherical head having pressure on the convex side, either seamless or of built-up construction with butt joints, shall not be less than that determined by the same design procedure as is used for ellipsoidal heads given in (d) above, using the appropriate value for R.

NC-3133.5 Stiffening Rings for Cylindrical Shells.

(a) The required moment of inertia of a circumferential stiffening ring shall be not less than that determined by one of the following two equations:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{14} \qquad (1)$$

$$I'_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9} \qquad (2)$$

If the stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener, the effective shell section for that stiffener shall be shortened by one-half of each overlap.

(b) The available moment of inertia I or I' for a stiffening ring shall be determined by the following procedure.

Step 1. Assuming that the shell has been designed and D_o, L_s, and T_n are known, select a member to be used for the stiffening ring and determine its cross-sectional area A_s. Then calculate factor B using the following equation:

$$B = \frac{3}{4}\left[\frac{PD_o}{T_n + A_s / L_s}\right]$$

Step 2. Enter the right-hand side of the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined by Step 1. If different materials are used for the shell and stiffening ring, use the material chart resulting in the larger value of A in Step 4 or Step 5, below.

Step 3. Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see Step 5.

Step 4. Move vertically to the bottom of the chart and read the value of A.

Step 5. For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the equation

$$A = \frac{2B}{E}$$

Step 6. Compute the value of the required moment of inertia from eqs. (a)(1) and (a)(2).

Step 7. Calculate the available moment of inertia I or I' of the stiffening ring using the section corresponding to that used in Step 6.

Step 8. If the required moment of inertia is greater than the moment of inertia for the section selected in Step 1, a new section with a larger moment of inertia must be selected and a new moment of inertia determined. If the required moment of inertia is smaller than the moment of inertia for the section selected in Step 1, that section should be satisfactory.

(c) For fabrication and installation requirements for stiffening rings, see NC-4437.

NC-3133.6 Cylinders Under Axial Compression. The maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in (a) or (b) below:

(a) the S value for the applicable material at design temperature given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3;

(b) the value of the B determined from the applicable chart in Section II, Part D, Subpart 3 using the following definitions for the symbols on the charts:

R = inside radius of the cylindrical shell or tubular product

T = minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance

The value of B shall be determined from the applicable chart contained in Section II, Part D, Subpart 3 as given in Steps 1 through 5.

Step 1. Using the selected values of T and R, calculate the value of factor A using the following equation:

$$A = \frac{0.125}{(R/T)}$$

Step 2. Using the value of A calculated in Step 1, enter the applicable material chart in Section II, Part D, Subpart 3 for the material under consideration. Move vertically to an intersection with the material/temperature line for the Design Temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see Step 4.

Step 3. From the intersection obtained in Step 2, move horizontally to the right and read the value of factor B. This is the maximum allowable compressive stress for the values of T and R used in Step 1.

Step 4. For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following equation:

$$B = \frac{AE}{2}$$

Step 5. Compare the value of B determined in Step 3 or 4 with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of T and R. If the value of B is smaller than the computed compressive stress, a greater value of T must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

NC-3133.7 Conical Heads. The required thickness of a conical head under external pressure shall not be less than that determined by the rules of (a), (b), and (c) below.

(a) When one-half of the included apex angle of the cone is equal to or less than $22\frac{1}{2}$ deg, the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the length of which equals the axial length of the cone or the axial distance center to center of stiffening rings, if used, and the outside diameter of which is equal to the outside diameter at the large end of the cone or section between stiffening rings.

(b) When one-half of the included apex angle of the cone is greater than $22\frac{1}{2}$ deg and not more than 60 deg, the thickness of the cone shall be the same as the required thickness of a cylindrical shell, the outside diameter of which equals the largest inside diameter of the cone measured perpendicularly to the cone axis, and the length of which equals an axial length that is the lesser of either the distance center to center of stiffening rings, if used, or the largest inside diameter of the section of the cone considered.

(c) When one-half of the included apex angle of the cone is greater than 60 deg, the thickness of the cone shall be the same as the required thickness for a flat head under external pressure, the diameter of which equals the largest inside diameter of the cone (NC-3325).

NC-3133.8 Tubes and Pipes When Used as Tubes. The required wall thickness for tubes and pipes under external pressure shall be determined in accordance with Figure NC-3133.8-1.

NC-3135 Attachments

(a) Except as in (c) and (d) below, attachments and connecting welds within the jurisdictional boundary of the component as defined in NC-1130 shall meet the stress limits of the component.

(b) The design of the component shall include consideration of the interaction effects and loads transmitted through the attachment to and from the pressure-retaining portion of the component. For vessels designed to NC-3200, thermal stresses, stress concentrations, and restraint of the pressure-retaining portion of the component shall be considered.

(c) Beyond $2t$ from the pressure-retaining portion of the component, where t is the nominal thickness of the pressure-retaining material, the appropriate design rules of Article NF-3000 may be used as a substitute for the design rules of Article NC-3000 for portions of attachments which are in the component support load path.

(d) Nonstructural attachments shall meet the requirements of NC-4435.

NC-3200 ALTERNATIVE DESIGN RULES FOR VESSELS

NC-3210 GENERAL REQUIREMENTS

NC-3211 Basis for Use

NC-3211.1 Scope.

(a) This subarticle contains design rules for vessels which may be used as an alternative to the design rules in NC-3300. When these requirements are met for design, the stress intensity values of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 may be used.

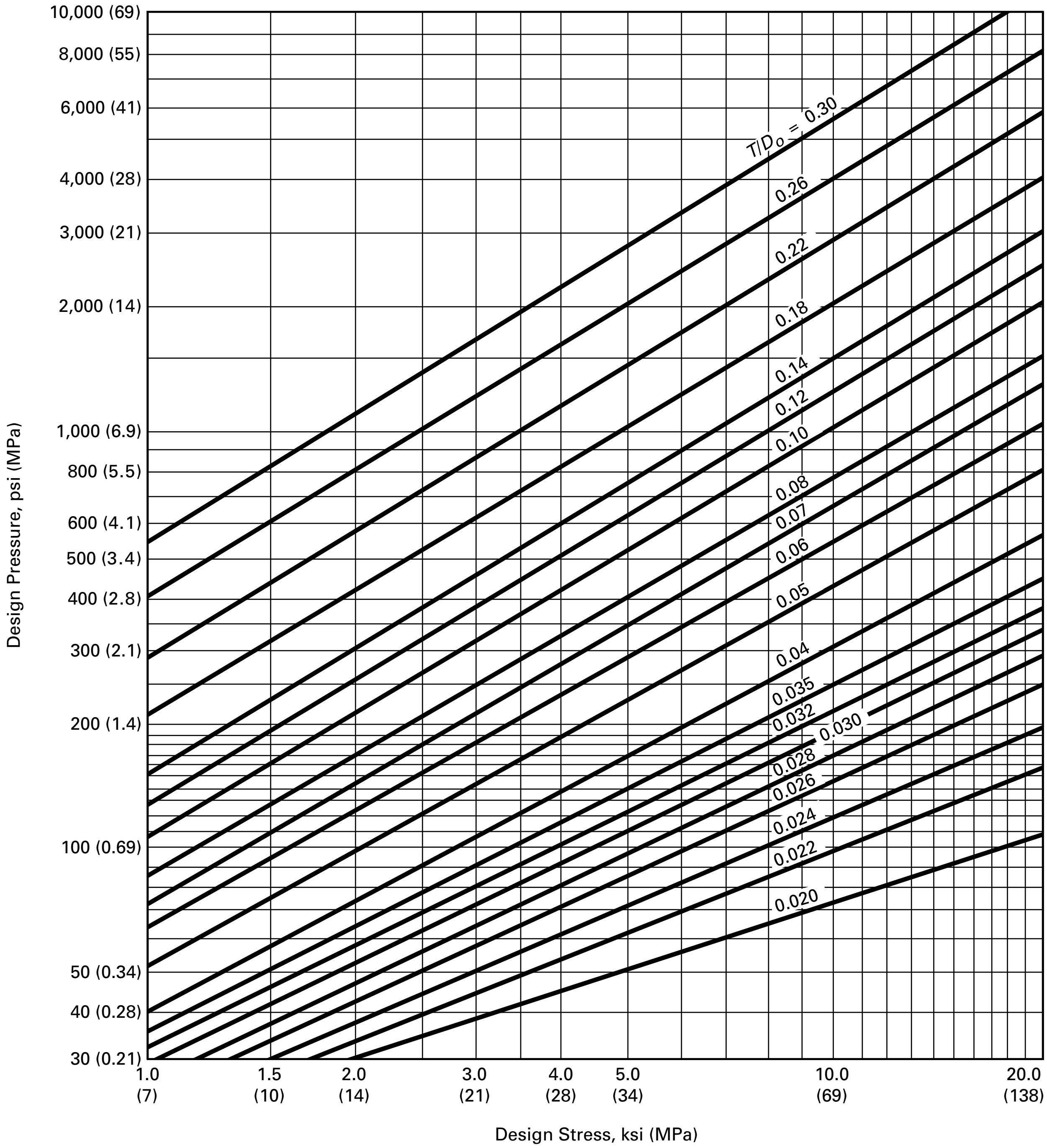
(b) These requirements provide specific design rules for some commonly used vessel shapes under pressure loadings and, within specified limits, rules for treatment of other loadings. Simplified rules are also included for the approximate evaluation of design cyclic service life. Rules are not given which cover all details of design.

(c) When complete rules are not provided or when the vessel designer chooses, a complete stress analysis of the vessel or vessel region shall be performed considering all the loadings of NC-3212 and the Design Specifications. This analysis shall be done in accordance with Section III Appendices, Mandatory Appendix XIII for all applicable stress categories. Alternatively, an experimental stress analysis shall be performed in accordance with Section III Appendices, Mandatory Appendix II.

(d) When these alternative design rules are used, the special requirements of NC-4260, NC-5250, NC-6221, and NC-6222 shall be met.

(e) A Design Report shall be prepared by the Certificate Holder showing compliance with this subarticle. This Design Report shall meet the requirements of NCA-3550 for a Design Report (Section III Appendices, Nonmandatory Appendix C).

Figure NC-3133.8-1
Chart for Determining Wall Thickness of Tubes Under External Pressure



NC-3211.2 Requirements for Acceptability.

(a) The design shall be such that the requirements of NC-3100 and this subarticle are satisfied. In cases of conflict, the requirements of this subarticle shall govern.

(b) The design shall be such that stress intensities do not exceed the limits given in NC-3216.

(c) For configurations where compressive stresses occur, the critical buckling stress shall be taken into account. For the special case of external pressure, the rules of NC-3133 shall be met.

NC-3211.3 Materials in Combination.

(a) A vessel may be designed for and constructed of any combination of materials permitted in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, provided the applicable rules are followed and the requirements in Section IX for welding dissimilar metals are met.

(b) A stress analysis of a vessel region shall be made in accordance with Section III Appendices, Mandatory Appendix XIII unless all of the provisions of (c) or (d) below apply. This does not obviate the need for such analysis where required by other provisions of this subarticle.

(c) See below.

(1) The junction is a girth seam between pressure parts.

(2) Any taper required because of different thickness shall be in the material having the higher design stress intensity, or in weld deposit appropriate for the stronger material.

(3) No discontinuity is involved except that due to thickness and modulus of elasticity difference.

(4) $S_{m2} \leq 1.2\, S_{m1}\ (E_2/E_1)$ where subscripts 1 and 2 denote the material having the lower and higher design stress intensity value, respectively, and S_m and E are as defined in NC-3216 and NC-3219, respectively.

(d) See below.

(1) The junction is at a seam between pressure parts other than a girth seam covered by (c) above.

(2) Any taper required because of different thickness is in material having the higher design stress intensity or in weld deposit appropriate for the stronger material.

(3) $S_{m2} \leq 1.1\ S_{m1}\ (E_2/E_1)$ where subscripts and symbols are as given in (c)(4) above.

NC-3211.4 Combination Units. When a vessel unit consists of more than one independent chamber, operating at the same or different pressures and temperatures, each chamber or vessel shall be designed and constructed to withstand the most severe condition of coincident pressure and temperature expected. Chambers which come within the scope of this subarticle may be connected to chambers constructed to the rules of NC-3300, provided the connection between such chambers meets all of the requirements of this subarticle.

NC-3211.5 Minimum Thickness of Shell or Head. The thickness after forming and without allowance for corrosion of any shell or head subject to pressure shall be not less than $^1/_4$ in. (6 mm) for carbon and low alloy steels or $^1/_8$ in. (3 mm) for stainless steel.

NC-3211.6 Selection of Material Thickness. The selected thickness of material shall be such that the forming, heat treatment, and other fabrication processes will not reduce the thickness of the material at any point below the minimum value required by these rules.

NC-3212 Loadings

The requirements of NC-3111 shall apply.

NC-3214 Cladding

The design calculations shall be based on a thickness equal to the nominal thickness of the base plate plus S_c/S_b times the nominal thickness of the cladding, less any allowance provided for corrosion, provided the conditions of (a), (b), and (c) below are met.

(a) The clad product conforms to one of the clad plate products referenced in NC-2121 or is overlay weld clad.

(b) The joints are completed by depositing corrosion resisting weld metal over the weld in the base material to restore the cladding.

(c) The S_m value of the weaker material is at least 70% of the S_m value of the stronger. Where

S_b = design stress intensity value for the base material at the Design Temperature, psi

S_c = design stress intensity value for the cladding or, for the weld overlay, that of the wrought material whose chemistry most closely approximates that of the cladding, at the Design Temperature, psi

the design stress intensity value shall be that given for base material in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. When S_c is greater than S_b, the multiplier S_c/S_b shall be taken equal to unity.

NC-3215 Design Basis

NC-3215.1 Pressure and Temperature Relationships.

(a) Table NC-3215.1(a)-1 sets forth the pressure, temperature, and static head relationships which shall be considered by the designer.

(b) The design for a vessel part is usually controlled by coincident pressure and temperature at a point. The design shall take into account the maximum difference in fluid pressure, which exists under the specified service conditions, between the inside and outside of the vessel at any point or between two chambers of a combination unit. The design thickness for pressure shall not include any metal added as corrosion or erosion allowance or any metal required for any combination of loadings listed in NC-3218 which are likely to occur coincident with the service pressure and temperature.

Table NC-3215.1(a)-1
Pressure and Temperature Relationships

Condition	Pressure at Top of Vessel	Pressure Due to Static Head [Note (1)]	Temperature	Remarks
Condition 1				
For vessel as a whole	Design Pressure	None	Coincident metal	Pressure and temperature to be stamped on nameplate
At any point	Coincident pressure	Pressure to point under consideration due to static head of vessel contents	Design coincident temperature	Temperature at various points may vary, in which case the maximum for these conditions shall be used for the vessel as a whole or coincident conditions for specific locations shall be listed on the Certificate Holder's Data Report and Stamping
Condition 2				
At any point	Coincident pressure	Coincident pressure to point under consideration due to static head	Design Temperature	Higher temperature and lower pressure combinations (than Condition 1) shall be checked or a part may be designed for the Maximum Design Pressure and the Design Temperature
Condition 3				
For vessel as a whole	Test pressure	None	Test temperature	
At any point	Test pressure	Pressure at point under consideration due to static head	Test Temperature	
Condition 4				
For vessel as a whole or any part	Coincident pressure	...	Minimum permissible temperature	Minimum permissible temperature is used together with impact testing to determine suitability of material at service temperature
	Safety value setting	...	...	Usually set above the service pressure but not over the limits set in Article NC-7000

NOTE:
(1) Similar applications shall be made for other sources of pressure variation such as that resulting from flow.

NC-3215.2 Definitions.

(a) Design Pressure. The provisions of NC-3112.1 shall apply.

(b) Design Temperature. The provisions of NC-3112.2 shall apply.

(c) Service Conditions. The provisions of NC-3113 shall apply.

(d) Test Pressure. The test pressure is the pressure to be applied at the top of the vessel during the test. This pressure plus any pressure due to static head at any point under consideration is used in the applicable equation to check the vessel under test conditions.

(e) Safety Valve Setting. The pressure for which the safety or safety relief valves are set to open is established by Article NC-7000.

NC-3216 Design Stress Intensity Values

NC-3216.1 Stress Tables. The design stress intensity values S_m are given in Section II, Part D, Subpart 1,Tables 2A, 2B, and 4. Values for intermediate temperatures may be found by interpolation. These S_m values form the basis for the various stress limits which are described in Section III Appendices, Mandatory Appendix XIII and are used in determining the membrane stress intensity limits for the various load combinations given in Table NC-3217-1.

NC-3216.2 Coefficients of Thermal Expansion and Moduli of Elasticity. Values of the coefficients of thermal expansion are in Section II, Part D, Subpart 2, Tables TE, and values of the moduli of elasticity are in Section II, Part D, Subpart 2, Tables TM.

NC-3216.3 Special Stress Limits. The deviations given in (a), (b), and (c) below from the basic stress limits are provided to cover special conditions or configurations.

(a) Bearing Loads

(1) The average bearing stress for resistance to crushing under the maximum design load shall be limited to the yield strength S_y at temperature except that, when the distance to a free edge is greater than the distance over which the bearing load is applied, a stress of $1.5S_y$

at temperature is permitted. For clad surfaces, the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(2) When bearing loads are applied on parts having free edges, such as at a protruding ledge, the possibility of a shear failure shall be considered. The average shear stress shall be limited to $0.6S_m$ in the case of design load stress [Section III Appendices, Mandatory Appendix XIII, XIII-1123(l)] and to $0.5S_y$ in the case of design load stress plus secondary stress [Section III Appendices, Mandatory Appendix XIII, XIII-1123(i)]. For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material. If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(3) When considering bearing stresses in pins and similar members, the S_y value at temperature is applicable, except that a value of $1.5S_y$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

(b) Pure Shear. The average primary shear stress across a section under Design Loadings in pure shear, for example, keys, shear rings, and screw threads, shall be limited to $0.6S_m$. The maximum primary shear under Design Loadings, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8S_m$.

(c) Progressive Distortion of Nonintegral Connections. Screwed-on caps, screwed-in plugs, shear ring closures, and breech lock closures are examples of nonintegral connections which are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities (Section III Appendices, Mandatory Appendix XIII, XIII-1145), which result in slippage between the parts of a nonintegral connection in which disengagement could occur as a result of progressive distortion, shall be limited to the value S_y given in Section II, Part D, Subpart 1, Table Y-1.

NC-3217 Design Criteria

These design requirements provide specific design rules for certain commonly used pressure vessel shapes under pressure loading and, within prescribed limits, rules for the treatment of other loadings. Simplified criteria are included for determining whether an analysis for cyclic operation shall be made. The thickness of the vessel parts and attached supports covered by these rules shall be determined by the applicable equation using the most severe combination of loadings and design stress intensities kS_m expected to occur simultaneously during design and service conditions. The basis for these equations is given in (a) through (d) below. Table NC-3217-1 lists values of k that are appropriate for various load combinations.

(a) The theory of failure used in this subarticle is the maximum shear stress theory, except in the case of some specifically designated configurations, shapes, or design rules included as a part of this subarticle. Stress intensity is defined as two times the maximum shear stress.

(b) The average value of the general primary membrane stress intensity across the thickness of the section under consideration P_m, due to any combination of pressure and mechanical loadings expected to occur simultaneously, should not exceed the design stress intensity value kS_m.

(c) The local primary membrane stress intensity P_L due to any combination of pressure and mechanical loadings expected to occur simultaneously is limited to $1.5kS_m$. The distance over which the stress intensity exceeds $1.1kS_m$ shall not extend in the meridional direction more than $1.0\sqrt{Rt}$, where R is the mean radius at the midsurface of the shell or head and t is the nominal thickness of the shell or head at the point under consideration.

(d) The general or local primary membrane plus bending stress intensity (P_m or P_L) + P_b due to any combination of pressure and mechanical loadings expected to occur simultaneously shall not exceed 1.5 kS_m. When

Table NC-3217-1 Stress Intensity k Factors for Design and Service Load Combinations

Service Limits [Note (1)]	k [Note (2)]
Design	1.0
Level A [Note (3)]	1.0
Level B [Note (3)]	1.1
Level C	1.2
Level D [Note (4)]	2.0

NOTES:
(1) For Design Limits, use Design Pressure at design metal temperature; for Service Limits, use service pressure at service metal temperature.
(2) The condition of structural instability or buckling must be considered.
(3) See NC-3219 and Section III Appendices, Mandatory Appendix XIV.
(4) When a complete analysis is performed in accordance with NC-3211.1(c), the stress limits of Section III Appendices, Nonmandatory Appendix F may be applied.

the design of vessels involves combinations of calculated stresses, the provisions of Section III Appendices, Mandatory Appendix XIII apply.

NC-3217.1 Secondary Stresses. Secondary stresses may exist in vessels designed and fabricated in accordance with the rules of this subarticle, but limitations are provided to restrict such stresses to levels consistent with the rules in Section III Appendices, Mandatory Appendix XIII. Where details are not covered or where design conditions exceed the equation limitations, a detailed stress analysis in accordance with the rules of Section III Appendices, Mandatory Appendix XIII shall be made. Secondary stresses need be evaluated only for Level A and Level B Limits.

NC-3217.2 Definitions.

P_b = primary bending stress intensity, psi (MPa). This stress intensity is the component of primary stress proportional to the distance from the centroid of the solid section. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

P_L = local primary membrane stress intensity, psi (MPa). This stress intensity is derived from the average value across the solid section under consideration. It considers discontinuities but not concentrations.

P_m = general primary membrane stress intensity, psi (MPa). This stress intensity is derived from the average value across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

S_m = design stress intensity values given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4, psi (MPa)

S_y = yield strength values given in Section II, Part D, Subpart 1, Table Y-1, psi (MPa)

(15) NC-3218 Upper Limits of Test Pressure

The evaluation of pressure test loadings shall be in accordance with (a) through (d) below.

(a) Test Pressure Limit. If the calculated pressure at any point in a vessel, including static head, exceeds the required test pressure defined in NC-6221 or NC-6321 by more than 6%, the resulting stresses shall be calculated using all the loadings that may exist during the test. The stress allowables for this situation are given in (b) and (c) below.

(b) Hydrostatically Tested Vessels. The hydrostatic test pressure of a completed vessel shall not exceed that value which results in the following stress intensity limits:

(1) a calculated primary membrane stress intensity P_m of 90% of the tabulated yield strength S_y at test temperature as given in Section II, Part D, Subpart 1, Table Y-1.

(2) a calculated primary membrane plus primary bending stress intensity $P_m + P_b$ shall not exceed the applicable limits given in (-a) or (-b) below:

(-a) $P_m + P_b \leq 1.35S_y$ for $P_m \leq 0.67S_y$

(-b) $P_m + P_b \leq (2.15S_y - 1.2P_m)$ for $0.67S_y < P_m \leq 0.90S_y$

where S_y is the tabulated yield strength at test temperature. For other than rectangular sections, $P_m + P_b$ shall not exceed a value of α times $0.9S_y$, where the factor α is defined as the ratio of the load set producing a fully plastic section divided by the load set producing initial yielding in the extreme fibers of the section.

(c) Pneumatically Tested Vessels. The limits given in (b) above shall apply to pneumatically tested vessels, except that the calculated membrane stress intensity shall be limited to 80% of the yield strength at the test temperature. For other than rectangular sections, $P_m + P_b$ shall not exceed a value of α times $0.8S_y$, where the factor α is defined in (b)(2) above.

(d) Multichamber Vessels. In the case of multichamber vessels, pressure may be applied simultaneously to the appropriate adjacent chamber to maintain the stress intensity limits given in (b) and (c) above (NC-6600).

NC-3219 Fatigue Evaluation

When determining whether or not a fatigue analysis shall be specified, the Owner may consider experience with comparable vessels under similar conditions in accordance with the provisions of NC-3219.1. When not based upon significant applicable service experience, the need for a fatigue analysis shall be determined in accordance with the provisions of NC-3219.2 and NC-3219.3.

NC-3219.1 Service Experience. When the Owner is considering experience with comparable vessels under similar service conditions as related to the design and service contemplated, particular attention shall be given to the possible deleterious effects of the design features of (a) through (e) below:

(a) nonintegral construction, such as the use of pad type reinforcements or of fillet welded attachments, as opposed to integral construction;

(b) use of pipe threaded connections, particularly for diameters in excess of $2^3/_4$ in. (70 mm);

(c) stud bolted attachments;

(d) partial penetration welds;

(e) major thickness changes between adjacent members.

NC-3219.2 Rules to Determine Need for Fatigue Analysis of Integral Parts of Vessels. A fatigue analysis need not be made, provided *all* of Condition A or *all* of Condition B is met. If neither Condition A nor B is met, a detailed fatigue analysis shall be made in accordance with the rules of Section III Appendices, Mandatory Appendices XIII and XIV for those parts which do not satisfy the conditions. The rules of Condition A or Condition B are applicable to all integral parts of the vessel, including integrally reinforced type nozzles. For vessels having pad-type nozzles or nonintegral attachments, the requirements of NC-3219.3 apply.

NC-3219.2.1 Condition A. Fatigue analysis is not mandatory for materials having a specified minimum tensile strength not exceeding 80.0 ksi (550 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 1,000 cycles:

(a) is *the expected design number of full range pressure cycles* including startup and shutdown;

(b) is *the expected number of service pressure cycles* in which the range of pressure variation exceeds 20% of the Design Pressure. Cycles in which the pressure variation does not exceed 20% of the Design Pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered;

(c) is *the effective number of changes in metal temperature*[11] *between any two adjacent points*[12] in the pressure vessel, including nozzles. The effective number of such changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor given in the following table, and by adding the resulting numbers. The factors are as follows:

Metal Temperature Differential, °F (°C)	Factor
50 (28) or less	0
51 to 100 (29 to 56)	1
101 to 150 (57 to 83)	2
151 to 250 (84 to 139)	4
251 to 350 (140 to 194)	8
351 to 450 (195 to 250)	12
Excess of 450 (250)	20

(For example: Consider a design subjected to metal temperature differentials for the following number of times:

ΔT, °F (°C)	Cycles
40 (22)	1,000
90 (50)	250
400 (220)	5

the effective number of changes in metal temperature is

$$1,000(0) + 250(1) + 5(12) = 310$$

The number used as type (c) in performing the comparison with 1,000 is then 310. Temperature cycles caused by fluctuations in atmospheric conditions need not be considered.)

(d) for vessels with welds between materials having different coefficients of expansion, is *the number of temperature cycles* which causes the value of $(\alpha_1 - \alpha_2)\ \Delta T$ to exceed 0.00034 where α_1 and α_2 are the mean coefficients of thermal expansion, 1/°F (1/°C) (Section II, Part D, Subpart 2, Tables TE), and ΔT is the operating temperature range, °F (°C). This does not apply to cladding.

NC-3219.2.2 Condition B. Fatigue analysis is not mandatory when all of the conditions of (a) through (f) below are met.

(a) The expected design number of full range pressure cycles, including startup and shutdown, does not exceed the number of cycles in the applicable fatigue curve of Section III Appendices, Mandatory Appendix XIV corresponding to an S_a value of 3 times the S_m value in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 for the material at the service temperature.

(b) The expected design range of pressure cycles during normal service[13] does not exceed the quantity ($^1/_3$) times the Design Pressure times S_a/S_m, where S_a is the value obtained from the applicable fatigue curve of Section III Appendices, Mandatory Appendix XIV for the specified number of significant pressure fluctuations, and S_m is the design stress intensity value found in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 for the service temperature. If the specified number of significant pressure fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_a value corresponding to the maximum number of cycles defined on the curve may be used. Significant pressure fluctuations are those for which the range exceeds the quantity: Design Pressure times ($^1/_3$) times S/S_m, where S is defined as follows:

(1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(c) The temperature difference in °F (°C) between any two adjacent points of the vessel during normal service and during startup and shutdown does not exceed $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve for the specified number of startup and shutdown cycles, and α is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperature at the two points, as given by Section II, Part D, Subpart 2, Tables TE. E is taken from Section II, Part D, Subpart 2, Tables TM at the mean value of the temperatures at the two points.

(d) The range of temperature difference in °F (°C) between any two adjacent points of the vessel does not change during normal service by more than the quantity $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature difference fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/(2E\alpha)$, where S is defined as follows:

(1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

(e) For components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, *the total algebraic range of temperature fluctuation in* °F (°C) experienced by the vessel during normal service does not exceed the magnitude $S_a/[2(E_1\alpha_1 - E_2\alpha_2)]$, where S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficient of thermal expansion at the mean temperature value involved for the two materials of construction (Section II, Part D, Subpart 2, Tables TE and TM). A temperature fluctuation shall be considered to be significant if its total excursion exceeds the quantity $S/[2(E_1\alpha_1 - E_2\alpha_2)]$, where S is defined as follows:

(1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve. If the two materials used have different applicable design fatigue curves, the lower value of S_a shall be used in applying the rules of this paragraph. This does not apply to cladding.

(f) *The specified full range of mechanical loads*, excluding pressure but including piping reactions, does not result in load stress intensities whose range exceeds the S_a value obtained from the applicable design fatigue curve for the total specified number of significant load fluctuations. If the total specified number of significant load fluctuations exceeds the maximum number of cycles defined on the applicable design fatigue curve, the S_a value corresponding to the maximum number of cycles defined on the curve may be used. A load fluctuation shall be considered to be significant if the total excursion of load stress intensity exceeds the quantity S, where S is defined as follows:

(1) If the total specified number of service cycles is 10^6 cycles or less, S is the value of S_a obtained from the applicable design fatigue curve for 10^6 cycles.

(2) If the total specified number of service cycles exceeds 10^6 cycles, S is the value of S_a obtained from the applicable design fatigue curve for the maximum number of cycles defined on the curve.

NC-3219.3 Rules to Determine Need for Fatigue Analysis of Nozzles With Separate Reinforcement and Nonintegral Attachments. A fatigue analysis of pad-type nozzles and nonintegral attachments need not be made, provided *all* of Condition AP or *all* of Condition BP is met. If neither Condition AP nor BP is met, a detailed fatigue analysis must be made in accordance with the rules of Section III Appendices, Mandatory Appendices XIII and XIV. NC-3237 gives further limitations on pad-type nozzles.

NC-3219.3.1 Condition AP. Fatigue analysis of pad-type nozzles and nonintegral attachments is not mandatory for materials having specified minimum tensile strength not exceeding 80.0 ksi (550 MPa) when the total of the expected number of cycles of types (a) plus (b) plus (c) plus (d), defined below, does not exceed 400:

(a) is *the expected design number of full range pressure cycles* including startup and shutdown;

(b) is *the expected number of service pressure cycles* in which the range of pressure variation exceeds 15% of the Design Pressure. Cycles in which the pressure variation does not exceed 15% of the Design Pressure are not limited in number. Pressure cycles caused by fluctuations in atmospheric conditions need not be considered.

(c) is *the effective number of changes in metal temperature*[11] *between any two adjacent points*[14] in the pressure vessel, including nozzles. In calculating the temperature difference between adjacent points, conductive heat transfer shall be considered only through welded or integral cross sections with no allowance for conductive heat transfer across unwelded contact surfaces. The effective number of changes is determined by multiplying the number of changes in metal temperature of a certain magnitude by the factor, given in the following table, and by adding the resulting numbers. The factors are as follows:

Metal Temperature Differential, °F (°C)	Factor
50 (28) or less	0
51 to 100 (29 to 56)	1
101 to 150 (57 to 83)	2
151 to 250 (84 to 139)	4
251 to 350 (140 to 194)	8
351 to 450 (195 to 250)	12
Excess of 450 (250)	20

(For example: Consider a design subjected to metal temperature differentials for the following number of times:

ΔT, °F (°C)	Cycles
50 (28)	1,000
90 (50)	250
400 (220)	5

the effective number of changes in metal temperature is

$$1,000(0) + 250(1) + 5(12) = 310$$

The number used as type (c) in performing the comparison with 1,000 is then 310. Temperature cycles caused by fluctuations in atmospheric conditions need not be considered.)

(d) for vessels with welds between materials having different coefficients of expansion, is *the number of temperature cycles* which causes the value of $(\alpha_1 - \alpha_2)\ \Delta T$ to exceed 0.00034, where α_1 and α_2 are the mean coefficients of thermal expansion, 1/°F (1/°C) (Section II, Part D, Subpart 2, Tables TE), and ΔT is the service temperature range, °F (°C). This does not apply to cladding.

NC-3219.3.2 Condition BP. All of the requirements of NC-3219.2.2, Condition B, are met using the adjusted values in (a) through (c) below.

(a) Use a value of 4 instead of 3 in NC-3219.2.2(a).

(b) Use a value of one-quarter instead of one-third in NC-3219.2.2(b).

(c) Use a value of 2.7 instead of 2 in the denominator of NC-3219.2.2(c), NC-3219.2.2(d), and NC-3219.2.2(e).

NC-3220 DESIGN CONSIDERATIONS

NC-3221 Design Loadings

The provisions of NC-3210 apply.

NC-3222 Special Considerations

The provisions of NC-3121 and NC-3214 apply.

NC-3223 General Design Rules

NC-3223.1 General Requirements. The design shall be such that the design rules of NC-3200 are satisfied for all configurations and loadings, using the design stress intensity values S_m of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 in the various equations.

NC-3223.2 Design Reports. The Certificate Holder shall provide a Design Report conforming to the requirements of NC-3211.1(e).

NC-3224 Vessels and Parts Under Internal Pressure

NC-3224.1 General Requirements. The thickness of vessels and parts under internal pressure shall be not less than that computed by the equations in the following paragraphs. In addition, provision shall be made for the applicable load combinations listed in NC-3218 in establishing the value of F as defined below.

NC-3224.2 Nomenclature. The symbols used are defined below. Except for test conditions, dimensions used or calculated shall be in the corroded condition.

D = inside diameter of a head skirt or inside length of the major axis of an ellipsoidal head or inside diameter of a conical head at the point under consideration measured perpendicular to the axis of revolution.

F = meridional membrane force in the shell wall at the point under consideration resulting from primary loadings other than internal pressure, lb/in. (N/mm) length of circumference. If this force is not uniform, as when resulting from wind or earthquake moment loading, the loading requiring the greatest shell thickness shall be used where the tensile load is positive.

h = one-half the length of the minor axis of an ellipsoidal head or the inside depth of an ellipsoidal head, measured from the tangent line

k = stress intensity factor for design, service, and test load combination from Table NC-3217-1

L = inside spherical or crown radius of torispherical and hemispherical heads

P = internal pressure at the top of vessel plus any pressure due to the static head of the fluid, at any point under consideration, psi (MPa)

Q = a factor in the equations for cone to cylinder junctions depending on P/S and α

R = inside radius of the shell under consideration. This radius is measured normal to the surface from the of revolution

R_L = radius of a cylinder at the large end of a cone to cylinder junction

R_s = radius of a cylinder at the small end of a cone to cylinder junction

r = inside knuckle radius of torispherical and toriconical heads

S = membrane stress intensity limit from Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 multiplied by the stress intensity factor in Table NC-3217-1
= kS_m, psi (MPa)

t = minimum required thickness of shell

t_r = Q times the required thickness of a cylinder calculated in accordance with NC-3224.13(b)(6)(-b)

α = one-half of the apex angle of a cone to cylinder junction

NC-3224.3 Minimum Thickness of Cylindrical Shells. The minimum thickness of cylindrical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{PR}{S - 0.5P}$$

If $P > 0.4S$, the following equation must be used:

$$\ln\frac{(R + t)}{R} = \frac{P}{S}$$

where ln is the natural log.

(b) If F is positive and exceeds $0.5PR$,

$$t = \frac{0.5PR + F}{S - 0.5P}$$

(c) If F is negative, the condition of axial structural instability or buckling shall be considered separately (see NC-3245).

NC-3224.4 Minimum Thickness of Spherical Shells. The minimum thickness of spherical shells shall be the greatest of the thicknesses determined by (a), (b), and (c) below.

(a)

$$t = \frac{0.5PR}{S - 0.25P}$$

If $P > 0.4S$, the following equation may be used:

$$\ln\frac{(R + t)}{R} = \frac{0.5P}{S}$$

(b) If F is positive,

$$t = \frac{0.5PR + F}{S - 0.25P}$$

(c) If F is negative, the condition of instability shall be considered. NC-3245 for cylinders may be used for spheres, provided biaxial compression does not exist.

NC-3224.5 Minimum Thickness of Formed Heads. The minimum thickness at the thinnest point after forming of ellipsoidal, torispherical, and hemispherical heads under pressure acting against the concave surface shall be determined by the appropriate rule or equation in the following subparagraphs.

(15) **NC-3224.6 Minimum Thickness of Ellipsoidal Heads.**[15, 16] The minimum thickness of a 2:1 ellipsoidal head shall be established using the procedures given in NC-3224.8 and the curve of Figure NC-3224.6-1 which is labeled "2:1 ellipsoidal head." Ellipsoidal head designs which have $D/2h$ values different from 2 shall be analyzed as equivalent torispherical heads or according to Section III Appendices, Mandatory Appendix II, Mandatory Appendix XIII, or Mandatory Appendix XIV. The cylindrical shell to which the head is attached shall be equal to or greater in thickness than the required head thickness for a distance, measured from the tangent line along the cylinder, of not less than $\sqrt{Rt}$. Transition joints to shells of thickness less than the required head thickness shall not be located within the minimum distance. Transition joints to shells of thickness greater than the required head thickness may be located within this minimum distance and shall be in accordance with NC-3361 and Figure NC-3358.1(a)-1.

NC-3224.7 Minimum Thickness of Hemispherical Heads. For hemispherical heads, the thickness shall be as required for spherical shells, NC-3224.4. The requirements for the transition to cylindrical shells of different thickness, given in NC-3361 and Figure NC-3361-1, shall be met.

(15) **NC-3224.8 Minimum Thickness of Torispherical Heads.**[16] The minimum thickness of a torispherical head having $t/L \geq 0.002$ up to a t/L where $P/S \leq 0.08$ (approximately $t/L = 0.04$ to 0.05) shall be established by using the curves in Figure NC-3224.6-1. Interpolation may be used for r/D values which fall within the range of the curves; however, no extrapolation of the curves is permitted. For designs where $P/S > 0.08$, which is above the upper limit of Figure NC-3224.6-1, the thickness shall be set by the following equation:

$$t = \frac{D}{2}\left(e^{P/S} - 1\right)$$

Where $t/L < 0.002$, which is below the lower limit of Figure NC-3224.6-1, the head design must be analyzed according to Section III Appendices, Mandatory Appendix II, Mandatory Appendix XIII, or Mandatory Appendix XIV. The cylindrical shell to which the head is attached shall be equal to or greater in thickness than the required head thickness for a distance, measured from the tangent line along the cylinder, of not less than $\sqrt{Rt}$. Transition joints to shells of thickness less than the required head thickness shall not be located within this minimum distance. Transition joints to shells of thickness greater than the required head thickness may be located within this minimum distance and shall be in accordance with NC-3361 and Figure NC-3358.1(a)-1.

NC-3224.8.1 Crown and Knuckle Radii. In connection with the design procedures of NC-3224.8 and Figure NC-3224.6-1, the inside crown radius to which an unstayed head is formed shall not be greater than the inside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall not be less than 6% of the outside diameter of the skirt nor less than three times the head thickness.

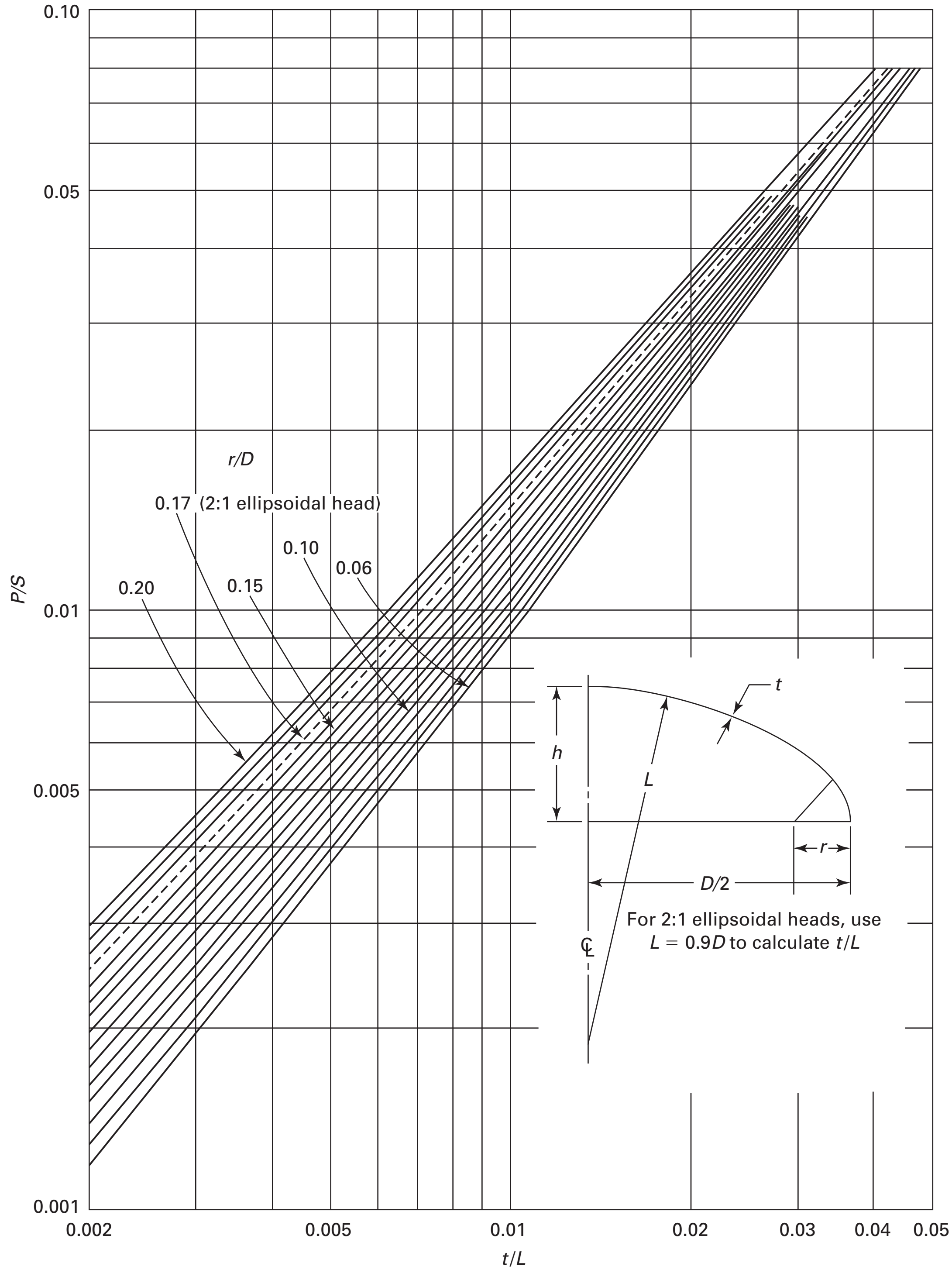
NC-3224.9 Minimum Thickness of Integral Head Skirts. In addition to the requirements of NC-3224.8 or NC-3224.6, when an integral head skirt is provided, the skirt thickness shall not be less than the required thickness of a seamless shell of the same diameter. All transition joints shall be in accordance with NC-3361 and Figure NC-3358.1(a)-1. (15)

NC-3224.10 Composite Head Shapes. A head for a cylindrical shell may be built up of several head shapes, the thicknesses of which satisfy the requirements of the appropriate equations above. The adjoining shapes must be so formed that they have a common tangent transverse to the joint. Any taper at a joint shall be within the boundary of the shape having the thinner wall (Figure NC-3361-1).

NC-3224.11 Loadings on Heads Other Than Pressure. Provision shall be made for other loadings given in NC-3212. For torispherical and ellipsoidal heads, the effect of other loadings must be determined in accordance with Section III Appendices, Mandatory Appendix II, Mandatory Appendix XIII, or Mandatory Appendix XIV. For the conical or spherical portions of heads, the effect of composite loading may be treated as in NC-3224.3, NC-3224.4, and NC-3224.13(a)(4).

NC-3224.12 Toriconical Heads. (In preparation.)

Figure NC-3224.6-1
Design Curves for Torispherical Heads and 2:1 Ellipsoidal Heads for Use With NC-3224.8 and NC-3224.6



(15) **NC-3224.13 Reducer Sections.**

(a) General Requirements

(1) Applicable Equations and Rules. These rules apply to concentric reducer sections when all the longitudinal loads are transmitted wholly through the shell of the reducer. When loads are transmitted in part or as a whole by other elements, such as inner shells, stays, or tubes, these rules do not apply.

(2) Minimum Thickness of Reducer Elements. The thickness of each element of a reducer under internal pressure shall not be less than that computed by the applicable equation. In addition, provisions shall be made for any of the other loadings listed in NC-3212.

(3) Transition Section Reducers Joining Two Cylindrical Shells. A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided these requirements are met.

(4) Minimum Thickness of Conical Shells. The minimum thickness of conical shells shall be determined by the same equations as for cylindrical shells in which R is the radius measured normal to the wall surface at the point under consideration. Subparagraphs (b) and (c) give rules for cone to cylinder junctions of the large and small end, respectively.

(-a)

$$t = \frac{PR}{S - 0.5P}$$

If $P > 0.4S$,

$$\ln \frac{(R + t)}{R} = \frac{P}{S}$$

(-b) If F is positive and exceeds $0.5\,PR$,

$$t = \frac{0.5PR + F}{S - 0.5P}$$

(-c) If F is negative, the condition of axial structural instability or buckling must be considered separately. NC-3245 for cylinders may be used for conical sections.

(5) Knuckle Tangent to the Larger Cylinder. When a knuckle is used at the large end of a reducer section, it shall have a shape that is a portion of an ellipsoidal, hemispherical, toriconical, or torispherical head. The thickness and other dimensions shall satisfy the requirements of NC-3224.5.

(6) Combination of Elements to Form a Reducer. When elements having different thicknesses are combined to form a reducer, the joints including the plate taper shall lie entirely within the limits of the thinner element being joined.

(7) Combination of Shapes to Form a Toriconical Reducer. A toriconical reducer may be shaped as a portion of a toriconical head or a portion of an ellipsoidal head plus a conical section, provided the design of the small end of the reducer element satisfies the requirements of (c).

(b) Supplementary Requirements for Reducer Sections and Conical Heads, Large End. These rules apply, provided the requirements of (1) through (6) below are met:

(1) the two parts to be joined have the same rotational axis

(2) the load is internal pressure (see NC-3224.11)

(3) the joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness

(4) the weld at the junction is radiographed and meets the requirements of NC-5250

(5) the junction is not closer than $4\sqrt{R_L \times t_r}$ to another junction or major discontinuity

(6) Reinforcement Requirements

(-a) When Inherent Reinforcement Is Adequate. The thickness of the cone and cylinder forming a junction at the large end for half apex angles up to 30 deg need not be thicker than required by NC-3224.3 or (a)(4)(-a), if the point representing the junction lies in the Adequate region of Figure NC-3224.13(b)(6)(-a)-1.

(-b) Requirements for Integral Reinforcement. When the half-apex angle exceeds the maximum permitted by Figure NC-3224.13(b)(6)(-a)-1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure NC-3224.13(b)(6)(-b)-1 gives Q values for ratios of Design Pressure P to S and values of α up to 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to t_r and provided that the requirements of (-1) through (-3) below are met.

(-1) The increased cylinder thickness extends a minimum distance of $2.0\sqrt{R_L t_r}$ from the junction, where R_L is the radius of the cylinder at the large end of the cone.

(-2) The increased cone thickness extends a minimum distance of $2.0\sqrt{R_L t_r / \cos \alpha}$ from the junction.

(-3) In no case shall t be less than the thickness required for the cone in accordance with NC-3224.3.

(c) Supplementary Requirements for Reducer Section's Small End. These rules apply, provided the requirements of (1) through (6) below are met:

(1) the two parts to be joined have the same rotational axis

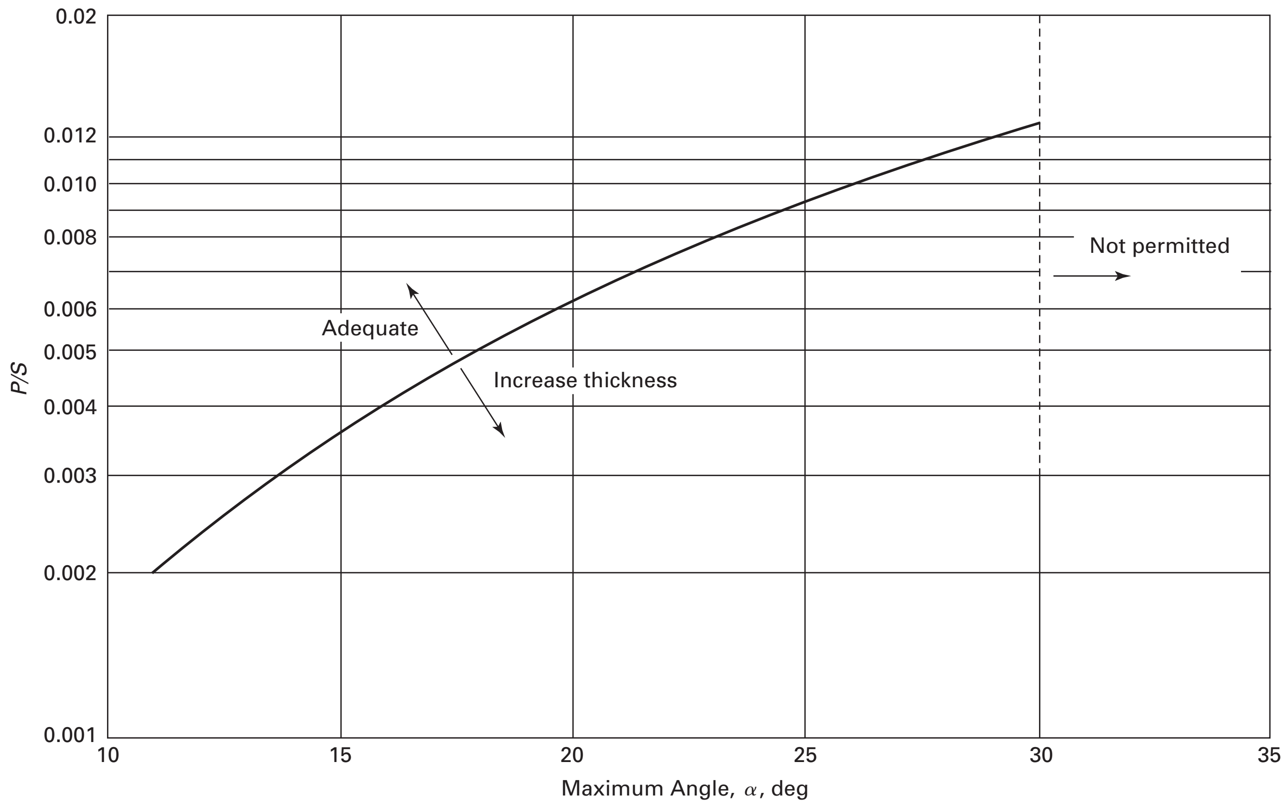
(2) the load is internal pressure (NC-3224.11)

(3) the joint is a butt weld having its surfaces merge smoothly, both inside and outside, with the adjacent cone and cylinder surfaces without reducing the thickness

(4) the weld at the junction is radiographed and meets the requirements of NC-5250

(5) the junction is not closer than $2.8\sqrt{R_s t_r}$ to another junction or discontinuity, where R_s is the radius of the cylinder at the small end of the cone

Figure NC-3224.13(b)(6)(-a)-1
Inherent Reinforcement for Large End of Cone–Cylinder Junction



GENERAL NOTE: Curve governed by maximum stress intensity at surface primarily due to axial bending stress, limited to $3S$.

(6) Reinforcement Requirements:

(-a) When Inherent Reinforcement Is Adequate. The thickness of the cone and cylinder forming a junction at the small end of half apex angles up to 30 deg need not be thicker than required by NC-3224.3 if the point representing the junction lies in the Adequate region of Figure NC-3224.13(c)(6)(-a)-1.

(-b) Requirements for Integral Reinforcement. When the half apex angle exceeds the maximum permitted by Figure NC-3224.13(c)(6)(-a)-1, the cone and cylinder must be reinforced in the area adjacent to the junction. Figure NC-3224.13(c)(6)(-b)-1 gives Q values for ratios of Design Pressure P to S and values of α up to 30 deg. The junction may be reinforced by making both the cylinder and cone thickness equal to t_r and provided that the requirements of (-1) through (-3) below are met.

(-1) The increased cylinder thickness t_r extends a minimum distance $1.4\sqrt{R_s t_r}$ from the junction.

(-2) The increased cone thickness t_r extends a minimum distance $1.4\sqrt{R_s t_r / \cos\alpha}$ from the junction.

(-3) In no case shall t_r be less than the thickness required for the cone in accordance with NC-3224.3 at a distance $1.4\sqrt{R_s t_r / \cos\alpha}$ from the junction.

(d) Supplementary Requirements for Reducer Sections, Small End, Treated As Openings. Cone to cylinder junctions at the small ends of reducers as shown in Figure NC-3224.13(d)-1 may be treated as openings in conical heads provided the requirements of (1) through (4) below are met.

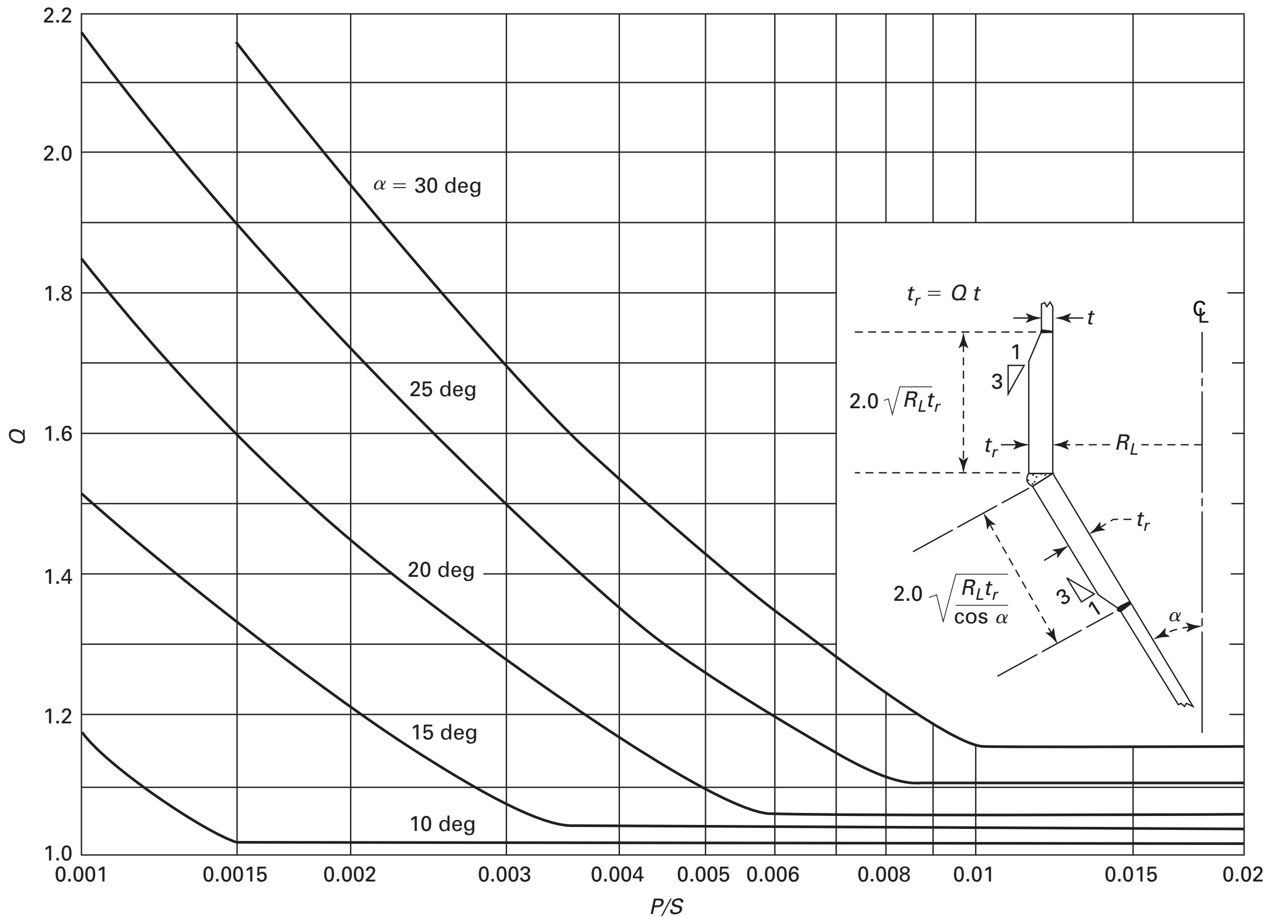
(1) The diameter d of the small end is not more than one-half the diameter of the large end.

(2) The half apex angle α is greater than 30 deg but not greater than 60 deg.

(3) The reinforcement meets the requirements of NC-3232 and NC-3234.1, except that the total cross-sectional area of reinforcement A required at the junction in any plane for a vessel under internal pressure shall not be less than $A = dt \tan\alpha/2$ and two-thirds of this area shall be provided within a limit of $0.5\sqrt{dt/2}$ measured along the cylinder and $0.5\sqrt{dt/2 \cos^2\alpha}$ measured along the cone.

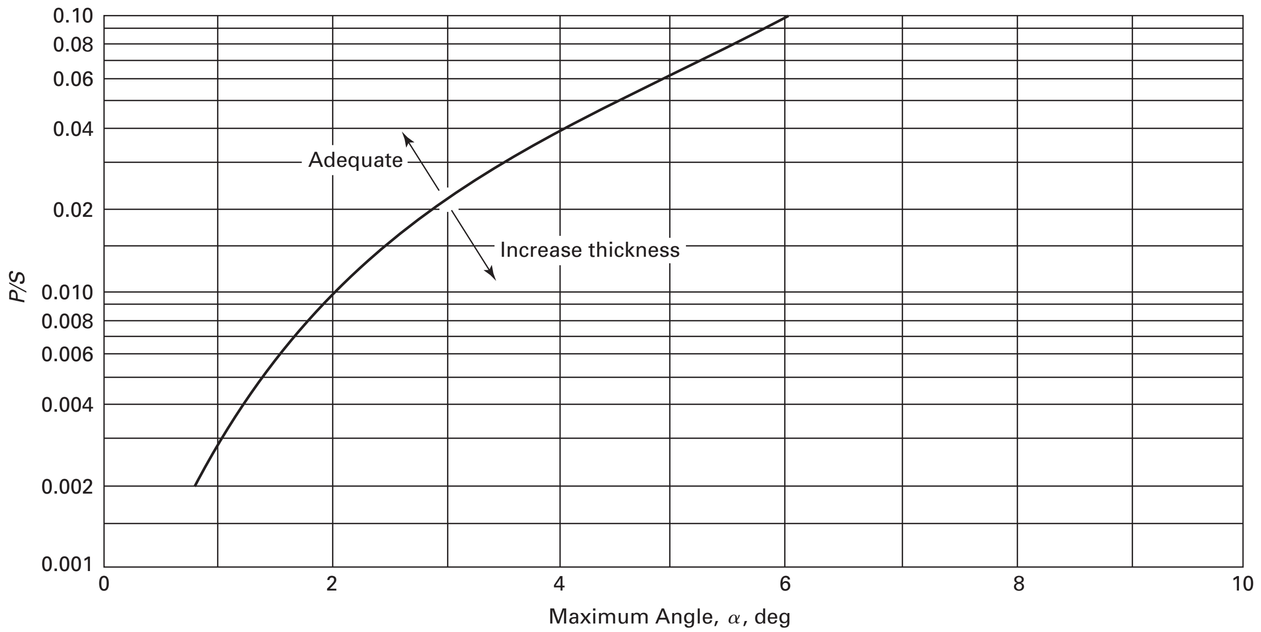
(4) Reinforcement shall be integral with cone or cylinder and all other applicable requirements of NC-3230 are met.

Figure NC-3224.13(b)(6)(-b)-1
Values for *Q* for Large End of Cone–Cylinder Junction



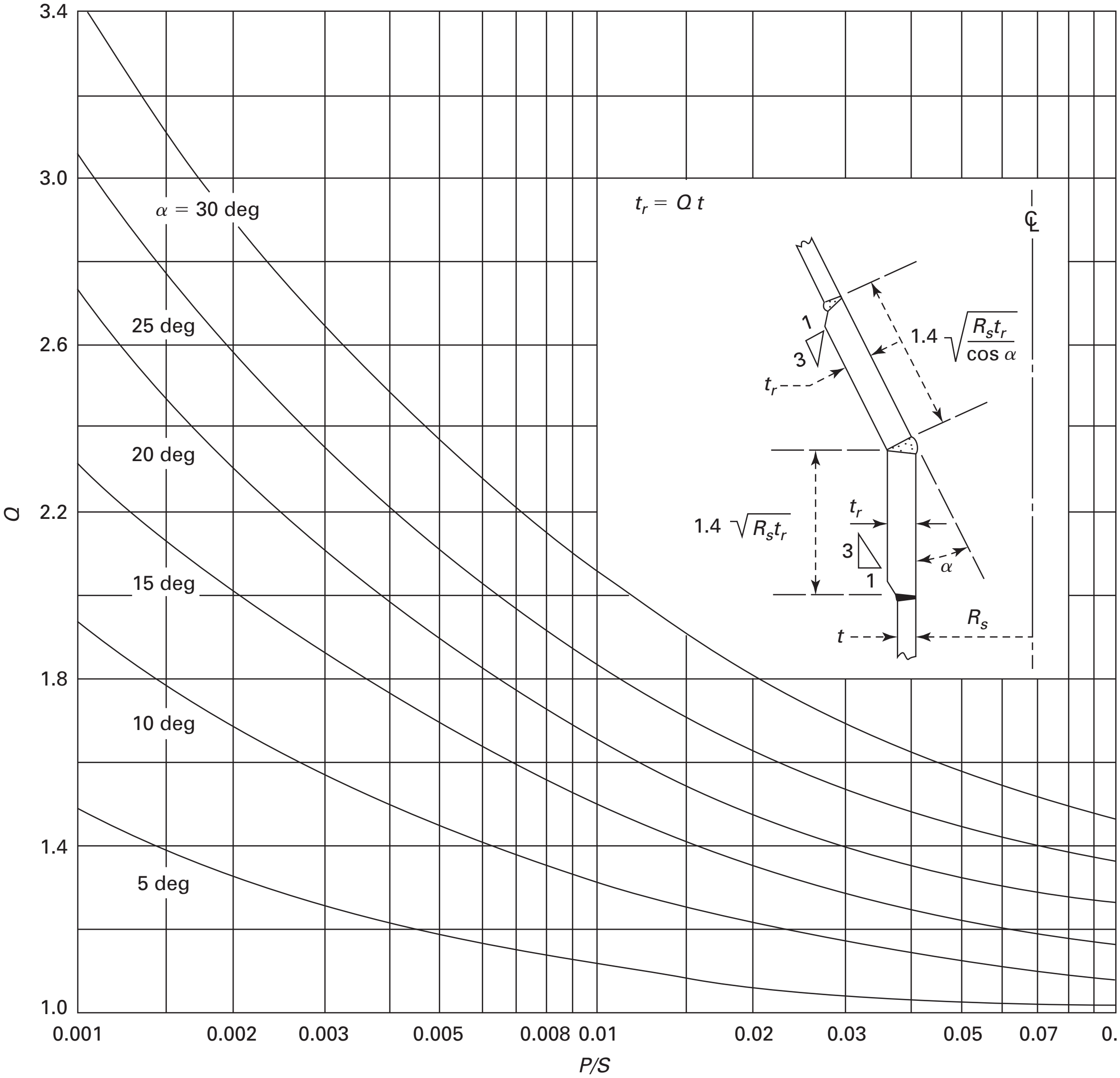
GENERAL NOTE: Curves governed by maximum stress intensity at surface primarily due to axial bending stress limited to $3S_m$.

Figure NC-3224.13(c)(6)(-a)-1
Inherent Reinforcement for Small End of Cone–Cylinder Junction



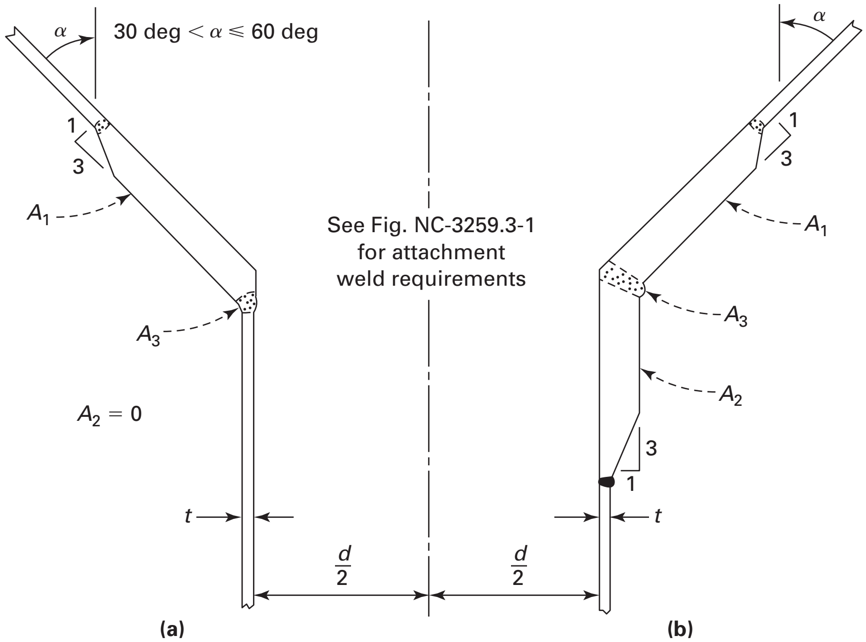
GENERAL NOTE: Curve governed by membrane stress intensity due to average circumferential tension stress and average radial compression stress limited by $1.1S_m$ at $0.25\sqrt{\text{rad.} \times \text{thk.}}$ either side of junction.

Figure NC-3224.13(c)(6)(-b)-1 Values for Q for Small End of Cone–Cylinder Junction



GENERAL NOTE: Curves governed by membrane stress intensity due to average circumferential tension stress and average radial compression stress limited by $1.1S_m$ at $0.25\sqrt{\text{rad.} \times \text{thk.}}$ either side of junction.

Figure NC-3224.13(d)-1
Cone–Cylinder Junction at Small End Treated as Opening



$$A \leq A_1 + A_2 + A_3$$

where

A_1 = reinforcement area integral with cone
A_2 = reinforcement area integral with cylinder
A_3 = area of fillet weld

NC-3224.14 Minimum Thickness of Nozzle Necks and Other Connections. The wall thickness of a nozzle neck or other connection shall not be less than the thickness computed for the applicable loadings plus the thickness added for corrosion and erosion allowance and, except for access openings and openings for inspection only, not less than the smaller of (a) and (b) below:

(a) the required thickness of the shell or head to which the connection is attached plus the corrosion allowance provided in the shell or head adjacent to the connection;

(b) the minimum thickness[17] of standard wall pipe plus the corrosion allowance on the connections.

NC-3224.15 Other Loadings. When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in NC-3111 other than pressure and temperature.

NC-3225 Flat Heads and Covers

The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this paragraph. Some acceptable types of flat heads and covers are shown in Figure NC-3225-2. The dimensions are exclusive of extra metal added for corrosion allowance.

NC-3225.1 Nomenclature. The notations used are defined as follows:

C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in NC-3225.2, dimensionless (Figures NC-3225-1 through NC-3225-3)
D = bolt circle diameter
d = diameter
h_G = gasket moment arm, equal to the radial distance from the center line of the bolts to the line of the gasket reaction (Figure NC-3225-2)
L = distance from center line of head to shell weld to tangent line on formed heads, as indicated in Figure NC-3225-2 sketch (a)
m = the ratio t_r/t_s, dimensionless
P = Design Pressure, psi (MPa)
r = inside corner radius on a head formed by flanging or forging
S = design stress intensity S_m from Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 multiplied by tabulated stress intensities, psi (MPa)
T = minimum required thickness of flat head, cover, or flange, exclusive of corrosion allowance
t_f = actual thickness of the flange on a formed head, at the large end, exclusive of corrosion allowance
t_p = the smallest dimension from the face of the head to the edge of the weld preparation
t_r = required thickness of shell or nozzle for pressure
t_s = actual thickness of shell or nozzle
W = total bolt load

NC-3225.2 Equations for Minimum Thickness.[18]

(a) The thickness of flat heads, as shown in Figures NC-3225-1 through NC-3225-3, shall be not less than that calculated by the following equation:

$$T = d\sqrt{CP/S}$$

(b) The thickness of cover plates and blind flanges attached by bolts causing an edge moment as shown in Figure NC-3225-2 shall be not less than that calculated by the following equation:

$$T = d\sqrt{CP/S + 1.27\,Wh_G/Sd^3}$$

NOTE: In some cases, the initial bolt load required to seat the gasket is larger than the service bolt load. The thickness should be checked for both the service condition and the initial bolt load required to seat the gasket.

NC-3227 Quick Actuating Closures

The requirements for quick actuating closures are given in NC-3327.

NC-3230 OPENINGS AND THEIR REINFORCEMENT

NC-3231 General Requirements

The rules contained in this subarticle provide for a satisfactory design in the vicinity of openings in the pressure shell, under pressure loading only, on the basis of its opening shape, area replacement, and distribution, provided a fatigue analysis is not required. These rules do not include design requirements for piping loads that may be imposed on the nozzle or shell portion or both and that may be added to the pressure loadings. Such additional loadings shall be considered by the designer.

NC-3231.1 Dimensions and Shape of Openings.

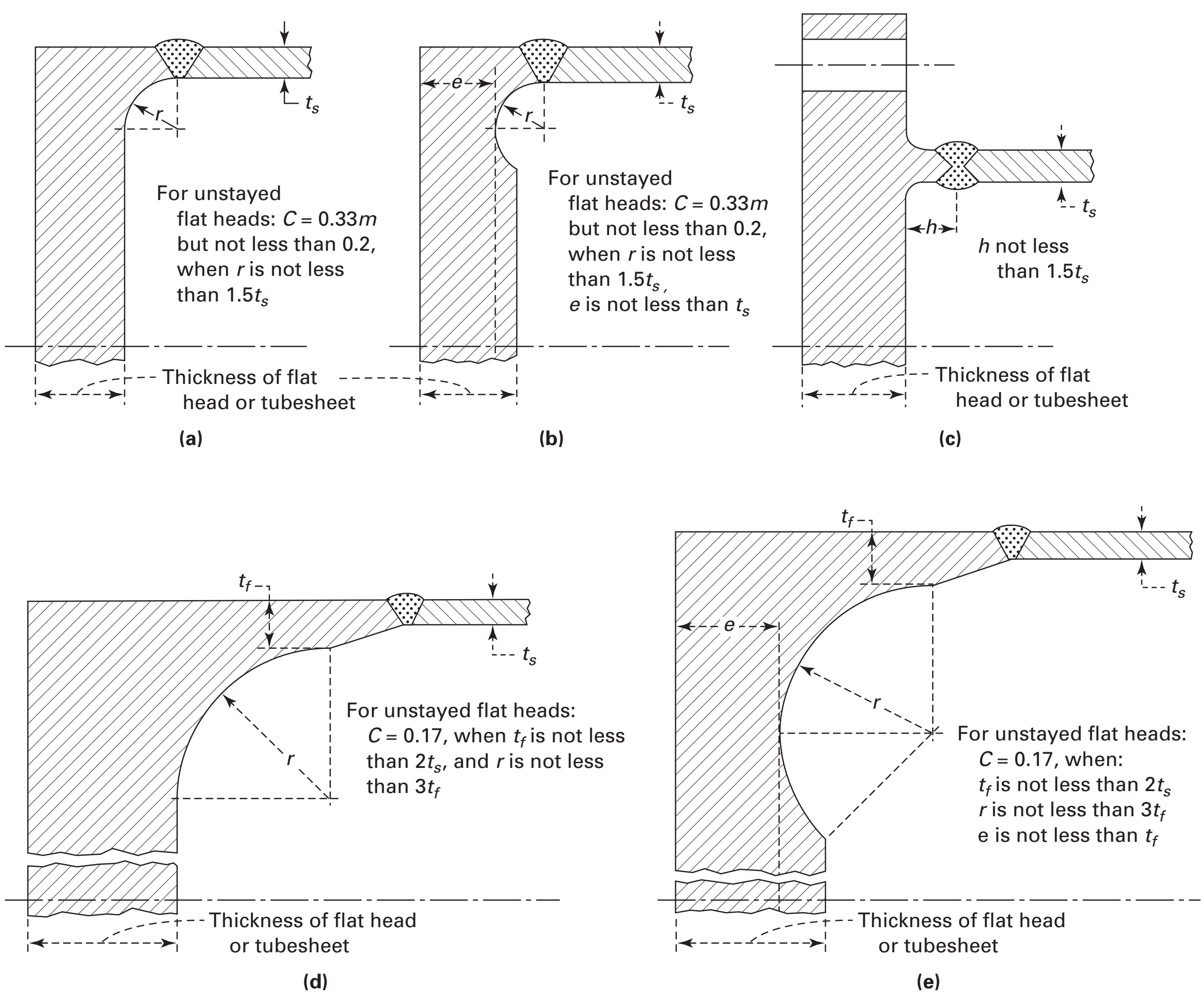
(a) Openings, except as permitted under (b), shall be circular, elliptical, or of any other shape which results from the intersection of a circular or elliptical cylinder with vessels of the shapes for which equations are given in NC-3220, provided the requirements of (1) through (4) below are met.

(1) The ratio of the diameter along the major axis to the diameter along the minor axis of the finished opening is 1.5 or less.

(2) The ratio $d/D \le 0.50$ where d is the largest inside diameter of the intersecting nozzle and D is the inside diameter of the vessel.

(3) The arc distance measured between the center lines of adjacent nozzles along the inside surface of the shell is not less than three times the sum of their inside radii for openings in a head or for openings along the longitudinal axis of a shell and is not less than two times the sum of their inside radii for openings along the circumference of a cylindrical shell. When two nozzles in a cylindrical shell are neither in a longitudinal line nor in a circumferential arc, their center line distance along

Figure NC-3225-1
Typical Flat Heads and Supported and Unsupported Tubesheets With Hubs



the inside surface of the shell shall be such that $[(L_c/2)^2 + (L_l/3)^2]^{1/2}$ is not less than the sum of their inside radii, where L_c is the component of the center line distance in the circumferential direction and L_l is the component of the center line distance in the longitudinal direction.

(4) Reinforcement is provided around the edge of the opening in amount and distribution such that the area requirements for reinforcement are satisfied for all planes through the center of the opening and normal to the vessel surface as stipulated in NC-3232.2.

(b) Openings of other shapes or dimensions may be used subject to the requirements of Section III Appendices, Mandatory Appendix XIII or Mandatory Appendix XIV.

(c) Any type of opening permitted by these rules may be located in a butt welded joint.

NC-3232 Reinforcement Requirements for Openings in Shells and Formed Heads

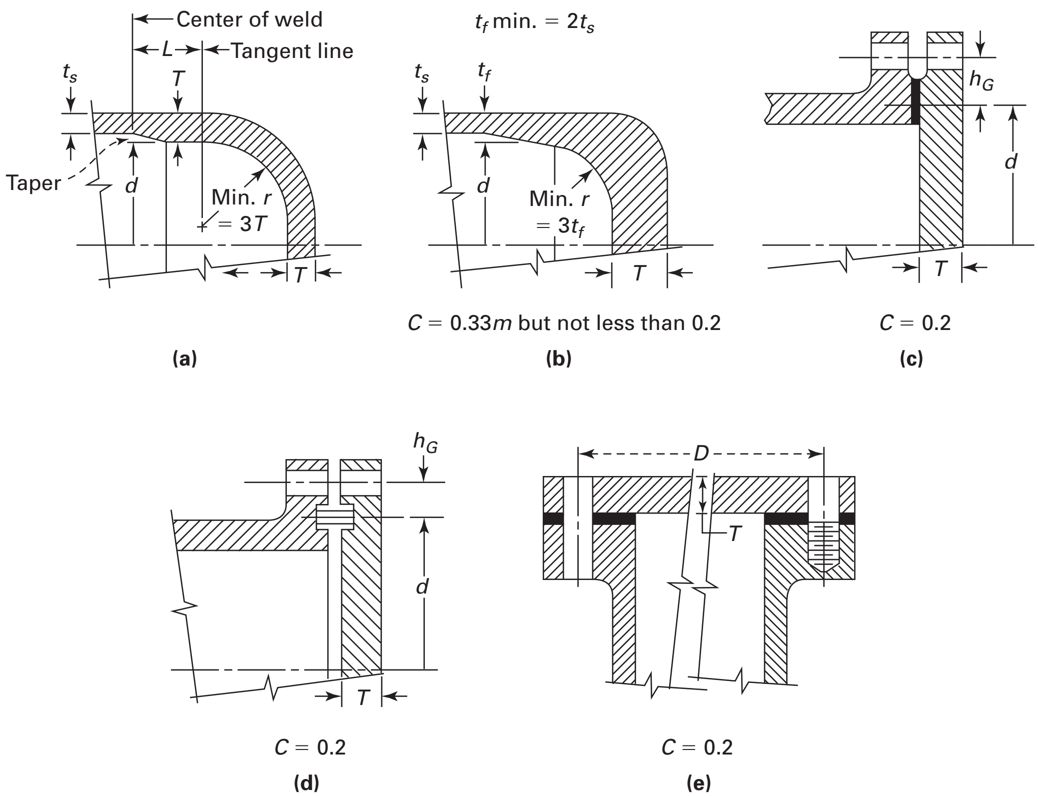
NC-3232.1 Circular Openings Not Requiring Reinforcement. Circular openings need not be provided with reinforcement if all the requirements in (a), (b), and (c) below are satisfied.

(a) A single opening has a diameter not exceeding $0.2\sqrt{Rt}$, or if there are two or more openings within any circle of diameter, $2.5\sqrt{Rt}$, then the sum of the diameters of such unreinforced openings shall not exceed $0.25\sqrt{Rt}$.

(b) No two unreinforced openings shall have their centers closer to each other, measured on the inside of the vessel wall, than 1.5 times the sum of their diameters.

(c) No unreinforced opening shall have its center closer than $2.5\sqrt{Rt}$ to the edge of a locally stressed area in the shell where R is the mean radius and t is the nominal

Figure NC-3225-2
Some Acceptable Types of Unstayed Flat Heads and Covers



GENERAL NOTE: All these illustrations are diagrammatic only. Other designs that meet the requirements of NC-3225.2 are acceptable.

thickness of the vessel shell or head at the location of the openings and where locally stressed area means any area in the shell where the primary local membrane stress exceeds $1.1kS_m$, but excluding those areas where such primary local membrane stress is due to an unreinforced opening.

(15) **NC-3232.2 Required Area of Reinforcement.**

(a) The total cross-sectional area of reinforcement A required in any given plane for a vessel under internal pressure shall be not less than

$$A = dt_rF$$

where

d = finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition

F = 1.00 when the plane under consideration is in the spherical portion of a head or when the given plane contains the longitudinal axis of a cylindrical shell. For other planes through a shell, use the value of F determined from Figure NC-3332.2-1 except that, for reinforcing pads, F = 1.

t_r = the thickness which meets the requirements of NC-3220 in the absence of the opening

(b) Not less than one-half the required material shall be on each side of the center line of the opening [NC-3234.1(b)].

NC-3233 Required Reinforcement for Openings in Flat Heads

(a) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement A, not less than that given by the equation

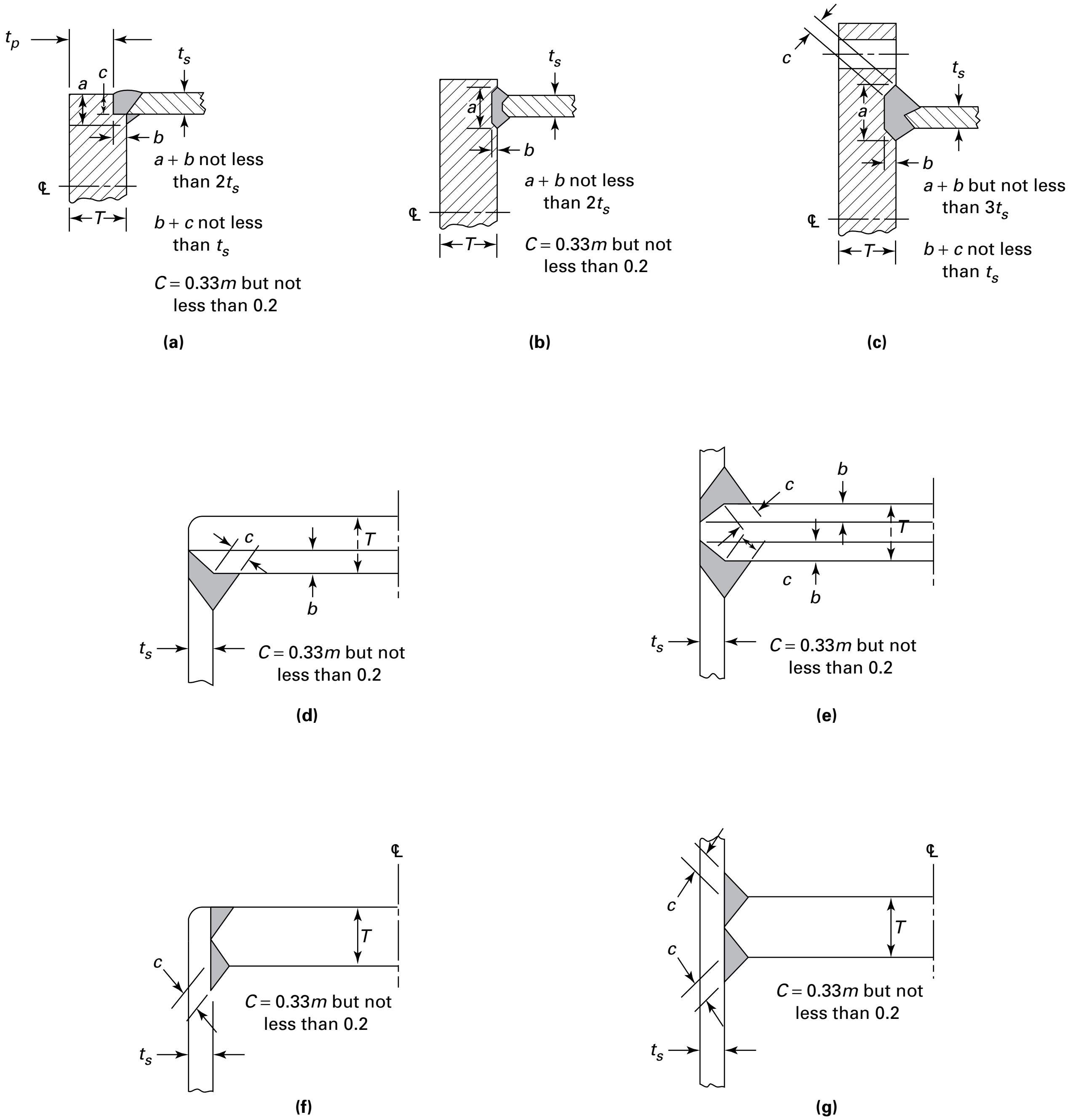
$$A = 0.5dt_r$$

where

d = the diameter of the finished opening in its corroded condition

t_r = the thickness that meets the requirements of NC-3225.2 in the absence of the opening

Figure NC-3225-3
Attachment of Pressure Parts to Plates to Form a Corner Joint



C min. = 0.7 t_s or $^1/_4$ in. (6 mm), whichever is less
b = the lesser of t_s or $T/2$

(b) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter shall be designed according to Section III Appendices, Mandatory Appendix XIX.

NC-3234 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are as described in the following subparagraphs.

NC-3234.1 Limit of Reinforcement Along the Vessel Wall. The limits of reinforcement, measured along the midsurface of the nominal wall thickness of the vessel, shall meet the following:

(a) 100% of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall;

(b) two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{Rt}$, where R is the mean radius of shell or head, t is the nominal vessel wall thickness, r is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

NC-3234.2 Limit of Reinforcement Normal to Vessel Wall. The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the limits given in (a), (b), and (c) below.

(a) For Figure NC-3234.2(a)-1 sketches (a) and (b), the limit is the larger of $\left(0.5\sqrt{r_m t_n} + k\right)$ or $(1.73x + 2.5t_p + k)$, but not to exceed either $2.5t$ or $(L + 2.5t_p)$, where

k = $0.73r_2$ when a transition radius (r_2) is used
= the smaller of two legs of the fillet when a fillet transition is used
L = length along nozzle with thickness of t_n plus transition length
r = inside radius of nozzle
r_2 = transition radius between nozzle and wall
r_m = mean nozzle radius = $r + 0.5t_n$
t = nominal vessel wall thickness
t_n = nominal nozzle thickness
t_p = nominal thickness of connecting pipe
x = $t_n - t_p$

(b) For Figure NC-3234.2(a)-1 sketch (c), when $45 \geq \theta \geq 30$ deg, the limit is the larger of $\left(0.5\sqrt{r_m t_n'}\right)$ or $(L' + 2.5t_p)$, but not to exceed $2.5t$; when $\theta < 30$ deg, the limit is the larger $\left(0.5\sqrt{r_m t_n'}\right)$ or $(1.73x + 2.5t_p)$, but not to exceed $2.5t$, where

L' = length of tapered section along nozzle
r_m = $r + 0.5t_n'$
t_n' = $t_p + 0.667x$
x = slope offset distance
θ = angle between vertical and slope

Other terms are defined in (a) above.

(c) For Figure NC-3234.2(a)-1 sketch (d), when reinforcing pads or insert plates are used, the limit is the larger of $\left(0.5\sqrt{r_m t_n} + t_e\right)$ or $(2.5t_n + t_e)$, but not to exceed $2.5t$. In no case can the thickness t_e, used to establish the limit normal to the shell, exceed $1.5t$ or $1.73W$, where

t_e = thickness of added reinforcing element
W = width of added reinforcing element

Other terms are defined in (a) above.

NC-3234.3 Nozzle Piping Transitions. The stress limits of NC-3200 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NC-3234, except as noted in NC-3234.4. Stresses in the extension of any nozzle beyond the limits of reinforcement shall meet the stress limits of NC-3600.

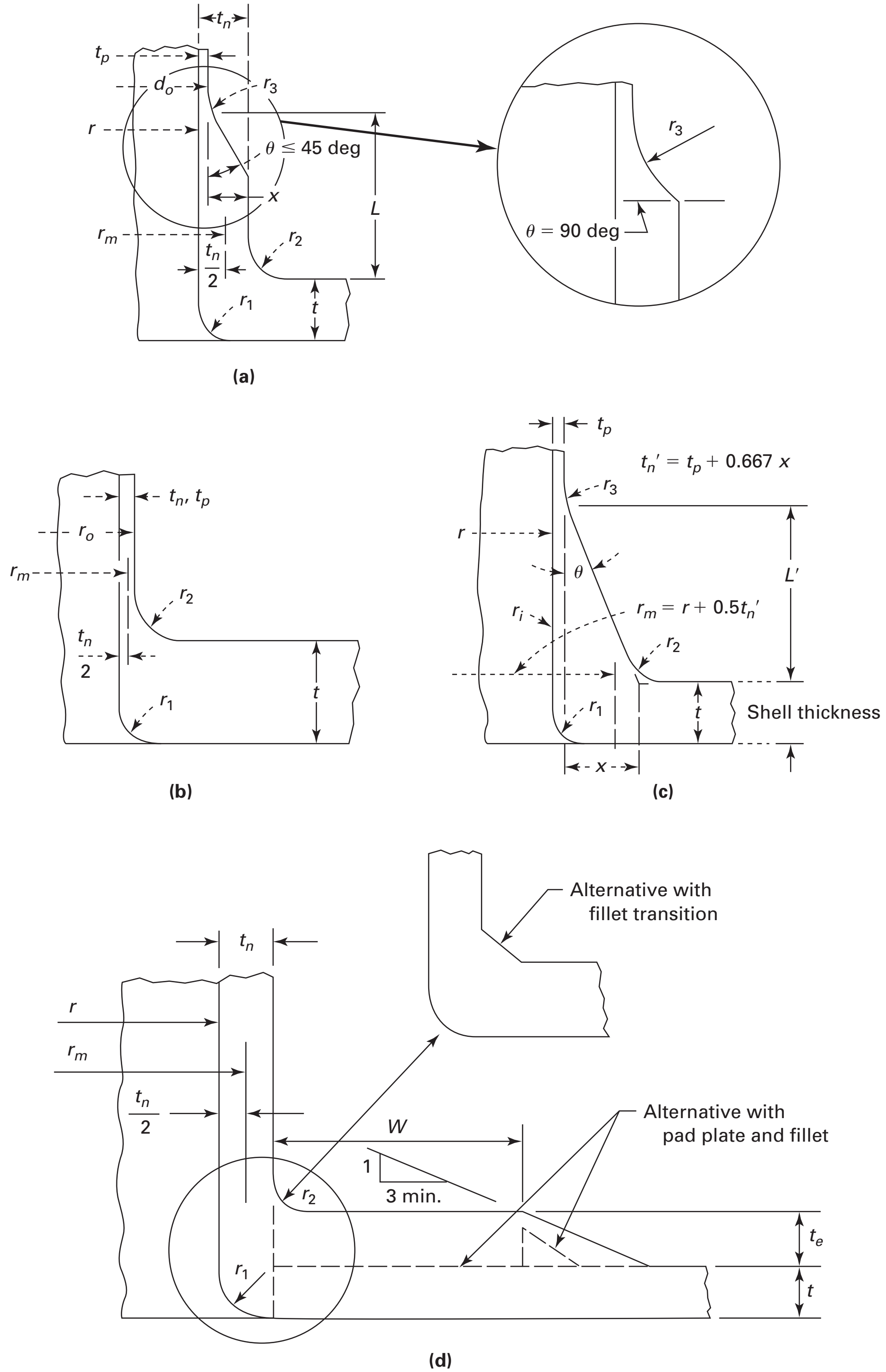
NC-3234.4 Consideration of Standard Reinforcement. Where a nozzle-to-shell juncture is reinforced in accordance with the rules of NC-3234, the stresses in this region due to internal pressure may be considered to satisfy the limits of NC-3217. Under these conditions, no analysis is required to demonstrate compliance for pressure-induced stresses in the nozzle region. Where external piping loads are to be designed for, membrane plus bending stresses shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure-induced stresses, shall meet the limits of NC-3217 for $(P_m$ or $P_L) + P_b$. In this case, the pressure-induced stresses in the $(P_m$ or $P_L) + P_b$ category may be assumed to be no greater than the limit specified for P_m in NC-3217 for a given condition.

NC-3235 Metal Available for Reinforcement (15)

Metal may be counted as contributing to the area of reinforcement called for in NC-3232.2 and NC-3233, provided it lies within the area of reinforcement specified in NC-3234 and shall be limited to material which meets the requirements of (a) through (e) below:

(a) metal forming a part of the vessel wall which is in excess of that required on the basis of primary stress intensity (NC-3221 through NC-3224 and NC-3225.2) and is exclusive of corrosion allowance;

Figure NC-3234.2(a)-1
Nozzle Nomenclature and Dimensions
Depicts Configuration Only



(b) similar excess metal in the nozzle wall, provided the nozzle is integral with the vessel wall or is joined to it by a full penetration weld;

(c) weld metal which is fully continuous with the vessel wall;

(d) metal not fully continuous with the shell, such as a pad continuously welded around its periphery, may be counted as reinforcement, provided the requirements of NC-3237 are met;

(e) the mean coefficient of thermal expansion of metal to be included as reinforcement under (b), (c), and (d) above shall be within 15% of the value for the metal in the vessel wall.

NC-3235.1 Metal Not Available for Reinforcement. Metal not fully continuous with the shell, as that in nozzles attached by partial penetration welds, shall not be counted as reinforcement.

NC-3235.2 Reinforcement Metal Limited to One Opening. Metal available for reinforcement shall not be considered as applying to more than one opening.

NC-3236 Strength of Reinforcement Material

Material used for reinforcement shall preferably have the same design stress intensity value as that of the vessel wall. In no case shall material with an allowable design stress intensity value less than 80% of the value of the vessel wall material at the Design Temperature be used in determining area available for reinforcement. If the material of the nozzle wall or reinforcement has a lower design stress intensity value S_m than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NC-3232 shall be taken as the actual area provided multiplied by the ratio of the nozzle or reinforcement design stress intensity value to the vessel material design stress intensity value. No reduction in the reinforcement requirement may be made if the reinforcing material or weld metal has a design stress intensity value higher than that of the material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses.

(15) NC-3237 Requirements for Nozzles With Separate Reinforcing Plates

Except for nozzles at small ends of cones reinforced in accordance with the requirements of NC-3224.13(d), added reinforcement in the form of separate reinforcing plates may be used, provided the vessel and the nozzles meet all the conditions of (a) through (d) below.

(a) The specified minimum tensile strengths of the materials do not exceed 80 ksi (550 MPa).

(b) The minimum elongation of materials is 12% in 2 in. (50 mm).

(c) The thickness of the added reinforcement does not exceed $1^1/_2$ times the shell thickness.

(d) The requirements of NC-3219 for pads in cyclic service are met.

NC-3239 Alternative Rules for Opening Reinforcement

The requirements of this paragraph constitute an acceptable alternative to the rules of NC-3231 through NC-3237 and Section III Appendices, Mandatory Appendix XIII, Article XIII-2000.

NC-3239.1 Limitations. These rules are applicable only to openings utilizing nozzles in vessels within the limitations of (a) through (f) below.

(a) The nozzle is circular in cross section and its axis is perpendicular to the vessel or head.

(b) The nozzle and required reinforcing are welded integrally into the vessel with full penetration welds between all parts. Details such as those shown in Figures NC-4266(a)-1, NC-4266(b)-1 sketches (a), (b), and (c), and NC-4266(c)-1 are acceptable. However, fillet welds must be ground to a radius in accordance with Figure NC-3239.1(b)-1.

(c) In the case of spherical shells and formed heads, at least 40% of the total nozzle reinforcement area shall be located beyond the outside surface of the minimum required vessel wall thickness.

(d) The spacing between the edge of the opening and the nearest edge of any other opening is not less than the smaller of 1.25 $(d_1 + d_2)$ and $2.5\sqrt{Rt_r}$, but in any case, not less than 1.0 $(d_1 + d_2)$, where d_1 and d_2 are the inside diameters of the openings.

(e) The materials used in the nozzle reinforcement and vessel wall adjacent to the nozzle shall have a ratio of UTS/YS of not less than 1.5, where

UTS = specified minimum ultimate tensile strength
YS = specified minimum yield strength

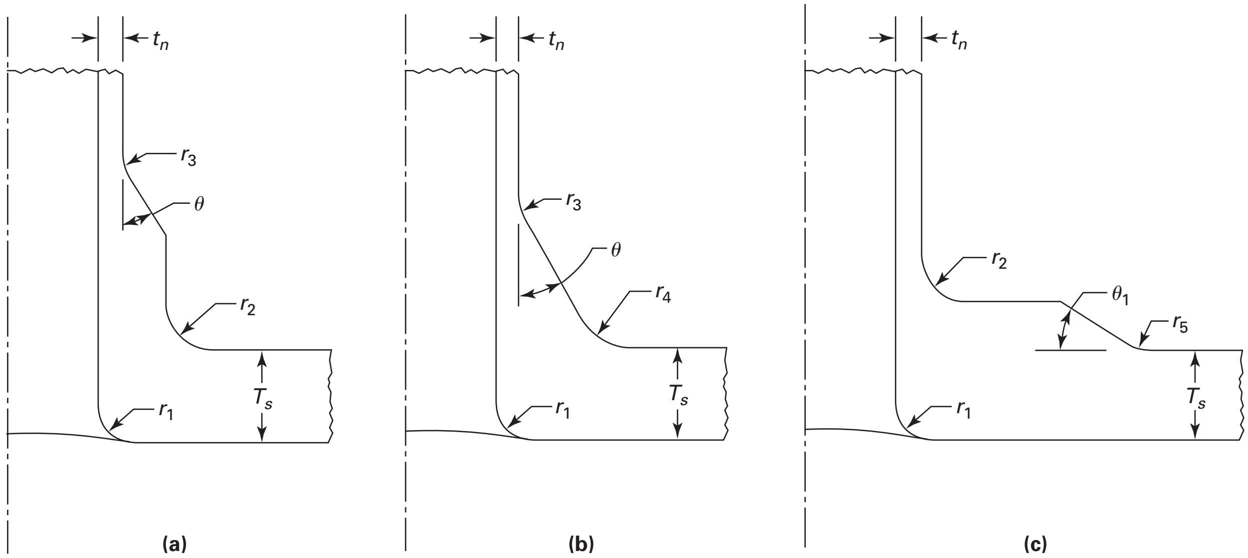
(f) The following dimensional limitations are met:

	Nozzles in Cylindrical Vessels	Nozzles in Spherical Vessels or Heads
D/t	10 to 100	10 to 100
d/D	0.5 max.	0.5 max.
$d/\sqrt{Dt}$	...	0.8 max.
$d/\sqrt{Dt_n r_2/t}$	1.5 max.	...

NC-3239.2 Nomenclature.

A_a = available reinforcing area
A_r = required minimum reinforcing area
D = inside diameter, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head
d = inside diameter of the nozzle in its corroded condition

Figure NC-3239.1(b)-1
Examples of Acceptable Transition Details



$r_1 = 0.1T_s$ to $0.5T_s$; $r_2 \geq$ larger of $\sqrt{dt}$ or $T_s/2$; $\geq$ larger of $\sqrt{\frac{\theta}{90}(dt)}$ or $\frac{\theta}{90}\,t_n$

$r_4 \geq$ larger of $\left(1 - \sqrt{\frac{\theta}{90}}\right)\sqrt{dt}$ or $1 - \frac{\theta}{90}\,(T_s/2)$; $r_5 = \frac{\theta_1}{90}\;T_s$; θ and θ_1 in degrees

R = inside radius, in corroded condition, of cylindrical vessel, spherical vessel, or spherical head
r = inside radius of the nozzle in its corroded condition
t = nominal wall thickness of vessel or head, less corrosion allowance
t_n = nominal wall thickness of nozzle, less corrosion allowance
t_r = wall thickness of vessel or head, computed by the equation given in NC-3224.3 for cylindrical vessels; by NC-3224.4 for spherical vessels or spherical heads
t_{rn} = wall thickness of nozzle, computed by the equation given in NC-3224.3

See Figure NC-3239.1(b)-1 for r_1, r_2, r_3, r_4, r_5, θ, and θ_1. See Figure NC-3239.4-1 for L_c and L_n. See Section III Appendices, Mandatory Appendix XIII, Figure XIII-2122-1 and NC-3239.7 for S, σ_t, σ_n, σ_r, and σ.

NC-3239.3 Required Reinforcement Area.

(a) The required minimum reinforcing area is related to the value of $d/\sqrt{Rt_r}$ shown in Table NC-3239.3(a)-1.

(b) The required minimum reinforcing area shall be provided in all planes containing the nozzle axis.

NC-3239.4 Limits of Reinforcing Zone. Reinforcing metal included in meeting the minimum reinforcing area specified in NC-3239.3 must be located within the reinforcing zone boundary shown in Figure NC-3239.4-1.

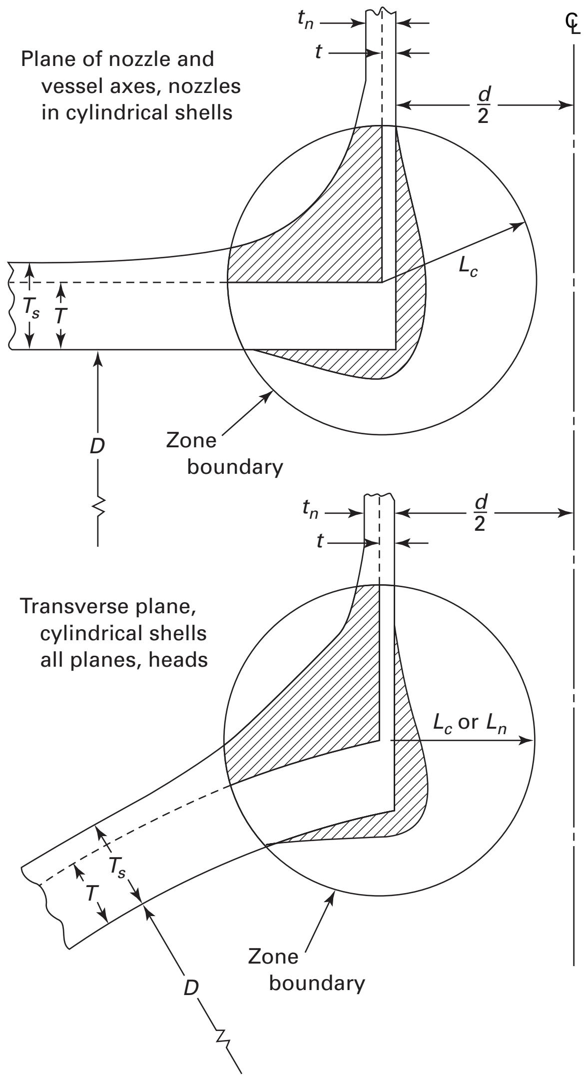
NC-3239.5 Strength of Reinforcing Material Requirements. Material in the nozzle wall used for reinforcing should preferably be the same as that of the vessel wall. If material with a lower design stress intensity value S_m is used, the area provided by such material shall be increased in proportion to the inverse ratio of the stress values of the nozzle and the vessel wall material. No reduction in the reinforcing area requirement may be taken for the increased strength of nozzle material or weld metal which has a higher design stress value than that of the

Table NC-3239.3(a)-1
Required Minimum Reinforcing Area, A_r

	Required Minimum Reinforcing Area, A_r	
Value of $d/\sqrt{Rt_r}$	Nozzles in Cylinders	Nozzles in Spherical Vessels or Heads
Less than 0.20	None [Note (1)]	None [Note (1)]
Greater than 0.20 and less than 0.40	$\{4.05\left[d/\sqrt{Rt_r}\right]^{1/2} - 1.81\}\, dt_r$	$\{5.40\left[d/\sqrt{Rt_r}\right]^{1/2} - 2.41\}\, dt_r$
Greater than 0.40	$0.75\, dt_r$	$dt_r \cos \Phi$ $\Phi = \sin^{-1}(d/D)$

NOTE:
(1) The transition radius r_2 shown in Figure NC-3239.1(b)-1, or equivalent, is required.

Figure NC-3239.4-1
Limits of Reinforcing Zone



GENERAL NOTES:

(a) *Reinforcing Zone Limit*

(1) $L_c = 0.75\,(T/D)^{2/3}D$ for nozzles in cylindrical shells.

(2) $L_n = (T/D)^{2/3}(d/D\ + 0.5)D$ for nozzles in heads.

(3) The center of L_c or L_n is at the juncture of the outside surfaces of the shell and nozzles of thickness, T and t.

(4) In constructions where the zone boundary passes through a uniform thickness wall segment, the zone boundary may be considered as L_c or L_n through the thickness.

(b) *Reinforcing Area*

(1) Hatched areas represent available reinforcement area, A_a.

(2) Metal area within the zone boundary, in excess of the area formed by the intersection of the basic shells, shall be considered as contributing to the required area A_r. The basic shells are defined as having inside diameter D, thickness T, inside diameter of the nozzle d, and thickness t.

(3) The available reinforcement area, A_a, shall be at least equal to $A_r/2$ on each side of the nozzle centerline and in every plane containing the nozzle axis.

material of the vessel wall. The strength of the material at the point under consideration shall be used in fatigue analyses. The mean coefficient of thermal expansion of metal to be included as reinforcement shall be within 15% of the value for the metal of the vessel wall.

NC-3239.6 Transition Details. Examples of acceptable transition tapers and radii are shown in Figure NC-3239.1(b)-1. Other configurations which meet the reinforcing area requirements of NC-3239.3 and with equivalent or less severe transitions are also acceptable, such as larger radius–thickness ratios.

NC-3239.7 Stress Indices.

(a) The term stress index is defined as the numerical ratio of the stress components σ_t, σ_n, and σ_r under consideration to the computed stress S. The symbols for the stress components are shown in Section III Appendices, Mandatory Appendix XIII, Figure XIII-2122-1 and are defined as follows:

P = service pressure, psi (MPa)
S = $P(2R + t)/2t$ for nozzles in cylindrical vessels, psi (MPa)
= $P(2R + t)/4t$ for nozzles in spherical vessels or heads, psi (MPa)
σ = the stress intensity, combined stress, at the point under consideration, psi (MPa)
σ_n = the stress component normal to the plane of the section, ordinarily the circumferential stress around the hole in the shell, psi (MPa)
σ_r = the stress component normal to the boundary of the section, psi (MPa)
σ_t = the stress component in the plane of the section under consideration and parallel to the boundary of the section, psi (MPa)

(b) When the conditions of NC-3239.1 through NC-3239.6 are satisfied, the stress indices given in Table NC-3239.7-1 may be used. These stress indices deal only with the maximum stresses, at certain general locations, due to internal pressure. In the evaluation of stresses in or adjacent to vessel openings and connections, it is often necessary to consider the effect of stresses due to external loadings or thermal stresses. In such cases, the total stress at a given point may be determined by superposition. In the case of combined stresses due to internal pressure and nozzle loading, the maximum stresses should be considered as acting at the same point and added algebraically. If the stresses are otherwise determined by more accurate analytical techniques or by the experimental stress analysis procedure of Section III Appendices, Mandatory Appendix II, the stresses are also to be added algebraically.

Table NC-3239.7-1
Stress Indices for Internal Pressure Loading

Nozzles in Spherical Shells and Spherical Heads		
Stress	Inside	Outside
σ_n	2.0 − (r/R)	2.0 − (r/R)
σ_t	−0.2	2.0 − (r/R)
σ_r	$-4t_r/(2R + t_r)$	0
σ	larger of: 2.2 − (r/R), or 2.0 + $[4t_r/(2R + t_r)]$ − (r/R)	2.0 − (r/R)

	Nozzles in Cylindrical Shells			
	Longitudinal Plane		Transverse Plane	
Stress	Inside	Outside	Inside	Outside
σ_n	3.1	1.2	1.0	2.1
σ_t	−0.2	1.0	−0.2	2.6
σ_r	$-2t_r/(2R + t_r)$	0	$-2t_r/(2R + t_r)$	0
σ	3.3	1.2	1.2	2.6

NC-3240 VESSELS UNDER EXTERNAL PRESSURE

NC-3241 General Requirements

These rules are applicable to spherical and cylindrical shells with or without stiffening rings and to formed heads and to tubular products (NC-4221.2). Charts for use in determining the thicknesses of these components are given in Section II, Part D, Subpart 3.

NC-3241.1 Nomenclature. The symbols used in this Article are defined below. Except for the test condition, dimensions used or calculated shall be in the corroded condition.

A = factor determined from the appropriate chart in Section II, Part D, Subpart 3 for the material used in the stiffening ring, corresponding to the factor B and the Design Temperature for the shell under consideration

A_s = cross-sectional area of the stiffening ring

B = factor from the charts in Section II, Part D, Subpart 3, psi (MPa)

D_o = outside diameter of the cylindrical shell course under consideration

I_s = required moment of inertia of the combined ring shell section about its neutral axis parallel to the axis of the shell. The width of shell that is taken as contributing to the combined moment of inertia shall not be greater than $1.10\sqrt{D_O/T}$ and shall be taken as lying done-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.

L = design length of a vessel section, using the applicable definition as follows: the distance between head bend lines plus one-third of the depth of each head if there are no stiffening rings; the greatest center to center distance between any two adjacent stiffening rings; or the distance from the center of the first stiffening ring to the head bend line plus one-third of the depth of the head, all measured parallel to the axis of the vessel.

L_s = one-half of the distance from the center line of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support, if any, on the other side of the stiffening ring, both measured parallel to the axis of the vessel. (A line of support is a stiffening ring that meets the requirements of this paragraph; a circumferential line on a head at one-third the depth of the head from the head bend line; a circumferential connection to a jacket.)

P = external Design Pressure, psi (MPa)

R = inside radius of spherical shells

T = minimum required thickness of the cylindrical or spherical shell or tubular product, exclusive of corrosion allowance

NC-3242 Cylindrical Shells

NC-3242.1 For $D_o/T \geq 10$. The minimum thickness of pipes or shell under external pressure[19] having D_o/T values equal to or greater than 10 shall be determined by the procedure given in NC-3133.3.

NC-3242.2 For $D_o/T < 10$. The minimum thickness of pipes or tubes under external pressure having D_o/T values less than 10 shall be determined by the procedure given in Steps 1 through 4 below:

Step 1. Compute a value for factor A from the equation

$$A = 1.1/\left(D_O/T\right)^2$$

Step 2. Enter the appropriate chart with the calculated value of A and move vertically to the material line for the Design Temperature or to the horizontal projection of the upper end of this material line where A falls to the right of the end of the material line. From this intersection, move horizontally to the right and read the value of B.

Step 3. Using this value of B, calculate the maximum allowable pressure by the following equation:

$$P_a = \left[\frac{2.167}{D_O/T} - 0.0833\right]B$$

Step 4. If P_a is less than the external Design Pressure P, repeat the procedure using a larger value for T.

NC-3243 Spherical Shells

The minimum thickness of a spherical shell under external pressure shall be determined by the procedure given in NC-3133.4.

NC-3244 Stiffening Rings for Cylindrical Shells

NC-3244.1 Required Moment of Inertia for Circumferential Stiffening Rings. The required moment of inertia of the combined ring shell section is given by the equation:

$$I_s = \frac{D_o^2 L_s (T + A_s / L_s) A}{10.9}$$

The moment of inertia for a stiffening ring shall be determined by the procedure given in Step 1 through Step 6 below.

Step 1. Assuming that the shell has been designed and D_o, L_s, and T are known, select a member to be used for the stiffening ring and determine its area A_s and the value of I_s. Calculate B by the equation:

$$B = \left[\frac{PD_o}{T + A_s / L_s}\right]\frac{3}{4}$$

Step 2. Enter the right hand side of the chart in Section II, Part D, Subpart 3 for the material under consideration at the value of B determined in Step 1.

Step 3. Move horizontally to the material line for the Design Temperature.

Step 4. From this intersection move vertically to the bottom of the chart and read the value of A.

Step 5. Compute the value of the required moment of inertia I_s from the equation given above.

Step 6. If the required I_s is greater than the computed moment of inertia for the combined ring shell section selected in Step 1, a new section with a larger moment of inertia must be selected and a new I_s determined. If the required I_s is less than the computed moment of inertia for the section selected in Step 1, that section should be satisfactory.

NC-3244.2 Permissible Methods of Attaching Stiffening Rings. Stiffening rings shall be attached to either the outside or the inside of the vessel in accordance with NC-4267.

NC-3245 Cylinders Under Axial Compression

The maximum allowable compressive stress in cylindrical shells subjected to loadings that produce longitudinal compressive stresses shall be the smaller of the values determined by (a) and (b) below:

(a) the S_m value for the applicable material at Design Temperature given in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4;

(b) the value of the factor B determined in accordance with NC-3133.6(b).

NC-3250 WELDED JOINTS

NC-3251 Welded Joint Categories

Welded joint categories are defined in NC-3351.

NC-3252 Permissible Types of Welded Joints

The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg are considered as meeting the requirements for butt joints. Figure NC-3352-1 shows typical butt welds for each category joint.

NC-3252.1 Joints of Category A. All welded joints of Category A shall meet the fabrication requirements of NC-4263 and shall be capable of being examined in accordance with NC-5251.

NC-3252.2 Joints of Category B. All welded joints of Category B shall meet the fabrication requirements of NC-4264 and shall be capable of being examined in accordance with NC-5252. When fatigue analysis of Type 2 joints is required and backing strips are not removed, stress concentration factors of 2.0 for membrane stresses and of 2.5 for bending stresses shall be applied in the design of the joints.

NC-3252.3 Joints of Category C. All welded joints of Category C shall meet the fabrication requirements of NC-4265 and shall be capable of being examined in accordance with NC-5253. Minimum dimensions shall be as specified in NC-3258.3 and NC-3258.4.

NC-3252.4 Joints of Category D. All welded joints of Category D shall be in accordance with the requirements of NC-3359 and one of (a) through (d) below.

(a) Butt Welded Nozzles. Nozzles shall meet the fabrication requirements of NC-4266(a) and shall be capable of being examined in accordance with NC-5254. The minimum dimensions and geometrical requirements of Figure NC-4266(a)-1 shall be met where:

r_1 = $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2 = $\frac{1}{4}$ in. (6 mm) min.
t = nominal thickness of part penetrated
t_n = nominal thickness of penetrating part

(b) Full Penetration Corner Welded Nozzles. Nozzles shall meet the fabrication requirements of NC-4266(b) and shall be capable of being examined as required in NC-5254. The minimum dimensions of Figure NC-4266(b)-1 shall be met where:

r_1 = $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2 = $\frac{1}{4}$ in. (6 mm) min.
r_3 = $\frac{1}{4}t_n$ or $\frac{3}{8}$ in. (10 mm), whichever is less, or chamfer at 45 deg to at least $\frac{5}{16}$ in. (8 mm).
t = thickness of part penetrated
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n = thickness of penetrating part

(c) Pad and Screwed Fitting Types of Welded Nozzles. Nozzles and fittings shall meet the fabrication requirements of NC-4266(c) and shall be capable of being

examined in accordance with NC-5254. The minimum dimensions and geometrical requirements of Figure NC-4266(c)-1 shall be met, where

c = smaller of $0.7t_e$ or $0.7t$
r_1 = $\frac{1}{4}t_n$ or $\frac{3}{8}$ in. (10 mm), whichever is less
r_3 = $\frac{1}{4}t_n$ or $\frac{3}{8}$ in. (10 mm), whichever is less, or chamfer at 45 deg to at least $\frac{5}{16}$ in. (8 mm)
t = nominal thickness of shell
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_e = thickness of reinforcement element
t_n = nominal thickness of neck

(d) Attachment of Nozzles Using Partial Penetration Welds. Partial penetration welds shall meet the fabrication requirements of NC-4266(d) and shall be capable of being examined in accordance with NC-5254. They shall be used only for attachments such as instrumentation openings and inspection openings, which are subjected to essentially no external mechanical loadings and on which there will be no thermal stresses greater than in the vessel itself. Such attachments shall satisfy the rules for reinforcement of openings, except that no material in the neck shall be used for reinforcement in the attachment. The inside diameter of such openings shall not exceed 4 in. (100 mm). The minimum dimensions of Figure NC-4266(d)-1 shall be met where:

C = maximum diametral clearance between nozzle and vessel penetration, in. (mm)
= 0.010 in. for $d \leq$ 1 in. (0.25 mm for $d \leq$ 25 mm)
= 0.020 in. for 1 in. < $d \leq$ 4 in. (0.50 mm for 25 mm < $d \leq$ 100 mm)
= 0.030 in. for $d >$ 4 in. (0.75 mm for $d >$ 100 mm), except that the above limits on maximum clearance need not be met for the full length of the opening, provided there is a region at the weld preparation and a region near the end of the opening opposite the weld that does meet the above limit on maximum clearance and the latter region is extensive enough (not necessarily continuous) to provide a positive stop for nozzle deflection.
d = outside diameter of nozzle
r_1 = $\frac{1}{4}t_n$ or $\frac{3}{4}$ in. (19 mm), whichever is less
t = nominal thickness of vessel
t_c = $0.7t$ or $\frac{1}{4}$ in. (6 mm), whichever is less
t_n = nominal thickness of neck
t_w = depth of weld penetration, not less than $1\frac{1}{4}t_n$, in. (mm)

NC-3254 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of NC-4267.

NC-3255 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in NC-3252.4.

NC-3257 Welded Joints Subject to Bending Stress

The requirements of NC-3357 shall be met.

NC-3258 Design Requirements for Head Attachments

NC-3258.1 Skirt Length of Formed Heads. (15)

(a) Ellipsoidal and other types of formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Figure NC-3358.1(a)-1.

(b) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections as shown in Figure NC-3358.1(a)-1 shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $\frac{1}{8}$ in., whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment [Figure NC-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

NC-3258.2 Unstayed Flat Head Welded to Shells. The requirements of welded unstayed flat heads to shells are given in NC-3225, NC-3258.3, and NC-3258.4.

NC-3258.3 Head Attachments Using Corner Joints. When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, the welds shall meet the requirements given in (a) through (e) below.

(a) On the cross section through the welded joint, the line between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b, respectively.

(b) For flange rings of bolted flanged connections and for flat heads and supported and unsupported tube sheets with a projection for a bolted connection, the sum of a and b shall be not less than three times the nominal wall thickness of the abutting pressure parts.

(c) For other parts, the sum of a and b shall be not less than two times the nominal wall thickness of the abutting pressure parts. Examples of such parts are flat heads and supported and unsupported tubesheets without a projection for a bolted connection and the side plates of a rectangular vessel.

(d) Joint details that have a dimension through the joint less than the thickness of the shell, head, or other pressure part or that provide eccentric attachment are not permitted.

(e) The minimum dimensions in Figures NC-4265-1 and NC-4265-2 are as follows:

(1) Figure NC-4265-1

Sketch (a)

$a + b$ not less than $2t_s$

$b + c$ not less than t_s

t_p not less than t_s

Sketch (b)

$a + b$ not less than $2t_s$

Sketch (c)

$a + b$ not less that $3t_s$

$b + c$ not less than t_s

Sketches (d) and (e)

(-a) For forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

b = the lesser of $t_s/2$ or $T/4$
c = $0.7t_s$ or $^1/_4$ in. (6 mm), whichever is less
T, t_s = nominal thickness of welded parts

(-b) For all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

b = the lesser of t_s or $T/2$
c = $0.7t_s$ or $^1/_4$ in. (6 mm), whichever is less
T, t_s = nominal thickness of welded parts sketches (f) and (g)

(2) Figure NC-4265-2

Sketch (a)

(-a) For forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

t, t_n = nominal thickness of welded parts
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_w = the lesser of $t_n/2$ or $t/4$

(-b) For all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

t, t_n = nominal thicknesses of welded parts
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_w = the lesser of t_n or $t/2$

Sketch (b)

t and t_n = nominal thickness of welded parts

h or g_1 = $0.25t_n$ but not less than $^1/_4$ in. (6 mm)

Sketch (c)

t_n = nominal thickness of neck

$a + b$ not less than $3t_n$

c not less than t_n

NC-3258.4 Head Attachments Using Butt Welds. When flat heads are attached using butt welds, as shown in Figure NC-4243.1-1, the minimum dimensions are as follows:

Sketch (a)
r not less than $1.5t_s$
Sketch (b)
r not less than $1.5t_s$
e not less than t_s
Sketch (c)
h not less than $1.5t_s$
Sketch (d)
t_f not less than $2t_s$
r not less than $3t_f$
Sketch (e)
t_f not less than $2t_s$
r not less than $3t_f$
e not less than t_f

NC-3259 Design Requirements for Nozzle Attachment Welds and Other Connections

The minimum design requirements for nozzle attachment welds and other connections are set forth in (a) through (c) below.

(a) Permitted Types of Nozzles and Other Connections. Nozzles and other connections may be any of the types for which rules are given in this subarticle, provided the requirements of (1) through (7) below are met.

(1) Nozzles shall meet requirements regarding location.

(2) The attachment weld shall meet the requirements of NC-3252.4.

(3) The requirements of NC-3230 shall be met.

(4) Type No. 1 full penetration joints shall be used when the openings are in shells $2^1/_2$ in. (64 mm) or more in thickness.

(5) The welded joints shall be examined by the methods stipulated in NC-5250.

(6) Studded connections shall meet the requirements of NC-3262.4.

(7) Threaded connections shall meet the requirements of NC-3266.

(b) Provision of Telltale Holes for Air Testing. Reinforcing plates and saddles attached to the outside of a vessel shall be provided with at least one telltale hole, of maximum size $^1/_4$ in. (6 mm) pipe tap, that may be tapped for a preliminary compressed air and soap solution or equivalent test for tightness of welds that seal off the inside of the vessel. These telltale holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall. Telltale holes shall not be plugged during heat treatment.

(c) *Attachments*. Typical attachments are shown in Figure NC-4267-1. The minimum dimensions in this figure are as follows:

$$a \geq t/4;\ b \geq t/2;\ C \geq t$$

where

c = minimum thickness of weld metal from the root to the face of the weld
t = thickness of attached member

NC-3260 SPECIAL VESSEL REQUIREMENTS

(15) ### NC-3261 Transition Joints Between Sections of Unequal Thickness

Unless the requirements of Section III Appendices, Mandatory Appendix XIII, Mandatory Appendix XIV, or Mandatory Appendix II are shown to be satisfied, a tapered transition as shown in Figures NC-3358.1(a)-1 and NC-3361-1 shall be provided at joints of Categories A and B between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $^1/_8$ in. (3 mm). The transition may be formed by any process that will provide a uniform taper. The weld may be partly or entirely in the tapered section. When Section III Appendices, Mandatory Appendix XIII, Mandatory Appendix XIV, or Mandatory Appendix II are not used, the following requirements of (a) through (e) below shall also apply.

(a) The length of taper shall be not less than three times the offset between adjacent surfaces.

(b) Figure NC-3361-1 shall apply to all joints of Categories A and B except joints connecting formed heads to main shells, for which case Figure NC-3358.1(a)-1 shall apply.

(c) When a taper is required on any formed head intended for butt welded attachment, the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

(d) An ellipsoidal or hemispherical head which has a greater thickness than a cylinder of the same inside diameter may be machined to the outside diameter of the cylinder, provided the remaining thickness is at least as great as that required for a shell of the same diameter.

(e) The requirements of this paragraph are not applicable to flange hubs.

NC-3262 Bolted Flanged Connections

NC-3262.1 Flanges and Flanged Fittings Conforming to ASME B16.5. Except as provided in NC-3262.3, the dimensional requirements of flanges used in bolted flange connections to external piping shall conform to ASME B16.5, Steel Pipe Flanges and Flanged Fittings. Flanges and flanged fittings conforming to ASME B16.5 and listed in Tables 8 through 28 of that Standard, with the exception of threaded and socket welding types, may be used at the pressure–temperature ratings specified in that Standard.

NC-3262.2 Slip-On Flanges Conforming to ASME B16.5. Slip-on flanges conforming to ASME B16.5 may be used, provided all the conditions of (a) through (e) below are met.

(a) The specified minimum tensile strengths of materials do not exceed 80.0 ksi (550 MPa).

(b) The minimum elongation of materials is 12% in 2 in. (50 mm).

(c) The thickness of the materials to which the flange is welded does not exceed $1^1/_4$ in. (32 mm).

(d) The throat thickness, taken as the minimum thickness in any direction through the attaching fillet welds, is at least 0.7 times the thickness of the material to which the flange is welded.

(e) The fatigue analysis required for nozzles with separate reinforcement and nonintegral attachments, as set forth in NC-3219.3, is applied to the design.

NC-3262.3 Flanges Not Conforming to ASME B16.5. Flanges that do not conform to ASME B16.5 shall be designed in accordance with the Rules for Bolted Flange Connections, Section III Appendices, Mandatory Appendix XI, or by the rules of Section III Appendices, Mandatory Appendices II, XIII, and XIV.

NC-3262.4 Studded Connections. Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d or

$$0.75d_s \times \frac{\text{Design stress intensity value of stud material at Design Temperature}}{\text{Design stress intensity value of tapped material at Design Temperature}}$$

in which d is the root diameter of the stud, except that the thread engagement need not exceed $1^1/_2 d_s$.

NC-3263 Access and Inspection Openings

The requirements for access and inspection openings are given in NC-3363.

NC-3264 Attachments and Supports

NC-3264.1 General Requirements. Supports, lugs, brackets, stiffeners, and other attachments may be welded or stud bolted to the outside or inside of a vessel wall. All stud bolted attachments require a detailed fatigue analysis in accordance with the requirements of Section III Appendices, Mandatory Appendices XIII and XIV unless the conditions of NC-3219 are met. Attachments shall conform reasonably to the curvature of the shell to which they are to be attached. The fabrication requirements of NC-4267 and the examination requirements of NC-5250 shall be met.

NC-3264.2 Attachment Materials. Materials welded directly to pressure parts shall meet the requirements of NC-2190.

NC-3264.3 Design of Attachments. The effects of attachments, including external and internal piping connections, shall be taken into account in the design. Attachments shall meet the requirements of NC-3135.

NC-3264.4 Design of Supports.

(a) All vessels shall be so supported and the supporting members so arranged and attached to the vessel as to provide for the maximum imposed loadings. Wind and earthquake loads need not be assumed to occur simultaneously.

(b) All supports should be designed to prevent excessive localized stresses due to temperature changes in the vessel or deformations produced by the internal pressure.

(c) Horizontal vessels supported by saddles shall provide bearing extending over at least one-third of the shell circumference.

(d) Additional requirements for the design of supports are given in NCA-3240 and Subsection NF.

NC-3264.5 Types of Attachment Welds. Welds attaching nonpressure parts or stiffeners to pressure parts shall meet the requirements of NC-4267.

NC-3264.6 Stress Values for Weld Material. Attachment weld strength shall be based on the nominal weld area and the design stress intensity values in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 and stress criteria in NC-3200 for the weaker of the two materials joined, or, where weaker weld metal is permitted, the design stress intensity values of the weld metal multiplied by the following reduction factors: 0.5 for fillet welds NC-3264.5; 0.75 for partial penetration groove or partial penetration groove plus fillet welds NC-3264.5; 1.0 for complete weld penetration. The nominal weld area for fillet welds is the throat area; for groove welds, the depth of penetration times the length of weld; and for groove welds with fillet welds, the combined throat and depth of penetration, exclusive of reinforcement, times the length of weld.

(a) Attachment Welds — Evaluation of Need for Fatigue Analysis. In applying Condition AP or BP of NC-3219.3, fillet welds and partial penetration welds are considered nonintegral attachments, except that the following welds need not be considered:

(1) welds for minor attachments

(2) welds for supports which may be considered integral as covered by Conditions A and B of NC-3219.2

NC-3266 Threaded Connections

(a) Threads

(1) Pipes, tubes, and other threaded connections that conform to ANSI/ASME B1.20.1, Pipe Threads, General Purpose, may be screwed into a threaded hole in a vessel wall, provided the pipe engages the minimum number of threads specified in Table NC-3266-1 after allowance has been made for curvature of the vessel wall. A built-up pad or a properly attached plate or fitting shall be used to provide the metal thickness and number of threads required in Table NC-3266-1 or to furnish reinforcement when required.

(2) Straight threaded connections may be employed as provided for in (b)(2).

(b) Restrictions on the Use of Threaded Connections

(1) Taper Threaded Connections. Internal taper pipe thread connections larger than NPS 2 (DN 50) shall not be used.

(2) Straight Threaded Connections

(-a) Threaded connections employing straight threads shall provide for mechanical seating of the assembly by a shoulder or similar means. Straight thread center openings in vessel heads shall meet the requirements of NC-3230. The length of the thread shall be calculated for the opening design and they shall not exceed the smaller of one-half the vessel diameter or NPS 8 (DN 200). In addition, they shall be placed at a point where the calculated stress without a hole, due to any combination of design pressure and mechanical loadings expected to occur simultaneously, is not more than $0.5S_m$.

(-b) Threaded connections above $2^3/_4$ in. (70 mm) in diameter may be used only if they meet the requirements of NC-3219, or, if these requirements are not met, a detailed fatigue analysis shall be made in accordance with the rules of Appendices XIII and XIV.

NC-3300 VESSEL DESIGN

NC-3310 GENERAL REQUIREMENTS

Class 2 vessel requirements as stipulated in the Design Specifications (NCA-3250) shall conform to the design requirements of this Article.

Table NC-3266-1
Minimum Number of Pipe Threads for Connections

Size of Pipe Connection, NPS (DN)	Threads Engaged	Min. Plate Thickness Required, in. (mm)
$^1/_2$ (15)	6	0.43 (11)
$^3/_4$ (20)	6	0.43 (11)
1 (25)	6	0.61 (16)
$1^1/_4$ (32)	6	0.61 (16)
$1^1/_2$ (40)	6	0.61 (16)
2 (50)	8	0.70 (18)

NC-3320 DESIGN CONSIDERATIONS

NC-3321 Stress Limits for Design and Service Loadings

Stress[20] limits for Design and Service Loadings are specified in Table NC-3321-1. The symbols used in Table NC-3321-1 are defined as follows:

S = allowable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3. The allowable stress shall correspond to the highest metal temperature at the section under consideration during the condition under consideration.

σ_b = bending stress. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress. This stress is the same as σ_m, except that it includes the effect of discontinuities.

σ_m = general membrane stress. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

Typical examples of locations for which σ_b, σ_L, and σ_m are applicable are shown in Table NC-3321-2.

NC-3322 Special Considerations

The provisions of NC-3120 apply.

NC-3323 General Design Rules

The provisions of NC-3130 apply except as modified by the rules of this subarticle. In case of conflict, this subarticle governs the design of vessels.

Table NC-3321-1
Stress Limits for Design and Service Loadings

Service Limit	Stress Limits [Note (1)]
Design and Level A	$\sigma_m \leq 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$
Level B	$\sigma_m \leq 1.10S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$

GENERAL NOTE: See NC-3321.1 for definitions of symbols.

NOTE:
(1) These limits do not take into account either local or general buckling that might occur in thin-wall vessels.

NC-3324 Vessels Under Internal Pressure

NC-3324.1 General Requirements. Equations are given for determining the minimum thicknesses under internal pressure loading in cylindrical and spherical shells and ellipsoidal, torispherical, toriconical, conical, and hemispherical heads. Provision shall be made for any of the other loadings listed in NC-3111 when such loadings are specified.

NC-3324.2 Nomenclature. The symbols used in this paragraph and Figure NC-3324.2-1 are defined as follows:

D = inside diameter of the head skirt; inside length of the major axis of an ellipsoidal head; or inside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis

D_o = outside diameter of the head skirt; outside length of the major axis of an ellipsoidal head; or outside diameter of a conical head at the point under consideration, measured perpendicular to the longitudinal axis

D_1 = inside diameter of the conical portion of a toriconical head at its point of tangency to the knuckle, measured perpendicular to the axis of the cone

$D/2h$ = ratio of the major to the minor axis of ellipsoidal heads, which equals the inside diameter of the skirt of the head divided by twice the inside height of the head and is used in Table NC-3324.2-1

h = one-half of the length of the minor axis of the ellipsoidal head or the inside depth of the ellipsoidal head measured from the tangent line, head bend line

K = a factor in the equations for ellipsoidal heads depending on the head proportion, $D/2h$ (Table NC-3324.2-1)

L = inside spherical or crown radius for torispherical and hemispherical heads

L = $K_1 D$ for ellipsoidal heads in which K_1 is obtained from Table NC-3332.2-1

L_o = outside spherical or crown radius

P = Design Pressure

R = inside radius of the shell course under consideration before corrosion allowance is added

r = inside knuckle radius

R_o = outside radius of the shell course under consideration

S = maximum allowable stress value (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)

t = minimum required thickness of shell or head after forming, exclusive of corrosion allowance

α = one-half of the included apex angle of the cone at the centerline of the head

Table NC-3321-2
Classification of Stress Intensity in Vessels for Some Typical Cases

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane	σ_m
			Gradient through plate thickness	Q
		Axial thermal gradient	Membrane	Q
			Bending	Q
	Junction with head or flange	Internal pressure	Membrane	σ_L
			Bending	Q [Note (1)]
Any shell or head	Any section across entire vessel	External load or moment, or internal pressure	General membrane averaged across full section; stress component perpendicular to cross section.	σ_m
		External load or moment	Bending across full section; stress component perpendicular to cross section.	σ_m
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane	σ_L
			Bending	Q
			Peak (fillet or corner)	F
	Any location	Temperature difference between shell and head	Membrane	Q
			Bending	Q
Dished head or conical head	Crown	Internal pressure	Membrane	σ_m
			Bending	σ_b
	Knuckle or junction to shell	Internal pressure	Membrane	σ_L [Note (2)]
			Bending	Q
Flat head	Center region	Internal pressure	Membrane	σ_m
			Bending	σ_b
	Junction to shell	Internal pressure	Membrane	σ_L
			Bending	Q [Note (1)]
Perforated head or shell	Typical ligament in a uniform pattern	Pressure	Membrane (averaged through cross section)	σ_m
			Bending (averaged through width of ligament, but gradient through plate)	σ_b
			Peak	F
	Isolated or atypical ligament	Pressure	Membrane	Q
			Bending	F
			Peak	F

Table NC-3321-2
Classification of Stress Intensity in Vessels for Some Typical Cases (Cont'd)

Vessel Part	Location	Origin of Stress	Type of Stress	Classification
Nozzle	Within the limits of reinforcement defined by para. NC-3334	Pressure and external loads and moments, including those attributable to restrained free end displacements of attached piping	General membrane	σ_m
			Bending (other than gross structural discontinuity stresses) averaged through nozzle thickness	σ_m
	Outside the limits of reinforcement defined by para. NC-3334	Pressure and external axial, shear, and torsional loads other than those attributable to restrained free end displacements of attached piping	General membrane stresses	σ_m
		Pressure and external loads and moments other than those attributable to restrained free end displacements of the attached piping	Membrane	σ_L
			Bending	σ_b
		Pressure and all external loads and moments	Membrane	σ_L
			Bending	Q
			Peak	F
	Nozzle wall	Gross structural discontinuities	Local membrane	σ_L
			Bending	Q
			Peak	F
		Differential expansion	Membrane	Q
			Bending	Q
			Peak	F
Cladding	Any	Differential expansion	Membrane	F
			Bending	F
Any	Any	Radial temperature distribution [Note (3)]	Equivalent linear stress [Note (4)]	Q
			Nonlinear portion of stress distribution	F
Any	Any	Any	Stress concentration (notch effect)	F

GENERAL NOTE: Q and F classifications of stresses refer to other than Design Condition.

NOTES:
(1) If the bending moment at the edge is required to maintain the bending stress in the middle within acceptable limits, the edge bending is classified as σ_b. Otherwise, it is classified as Q.
(2) Consideration must also be given to the possibility of wrinkling and excessive deformation in vessels with large diameter-to-thickness ratio.
(3) Consider the possibility of thermal stress ratchet.
(4) *Equivalent linear stress* is defined as the linear distribution that has the same net bending moment as the actual stress distribution.

Figure NC-3324.2-1
Principal Dimensions of Typical Heads

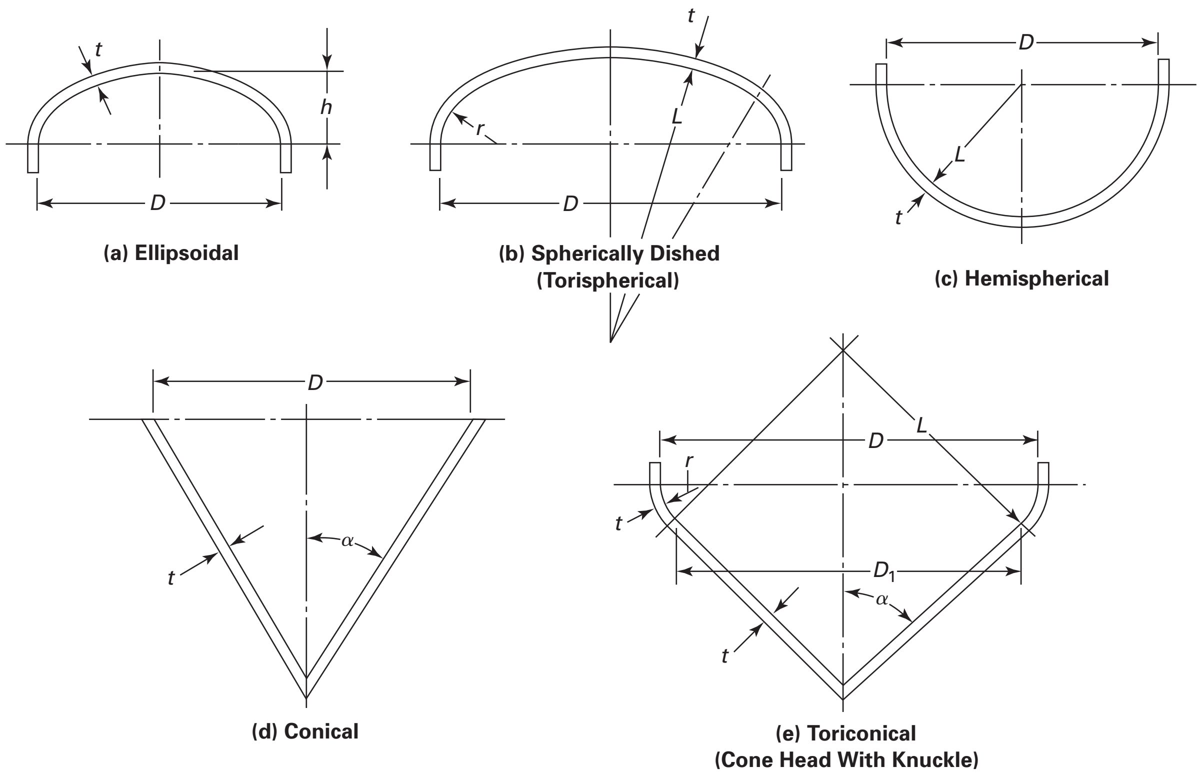


Table NC-3324.2-1
Values of Factor K
Use Nearest Value of $D/2h$; Interpolation Unnecessary

$D/2h$	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2	2.1	2.0
K	1.83	1.73	1.64	1.55	1.46	1.37	1.29	1.21	1.14	1.07	1.00
$D/2h$	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.0	...
K	0.93	0.87	0.81	0.76	0.71	0.66	0.61	0.57	0.53	0.50	...

NC-3324.3 Cylindrical Shells. The minimum thickness of cylindrical shells shall be the greater thickness as given by (a) through (d) below.

(a) Circumferential Stress (Longitudinal Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed $0.385S$, the following equations shall apply:

$$t = \frac{PR}{S - 0.6P} \quad \text{or} \quad P = \frac{St}{R + 0.6t}$$

(b) Longitudinal Stress (Circumferential Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed $1.25S$, the following equations shall apply:

$$t = \frac{PR}{2S + 0.4P} \quad \text{or} \quad P = \frac{2St}{R - 0.4t}$$

(c) Thickness of Cylindrical Shells. The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in (a) above:

$$t = \frac{PR_o}{S + 0.4P} \quad \text{or} \quad P = \frac{St}{R_o - 0.4t}$$

(d) Thick Cylindrical Shells

(1) Circumferential Stress (Longitudinal Joints). When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius, or when P exceeds $0.385S$, the following equations shall apply.

When P is known and t is desired:

$$t = R\left(Z^{1/2} - 1\right) = R_o\frac{\left(Z^{1/2} - 1\right)}{Z^{1/2}}$$

where

$$Z = \frac{S + P}{S - P}$$

When t is known and P is desired:

$$P = S\left(\frac{Z - 1}{Z + 1}\right)$$

where

$$Z = \left(\frac{R + t}{R}\right)^2 = \left(\frac{R_o}{R}\right)^2 = \left(\frac{R_o}{R_o - t}\right)^2$$

(2) Longitudinal Stress (Circumferential Joints). When the thickness of the cylindrical shell under internal pressure exceeds one-half of the inside radius, or when P exceeds $1.25S$, the following equations shall apply.

When P is known and t is desired:

$$t = R\left(Z^{1/2} - 1\right) = R_o\frac{\left(Z^{1/2} - 1\right)}{Z^{1/2}}$$

where

$$Z = \left(\frac{P}{S} + 1\right)$$

When t is known and P is desired:

$$P = S\left(Z - 1\right)$$

where

$$Z = \left(\frac{R + t}{R}\right)^2 = \left(\frac{R_o}{R}\right)^2 = \left(\frac{R_o}{R_o - t}\right)^2$$

NC-3324.4 Spherical Shells.

(a) When the thickness of the shell of a spherical vessel does not exceed $0.356R$, or P does not exceed $0.665S$, the following equations shall apply. Any reduction in thickness within a shell course of a spherical shell shall be in accordance with NC-3361.

$$t = \frac{PR}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{R + 0.2t}$$

(b) The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in (a) above.

$$t = \frac{PR_o}{2S + 0.8P}$$

$$P = \frac{2St}{R_o - 0.8t}$$

(c) When the thickness of the shell of a spherical vessel or of a hemispherical head under internal pressure exceeds $0.356R$, or when P exceeds $0.665S$, the following equations shall apply.

When P is known and t is desired:

$$t = R\left(Y^{1/3} - 1\right) = R_o\left(\frac{Y^{1/3} - 1}{Y^{1/3}}\right)$$

where

$$Y = \frac{2\left(S + P\right)}{2S - P}$$

When t is known and P is desired:

$$P = 2S\left(\frac{Y - 1}{Y + 2}\right)$$

where

$$Y = \left(\frac{R + t}{R}\right)^3 = \left(\frac{R_o}{R_o - t}\right)^3$$

NC-3324.5 Formed Heads, General Requirements. Formed heads shall meet the requirements of (a) through (g) below.

(a) All formed heads, thicker than the shell and concave to pressure, for butt welded attachment, shall have a skirt length sufficient to meet the requirements of Figure NC-3358.1(a)-1 when a tapered transition is required.

(b) Any taper at a welded joint within a formed head shall be in accordance with NC-3361. The taper at a circumferential welded joint connecting a formed head to a main shell shall meet the requirements of NC-3358 for the respective type of joint shown therein.

(c) All formed heads concave to pressure and for butt welded attachment need not have an integral skirt when the thickness of the head is equal to or less than the thickness of the shell. When a skirt is provided, its thickness shall be at least that required for a seamless shell of the same diameter.

(d) The inside crown radius to which an unstayed head is dished shall be not greater than the outside diameter of the skirt of the head. The inside knuckle radius of a torispherical head shall be not less than 6% of the outside diameter of the skirt of the head but in no case less than three times the head thickness.

(e) When an ellipsoidal, torispherical, hemispherical, conical, or toriconical head is of a lesser thickness than required by the rules of this paragraph, it shall be stayed as a flat surface according to the rules of NC-3329.

(f) If a torispherical, ellipsoidal, or hemispherical head is formed with a flattened spot or surface, the diameter of the flat spot shall not exceed that permitted for flat heads as given by eqs. NC-3325.2(b)(5) or NC-3325.2(b)(6) using $C = 0.25$.

(g) Openings in formed heads under internal pressure shall comply with the requirements of NC-3330.

NC-3324.6 Ellipsoidal Heads.

(a) Ellipsoidal Heads. The required thickness of a dished head of semiellipsoidal form, in which one-half the minor axis, inside depth of the head minus the skirt, equals one-fourth the inside diameter of the head skirt, shall be determined by:

$$t = \frac{PD}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{D + 0.2t}$$

(b) Ellipsoidal Heads of Other Ratios. The minimum required thickness of an ellipsoidal head of other than a 2:1 ratio shall be determined by:

$$t = \frac{PDK}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{KD + 0.2t}$$

$$t = \frac{PD_oK}{2S + 2P(K - 0.1)}$$

or

$$P = \frac{2St}{KD_o - 2t(K - 0.1)}$$

where

$$K = \frac{1}{6}\left[2 + \left(\frac{D}{2h}\right)^2\right]$$

Numerical values of the factor K are given in Table NC-3324.2-1.

NC-3324.7 Hemispherical Heads.

(a) When the thickness of a hemispherical head does not exceed $0.356L$ or P does not exceed $0.665S$, the following equations shall apply:

$$t = \frac{PL}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{L + 0.2t}$$

(b) When the thickness of the hemispherical head under internal pressure exceeds $0.356L$, or when P exceeds $0.665S$, the following equations shall apply:

$$t = L\left(Y^{1/3} - 1\right) = L_o\left(\frac{Y^{1/3} - 1}{Y^{1/3}}\right)$$

where

$$Y = \frac{2(S + P)}{2S - P}$$

or

$$P = 2S\left(\frac{Y - 1}{Y + 2}\right)$$

where

$$Y = \left(\frac{L + t}{L}\right)^3 = \left(\frac{L_o}{L_o - t}\right)^3$$

NC-3324.8 Torispherical Heads.

(a) Torispherical Heads With a 6% Knuckle Radius. The required thickness of a torispherical head in which the knuckle radius is 6% of the inside crown radius shall be determined by:

$$t = \frac{0.885PL}{S - 0.1P} \quad \text{or} \quad P = \frac{St}{0885L + 0.1t}$$

(b) Torispherical Heads of Other Proportions. The required thickness of a torispherical head in which the knuckle radius is other than 6% of the crown radius shall be determined by:

$$t = \frac{PLM}{2S - 0.2P} \quad \text{or} \quad P = \frac{2St}{LM + 0.2t}$$

$$t = \frac{PL_oM}{2S + P(M - 0.2)}$$

or

$$P = \frac{2St}{ML_o - t(M - 0.2)}$$

where

$$M = \frac{1}{4}\left(3 + \sqrt{\frac{L}{r}}\right)$$

Numerical values of the factor M are given in Table NC-3324.8(b)-1.

(c) Torispherical heads made of materials having a specified minimum tensile strength exceeding 80 ksi (550 MPa) shall be designed using a value of S equal to 20 ksi (140 MPa) at room temperature and reduced in proportion to the reduction in maximum allowable stress values at temperature for the material as shown in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NC-3324.9 Conical Heads Without Transition Knuckle. The required thickness of conical heads or conical shell sections that have a half apex angle α not greater than 30 deg shall be determined by:

$$t = \frac{PD}{2\cos\alpha(S - 0.6P)} \quad \text{or} \quad P = \frac{2St\cos\alpha}{D + 1.2t\cos\alpha}$$

For α greater than 30 deg, see NC-3324.11(b)(5). A compression ring shall be provided when required by the rule in NC-3324.11(b).

NC-3324.10 Toriconical Heads. Toriconical heads in which the inside knuckle radius is neither less than 6% of the outside diameter of the head skirt nor less than three times the knuckle thickness shall be used when the angle α exceeds 30 deg, except when the design complies with NC-3324.11. The required thickness of the knuckle shall be determined by the first equation of NC-3324.8(b) in which

$$L = \frac{D_1}{2\cos\alpha}$$

The required thickness of the conical portion shall be determined by the equation in NC-3324.9, using D_1 in place of D.

NC-3324.11 Reducer Sections.

(a) General Requirements

(1) The rules of (a) apply to concentric reducer sections.

(2) The symbols used are defined as follows:

A = required area of reinforcement
A_e = effective area of reinforcement, due to excess metal thickness
D_1 = inside diameter of reducer section at point of tangency to the knuckle or reverse curve
m = the lesser of

$$\left[\frac{t_s}{t}\cos(\alpha - \Delta)\right] \quad \text{or} \quad \left[\frac{t_c\cos\alpha\cos(\alpha - \Delta)}{t}\right]$$

R_L = inside radius of larger cylinder
r_L = inside radius of knuckle at larger cylinder
R_s = inside radius of smaller cylinder
r_s = radius to the inside surface of flare at the small end
t_c = nominal thickness of cone at cone-to-cylinder junction, exclusive of corrosion allowance
t_e = the smaller of $(t_s - t)$ or $[t_c - (t/\cos\alpha)]$
t_s = nominal thickness of cylinder at cone-to-cylinder junction, exclusive of corrosion allowance
Δ = value to indicate need for reinforcement at cone-to-cylinder intersection having a half-apex angle $\alpha \le$ 30 deg. When $\Delta \ge \alpha$, no reinforcement at the junction is required [Tables NC-3324.11(b)(2)-1 and NC-3324.11(b)(3)-1].

(3) The thickness of each element of a reducer, as defined in (4) below, under internal pressure shall not be less than that computed by the applicable equation. In addition, provisions shall be made for any of the other loadings listed in NC-3111 when such loadings are expected.

Table NC-3324.8(b)-1
Values of Factor *M*

L/r	1.0	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22
L/r	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
M	1.25	1.28	1.31	1.34	1.36	1.39	1.41	1.44	1.46	1.48	1.50
L/r	9.5	10.00	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0	16.67 (1)
M	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75	1.77

GENERAL NOTE: Use nearest value of L/r; interpolation unnecessary.

NOTE:
(1) Maximum ratio allowed by NC-3324.5(d) when L equals the outside diameter of the skirt of the head.

Table NC-3324.11(b)(2)-1
Values of Δ for Junctions at the Large Cylinder for $\alpha \leq$ 30 deg

P/S	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009 (1)	...
Δ, deg	11	15	18	21	23	25	27	28.5	30	...

NOTE:
(1) Δ = 30 deg for greater values of P/S.

(4) A transition section reducer consisting of one or more elements may be used to join two cylindrical shell sections of different diameters but with a common axis, provided the requirements of (-a) and (-b) below are met.

(-a) Conical Shell Section. The required thickness of a conical shell section or the allowable pressure for such a section of given thickness shall be determined by the equations given in NC-3324.9.

(-b) Knuckle Tangent to the Larger Cylinder. Where a knuckle is used at the large end of a reducer section, its shape shall be that of a portion of an ellipsoidal, hemispherical, or torispherical head. The thickness and other dimensions shall satisfy the requirements.

(5) When elements of (4) above having different thicknesses are combined to form a reducer, the joints including the plate taper required by NC-3361 shall lie entirely within the limits of the thinner element being joined.

(6) A reducer may be a simple conical shell section [Figure NC-3324.11(a)(6)-1, sketch (a)] without knuckle, provided the half apex angle, α, is not greater than 30 deg except as provided for in (b) below. A reinforcement ring shall be provided at either or both ends of the reducer when required by (b) below.

(7) A toriconical reducer [Figure NC-3324.11(a)(6)-1, sketch (b)] may be shaped as a portion of a toriconical shell, a portion of a hemispherical head plus a conical section, or a portion of an ellipsoidal head plus a conical section, provided the half apex angle, α, is not greater than 30 deg, except as provided for in (b) below. A reinforcement ring shall be provided at the small end of a conical reducer element when required by (b) below.

(8) Reverse curve reducers [Figure NC-3324.11(a)(6)-1, sketches (c) and (d)] may be shaped of elements other than those illustrated.

(b) Supplementary Requirements for Reducer Sections and Conical Heads Under Internal Pressure

(1) The eqs. of (2)(-b)(2) and (3)(-a)(3) below provide for the design of reinforcement, if needed, at the cone to cylinder junctions for reducer sections and conical heads where all the elements have a common axis and the half apex angle $\alpha \leq$ 30 deg. In (5) below, provision is made for special analysis in the design of cone to cylinder intersections with or without reinforcing rings where α is greater than 30 deg.

(2) Reinforcement shall be provided at the junction of the cone with the large cylinder for conical heads and reducers without knuckles when the value of Δ, obtained from Table NC-3324.11(b)(2)-1, using the appropriate ratio P/S, is less than α. Interpolation may be made in the table.

(-a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

$$A = \frac{PR_L^2}{2S}\left(1 - \frac{\Delta}{\alpha}\right)\tan\alpha \quad (1)$$

(-b) When the thickness, less corrosion allowance, of both the reducer and cylinder exceeds that required by the applicable design equations, the minimum excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$A_e = 4t_e\sqrt{R_L t_s} \quad (2)$$

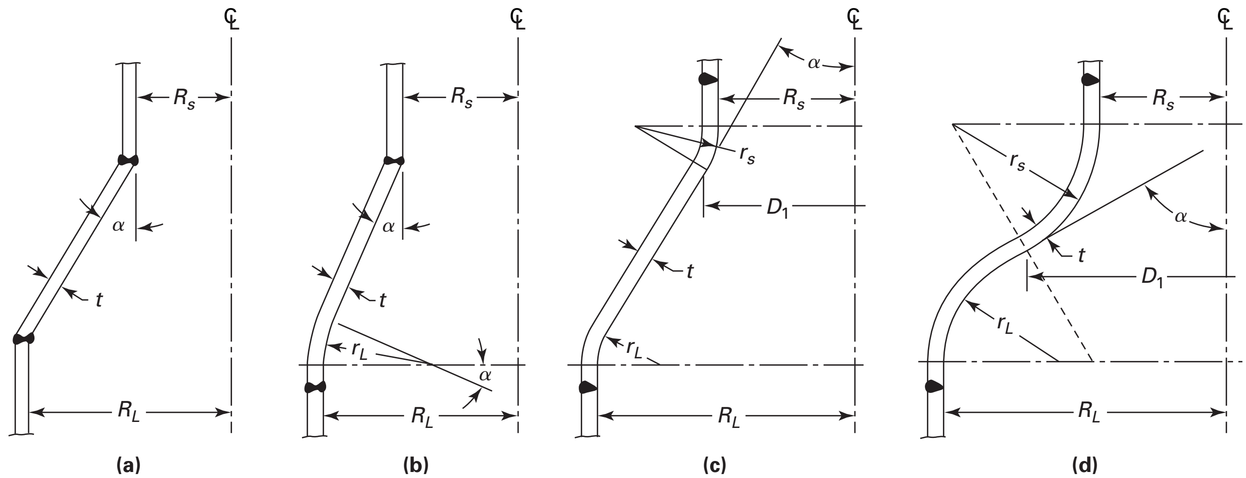
(-c) Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_L t_s}$ from the junction of the reducer and the cylinder. The centroid of the added area shall be within a distance of $0.5\sqrt{R_L t_s}$ from the junction.

Table NC-3324.11(b)(3)-1
Values of Δ for Junctions at the Small Cylinder for $\alpha \leq$ 30 deg

P/S	0.002	0.005	0.010	0.02	0.04	0.08	0.10	0.125 (1)
Δ, deg	4	6	9	12.5	17.5	24	27	30

NOTE:
(1) Δ = 30 deg for greater values of P/S.

Figure NC-3324.11(a)(6)-1
Large Head Openings, Reverse Curve, and Conical Shell Reducer Sections



GENERAL NOTES:
(a) r_L shall not be less than the smaller of 0.12 $(R_L + t)$ or $3t$.
(b) r_s has no dimensional requirement.

(3) Reinforcement shall be provided at the junction of the conical shell of a reducer without a flare and the small cylinder when the value of Δ obtained from Table NC-3324.11(b)(3)-1, using the appropriate ratio P/S, is less than α.

(-a) The cross-sectional area of the reinforcement ring shall be at least equal to that indicated by the following equation:

$$A = \frac{PR_s^2}{2S}\left(1 - \frac{\Delta}{\alpha}\right)\tan\alpha \quad (3)$$

(-b) When the thickness, less corrosion allowance, of either the reducer or cylinder exceeds that required by the applicable design equation, the excess thickness may be considered to contribute to the required reinforcement ring in accordance with the following equation:

$$A_e = m\sqrt{R_s t}\left[\left(t_c - (t/\cos\alpha)\right) + \left(t_s - t\right)\right] \quad (4)$$

(-c) Any additional area of reinforcement which is required shall be situated within a distance of $\sqrt{R_s t_s}$ from the junction, and the centroid of the added area shall be within a distance of $0.5\sqrt{R_s t_s}$ from the junction.

(4) Reducers not described in (a)(3), such as those made up of two or more conical frustums having different slopes, may be designed in accordance with (5) below.

(5) When the half apex angle α is greater than 30 deg, cone-to-cylinder junctions without a knuckle may be used, with or without reinforcing rings, if the design is based on stress analysis. When a stress analysis is made, the calculated localized stresses at the discontinuity shall not exceed the following values:

(-a) membrane hoop stress plus average discontinuity hoop stress shall not be greater than $1.5S$, where the "average discontinuity hoop stress" is the average hoop stress across the wall thickness due to the discontinuity at the junction, disregarding the effect of Poisson's ratio times the longitudinal stress at the surfaces;

(-b) membrane longitudinal stress plus discontinuity longitudinal stress due to bending shall not be greater than $3S$;

(-c) the angle joint between the cone and cylinder shall be designed equivalent to a double butt welded joint and, because of the high bending stress, there shall be no weak zones around the angle joint. The thickness of the cylinder may have to be increased to limit the difference in thickness so that the angle joint has a smooth contour.

NC-3324.12 Nozzles.

(a) The wall thickness of a nozzle or other connection shall not be less than the nominal thickness of the connecting piping. In addition, the wall thickness shall not be less than the thickness computed for the applicable loadings in NC-3111 plus the thickness added for corrosion. Except for access openings and openings for inspection only, the wall thickness shall not be less than the smaller of (1) and (2) below:

(1) the required thickness of the shell or head to which the connection is attached plus the corrosion allowance provided in the shell or head adjacent to the connection;

(2) the minimum thickness[17] of standard wall pipe plus the corrosion allowance on the connection; for nozzles larger than the largest pipe size included in ASME B36.10M, the wall thickness of that largest size, plus corrosion allowance.

(b) The allowable stress value for shear in a nozzle neck shall be 70% of the allowable tensile stress for the vessel material.

NC-3324.13 Nozzle Piping Transitions. The stress limits of Table NC-3321-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NC-3334, except as provided for in NC-3324.14. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of NC-3600.

NC-3324.14 Consideration of Standard Reinforcement.

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NC-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NC-3321-1. Under these conditions, no analysis is required to demonstrate compliance for pressure-induced stresses in the nozzle region.

(b) Where external piping loads are specified, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure-induced stresses, shall meet the limits of Table NC-3321-1 for (σ_m or σ_L) + σ_b. In this case, the pressure-induced stresses in the (σ_m or σ_L) + σ_b category may be assumed to be no greater than the limit for σ_m in Table NC-3321-1 for a given condition.

NC-3324.15 Other Loadings. When necessary, vessels shall be provided with stiffeners or other additional means of support to prevent overstress or large distortions under the external loadings listed in NC-3111 other than pressure and temperature.

NC-3325 Flat Heads and Covers

The minimum thickness of unstayed flat heads, cover plates, and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to circular heads and covers. Some acceptable types of flat heads and covers are shown in Figure NC-3325-1. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extra metal required for corrosion allowance.

NC-3325.1 Nomenclature. The symbols used are defined as follows:

C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in NC-3325.3; dimensionless

d = diameter, measured as indicated in Figure NC-3325-1

h_G = gasket moment arm, equal to the radial distance from the centerline of the bolts to the line of the gasket reaction, as shown in Section III Appendices, Mandatory Appendix XI, Table XI-3221.1-2

l = length of flange of flanged heads, measured from the tangent line of knuckle, as indicated in Figure NC-3325-1, sketch (a)

m = the ratio of t_r/t_s; dimensionless

P = Design Pressure

r = inside corner radius on a head formed by flanging or forging

S = maximum allowable stress value from Section II, Part D, Subpart 1, Tables 1A, 1B, and 3

t = minimum required thickness of flat head or cover, exclusive of corrosion allowance

t_f = actual thickness of the flange on a forged head, at the large end, exclusive of corrosion allowance, as indicated in Figure NC-3325-1, sketches (b-1) and (b-2)

t_h = actual thickness of flat head or cover, exclusive of corrosion allowance

t_r = required thickness of shell, for pressure

t_s = actual thickness of shell, exclusive of corrosion allowance

W = total bolt load given for circular heads for Section III Appendices, Mandatory Appendix XI, XI-3223, eqs. (3) and (4)

NC-3325.2 Thickness. The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following two requirements.[18]

(a) Circular blind flanges of ferrous materials conforming to ASME B16.5 shall be acceptable for the diameters and pressure–temperature ratings in Tables 2 to 8 of that Standard, when of the types shown in Figure NC-3325-1, sketches (d) and (e).

(b) The minimum required thickness of flat unstayed circular heads, covers, and blind flanges shall be calculated by the equation

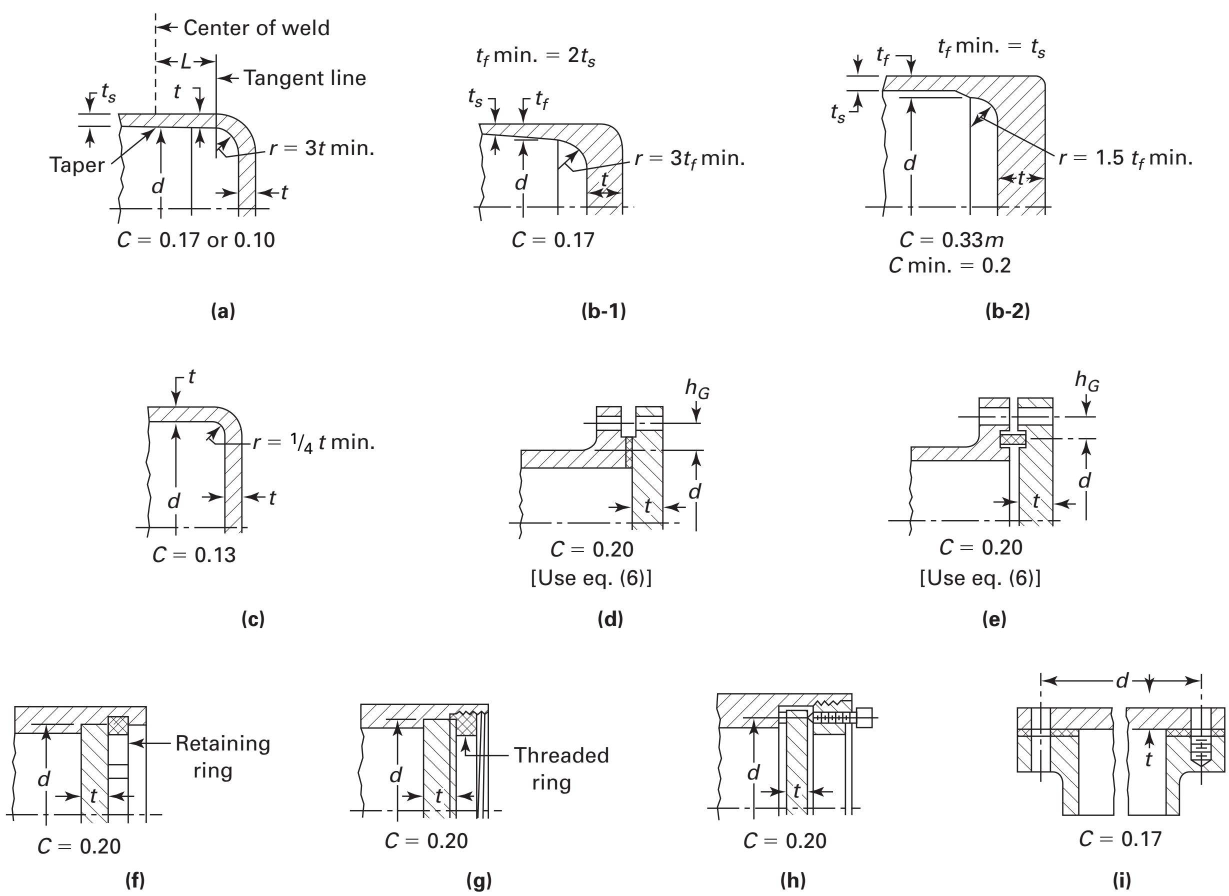
$$t = d\sqrt{CP/S} \qquad (5)$$

except when the head, cover, or blind flange is attached by bolts causing an edge moment [Figure NC-3325-1, sketches (d) and (e)], in which case the thickness shall be calculated by

$$t = d\sqrt{CP/S + 1.27Wh_G/Sd^3} \qquad (6)$$

When using eq. (6), the thickness t shall becalculated for both service loadings and gasket seating, and the greater of the two values shall be used. For service loadings, the value of P shall be the Design Pressure, and the values of S at the Design Temperature and W from Section III Appendices, Mandatory Appendix XI, XI-3223, eq. (3) shall be used. For gasket seating, P equals zero,

Figure NC-3325-1
Some Acceptable Types of Unstayed Flat Heads and Covers



and the values of S at atmospheric temperature and W from Section III Appendices, Mandatory Appendix XI, XI-3223, eq. (4) shall be used.

NC-3325.3 Values of *C*. For the types of construction shown in Figures NC-3325-1, NC-4243-1, NC-4243-2, and NC-4243.1-1, the minimum values of C to be used in eqs. NC-3325.2(b)(5) and NC-3325.2(b)(6) shall be as given in (a) through (g) for Figure NC-3325-1 and in (h) for Figures NC-4243.1-1 and NC-4243-1, in (i) for Figure NC-4243-2, and in (j) for Figure NC-4243.1-1.

(a) In sketch (a), C = 0.17 for flanged circular heads forged integral with or butt welded to the vessel with an inside corner radius not less than three times the required head thickness, with no special requirement with regard to length of flange.

(1) C = 0.10 for circular heads, when the flange length for heads of the above design is not less than

$$l = \left(1.1 - 0.8\frac{t_s^2}{t_h^2}\right)\sqrt{dt_h} \qquad (7)$$

(2) C = 0.10 for circular heads, when the flange length l is less than the requirement in (1) above but the shell thickness is not less than

$$t_s = 1.12t_h\sqrt{1.1 - l/\sqrt{dt_h}} \qquad (8)$$

for a length of at least $2\sqrt{dt_s}$.

(3) When C = 0.10 is used, the taper shall be 1:4.

(b) In sketch (b-1), C = 0.17 for forged circular heads integral with or butt welded to the vessel, where the flange thickness is not less than two times the shell thickness, the corner radius on the inside is not less than three times the flange thickness, and the welding meets all the requirements of Article NC-4000.

(c) In sketch (b-2), $C = 0.33m$ but not less than 0.2 for forged circular heads integral with or butt welded to the vessel, where the flange thickness is not less than the shell thickness and the corner radius on the inside is not less than 1.5 times the flange thickness. see Figure NC-4243.1-1 sketches (a) and (b) for the special cases where $t_f = t_s$.

(d) In sketch (c), C = 0.13 for integral flat circular heads when the dimension d does not exceed 24 in. (600 mm), the ratio of thickness of the head to the dimension d is not less than 0.05 nor greater than 0.25, the head thickness t_h is not less than the shell thickness t_s, the inside corner radius is not less than 0.25t, and the construction is obtained by special techniques of upsetting and spinning the end of the shell, such as employed in closing header ends.

(e) In sketches (d) and (e), C = 0.2 for circular heads and covers bolted to the vessel as indicated in the figures. Note that eq. NC-3325.2(b)(6) shall be used because of the extra moment applied to the cover by the bolting. When the cover plate is grooved for a peripheral gasket as shown in sketch (e), the net cover plate thickness under the groove or between the groove and the outer edge of the cover plate shall be not less than $d\sqrt{1.27Wh_G/Sd^3}$ for circular heads and covers.

(f) In sketches (f), (g), and (h), C = 0.2 for a circular plate inserted into the end of a vessel and held in place by a positive mechanical locking arrangement, and when all possible means of failure (by shear, tension, compression, or radial deformation, including flaring) resulting from pressure and differential thermal expansion are resisted using stresses consistent with this Article. Seal welding may be used, if desired.

(g) In sketch (i), C = 0.17 for circular covers, bolted with a full-face gasket, to shells, flanges, or side plates.

(h) In Figure NC-4243-1 sketches (b), (c), (e), and (f), C = 0.33m but not less than 0.3 when the dimensional requirements of NC-3358.3 are met.

(i) In Figure NC-4243.1-1, C = 0.33m but not less than 0.3 when the dimensional requirements of NC-3358.4 are met.

(j) In Figure NC-4243-2 sketches (a) and (b), C = 0.33m but not less than 0.2 when the dimensional requirements of NC-3358.3 are met.

NC-3326 Spherically Dished Covers With Bolting Flanges

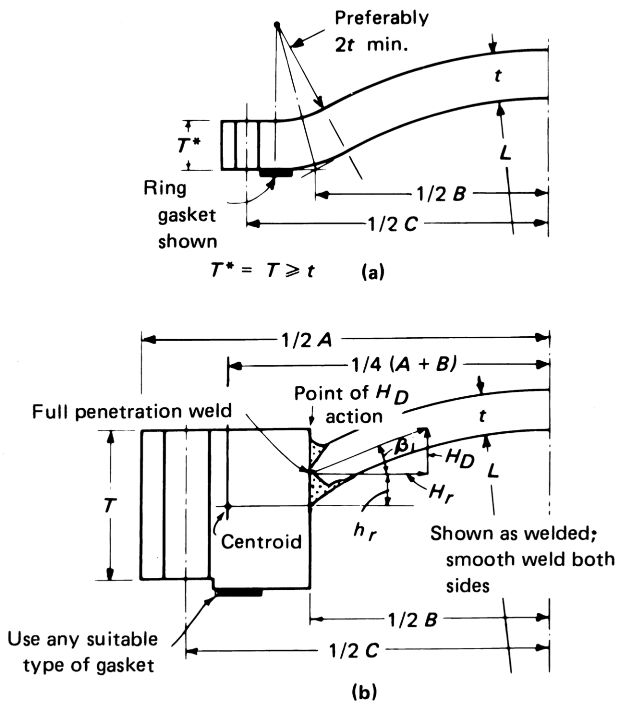
NC-3326.1 Nomenclature. The symbols used are defined as follows:

A = outside diameter of flange
B = inside diameter of flange
C = bolt circle diameter
H_D = axial component of the membrane load in the spherical segment acting at the inside of the flange ring = $0.785B^2P$
h_D = radial distance from the bolt circle to the inside of the flange ring
H_r = radial component of the membrane load in the spherical segment = $H_D \cot \beta_1$ acting at the intersection of the inside of the flange ring with the center line of the dished cover thickness
h_r = lever arm of H_r about centroid of flange ring
L = inside spherical or crown radius
M_o = the total moment determined as in Section III Appendices, Mandatory Appendix XI, XI-3230 for heads concave to pressure, and Section III Appendices, Mandatory Appendix XI, XI-3260 for heads convex to pressure; except that for heads of the type shown in Figure NC-3326.1-1 sketch (b), H_D and h_D shall be as defined above, and an additional moment, $H_r h_r$[21] shall be included
P = Design Pressure
r = inside knuckle radius
S = maximum allowable stress value
T = flange thickness
t = minimum required thickness of head plate after forming
β_1 = angle formed by the tangent to the center line of the dished cover thickness at its point of intersection with the flange ring, and a line perpendicular to the axis of the dished cover, where

$$\beta_1 = \arc \sin\left(\frac{B}{2L + t}\right)$$

NC-3326.2 Spherically Dished Heads With Bolting Flanges. Circular spherically dished heads with bolting flanges, both concave and convex to the pressure, and conforming to the several types illustrated in Figure NC-3326.1-1, shall be designed in accordance with the

Figure NC-3326.1-1
Spherically Dished Covers With Bolting Flanges



requirements of (a) and (b) below. For heads convex to pressure, the spherical segments shall be thickened, if necessary, to meet the requirements of NC-3133. The actual value of the total moment M_o may calculate to be either plus or minus for both the heads concave to pressure and the heads convex to pressure. However, for use in all of the equations which follow, the absolute values for both P and M_o shall be used.

(a) Heads of the type shown in Figure NC-3326.1-1, sketch (a):

(1) head thickness:

$$t = 5PL/6S \tag{9}$$

(2) flange thickness, T:

for ring gasket:

$$T = Q + \sqrt{\frac{1.875M_o(C + B)}{SB(7C - 5B)}} \tag{10}$$

for full face gasket:

$$T = Q + \sqrt{Q^2 + \frac{3BQ(C - B)}{L}} \tag{11}$$

where

$$Q = \frac{PL}{4S}\left(\frac{C + B}{7C - 5B}\right) \tag{12}$$

for heads with round bolting holes or where

$$Q = \frac{PL}{4S}\left(\frac{C + B}{3C - B}\right) \tag{13}$$

for heads with bolting holes slotted through edge of head;

(3) the larger of the values of t given by (1) and (2) above shall be used.

(b) Heads of the type shown in Figure NC-3326.1-1 sketch (b):

(1) head thickness:

$$t = 5PL/6S \tag{14}$$

(2) flange thickness for ring gaskets shall be calculated as follows:

(-a) for heads with round bolting holes:

$$T = Q + \sqrt{\frac{1.875M_o(C + B)}{SB(7C - 5B)}} \tag{15}$$

where

$$Q = \frac{PL}{4S}\left(\frac{C + B}{7C - 5B}\right) \tag{16}$$

(-b) for heads with bolting holes slotted through the edge of the head:

$$T = Q + \sqrt{\frac{1.875M_o(C + B)}{SB(3C - B)}} \tag{17}$$

where

$$Q = \frac{PL}{4S}\left(\frac{C + B}{3C - B}\right) \tag{18}$$

(3) flange thickness for full face gaskets shall be calculated by the following equation:

$$T = Q + \sqrt{Q^2 + \frac{3BQ(C - B)}{L}} \tag{19}$$

The value of Q in eq. (19) is calculated by eq. (2)(-a)(16) for round bolting holes or by eq. (2)(-b)(18) for bolting holes slotted through the edge of the head [see (2) above].

(4) the required flange thickness shall be T as calculated in (2) or (3) above, but in no case less than the value of t calculated in (1).

NOTE: These equations are approximate in that they do not take into account continuity between the flange ring and the dished head. A more exact method of analysis which takes this into account may be used. Such a method may parallel the method of analysis and allowable stresses for flange design in Section III Appendices, Mandatory Appendix XI. The dished portion of a cover designed under this rule may, if welded, require evaluation of any welded joint.

NC-3327 Quick Actuating Closures

Closures other than the multibolted type designed to provide access to the contents space of a component shall have the locking mechanism or locking device so designed that failure of any one locking element or component in the locking mechanism cannot result in the failure of all other locking elements and the release of the closure. Quick actuating closures shall be so designed and installed that it may be determined by visual external observation that the holding elements are in good condition and that their locking elements, when the closure is in the closed position, are in full engagement.

NC-3327.1 Positive Locking Devices. Quick actuating closures that are held in position by positive locking devices and that are fully released by partial rotation or limited movement of the closure itself or the locking mechanism and any closure that is other than manually operated shall be so designed that when the vessel is installed the conditions of (a) through (c) below are met.

(a) The closure and its holding elements are fully engaged in their intended operating position before pressure can be built up in the vessel.

(b) Pressure tending to force the closure clear of the vessel will be released before the closure can be fully opened for access.

(c) In the event that compliance with (a) and (b) is not inherent in the design of the closure and its holding elements, provision shall be made so that devices to accomplish this can be added when the vessel is installed.

NC-3327.2 Manual Operation. Quick actuating closures that are held in position by a locking device or mechanism that requires manual operation and are so designed that there will be leakage of the contents of the vessel prior to disengagement of the locking elements and release of closure need not satisfy NC-3327.1, but such closures shall be equipped with an audible or visible warning device that will serve to warn the operator if pressure is applied to the vessel before the closure and its holding elements are fully engaged in their intended position and further will serve to warn the operator if an attempt is made to operate the locking mechanism or device before the pressure within the vessel is released.

NC-3327.3 Pressure Indicating Device. When installed, all vessels having quick actuating closures shall be provided with a pressure indicating device visible from the operating area.

NC-3329 Ligaments

(a) The symbols used are defined as follows:

d = diameter of tube holes
n = number of tube holes in length p_1
p = longitudinal pitch of tube holes
p_1 = unit length of ligament
p' = diagonal pitch of tube holes

(b) When a cylindrical shell is drilled for tubes in a line parallel to the axis of the shell for substantially the full length of the shell as shown in Figures NC-3329(b)-1 through NC-3329(b)-3, the efficiency of the ligaments between the tube holes shall be determined by (1) or (2) below:

Figure NC-3329(b)-1
Example of Tube Spacing With Pitch of Holes Equal in Every Row

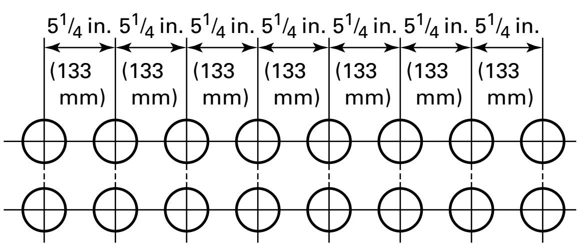
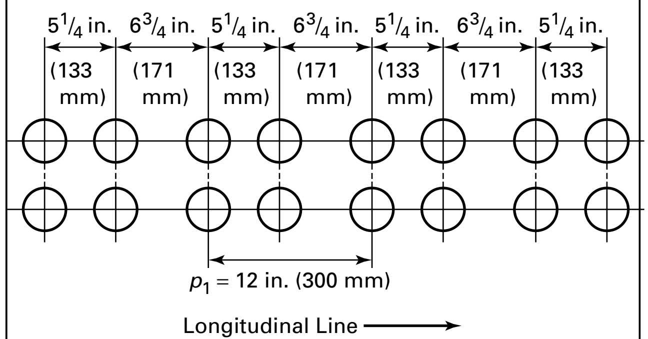


Figure NC-3329(b)-2
Example of Tube Spacing With Pitch of Holes Unequal in Every Second Row



(1) when the pitch of the tube holes on every row is equal [Figure NC-3329(b)-1], the equation is:

$$\frac{p - d}{p} = \text{efficiency of ligament}$$

(2) when the pitch of tube holes on any one row is unequal [Figures NC-3329(b)-2 and NC-3329(b)-3], the equation is:

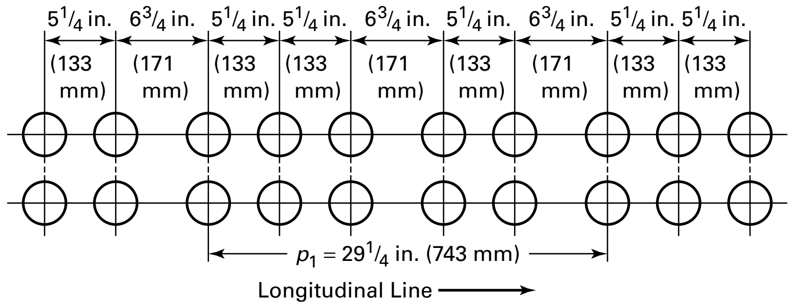
$$\frac{p_1 - nd}{p_1} = \text{efficiency of ligament}$$

(c) The strength of ligaments between tube holes measured circumferentially shall be at least 50% of the strength of ligaments of similar dimensions taken in a line parallel to the axis of the cylindrical shell.

(d) When a cylindrical shell is drilled for tube holes so as to form diagonal ligaments, as shown in Figure NC-3329(d)-1, the efficiency of these ligaments shall be that given by the diagram in Figure NC-3329(d)-2. The pitch of tube holes shall be measured either on the flat plate before rolling or on the middle line of the plate after rolling. To use the diagram in Figure NC-3329(d)-2, compute the value of p'/p_1 and also the efficiency of the longitudinal ligament. Next, find in the diagram the vertical line corresponding to the longitudinal efficiency of the ligament and follow this line vertically to the point where it intersects the diagonal line representing the ratio of p'/p_1. Then project this point horizontally to the left and read the diagonal efficiency of the ligament on the scale at the edge of the diagram. The shell thickness and the maximum allowable pressure shall be based on the ligament that has the lower efficiency.

(e) When tube holes in a cylindrical shell are arranged in symmetrical groups which extend a distance greater than the inside diameter of the shell along lines parallel to the axis and the same spacing is used for each group,

Figure NC-3329(b)-3
Example of Tube Spacing With Pitch Holes Varying in Every Second and Third Row



the efficiency for one of the groups shall be not less than the efficiency on which the maximum allowable pressure is based.

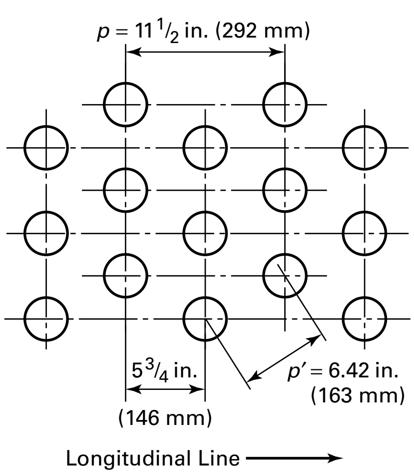
(f) The average ligament efficiency in a cylindrical shell, in which the tube holes are arranged along lines parallel to the axis with either uniform or nonuniform spacing, shall be computed by the following rules and shall satisfy the requirements of both (1) and (2) below.[22]

(1) For a length equal to the inside diameter of the shell for the position which gives the minimum efficiency, the efficiency shall not be less than that on which the maximum allowable pressure is based. When the diameter of the shell exceeds 60 in. (1 500 mm), the length shall be taken as 60 in. (1 500 mm) in applying this rule.

(2) For a length equal to the inside radius of the shell for the position which gives the minimum efficiency, the efficiency shall be not less than 80% of that on which the maximum allowable pressure is based. When the radius of the shell exceeds 30 in. (750 mm), the length shall be taken as 30 in. (750 mm) in applying this rule.

(g) For holes which are not in line, placed longitudinally along a cylindrical shell, the rules in (f) above for calculating efficiency shall hold, except that the equivalent longitudinal width of a diagonal ligament shall be used. To obtain the equivalent width, the longitudinal pitch of the two holes having a diagonal ligament shall be multiplied by the efficiency of the diagonal ligament. The efficiency to be used for the diagonal ligaments is given in Figure NC-3329(g)-1.

Figure NC-3329(d)-1
Example of Tube Spacing With Tube Holes on Diagonal Lines



NC-3330 OPENINGS AND REINFORCEMENT

NC-3331 General Requirements for Openings

(a) Openings in cylindrical or conical portions of vessels or in formed heads shall preferably be circular, elliptical, or obround. When the long dimension of an elliptical, or obround, opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

(b) Openings may be of other shapes than those given in (a) and all corners shall be provided with a suitable radius.

(c) See below.

(1) The rules for reinforcement of openings given in NC-3330 are intended to apply to openings not exceeding the following:

(-a) for vessels 60 in. (1 500 mm) diameter and less, one half the vessel diameter but not to exceed 20 in. (500 mm);

(-b) for vessels over 60 in. (1 500 mm) diameter, one-third the vessel diameter but not to exceed 40 in. (1 000 mm).

(2) Larger openings shall be given special attention. Two-thirds of the required reinforcement shall be within $\frac{1}{2}r$ parallel to the vessel surface and measured from the edge of the opening, where r is the radius of the finished opening. The limit normal to the vessel wall is the smaller

Figure NC-3329(d)-2
Diagram for Determining the Efficiency of Longitudinal and Diagonal Ligaments Between Openings in Cylindrical Shells

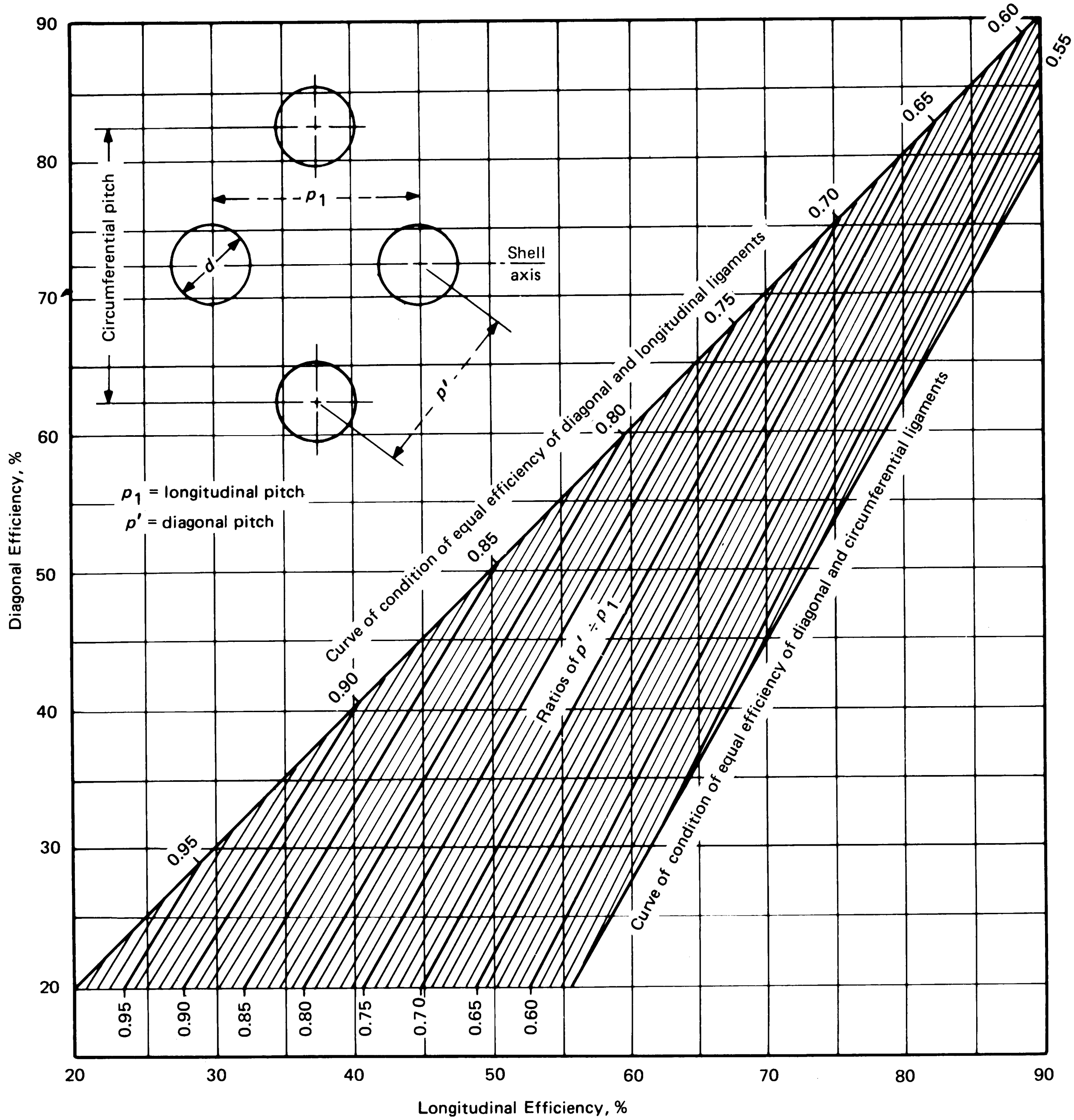
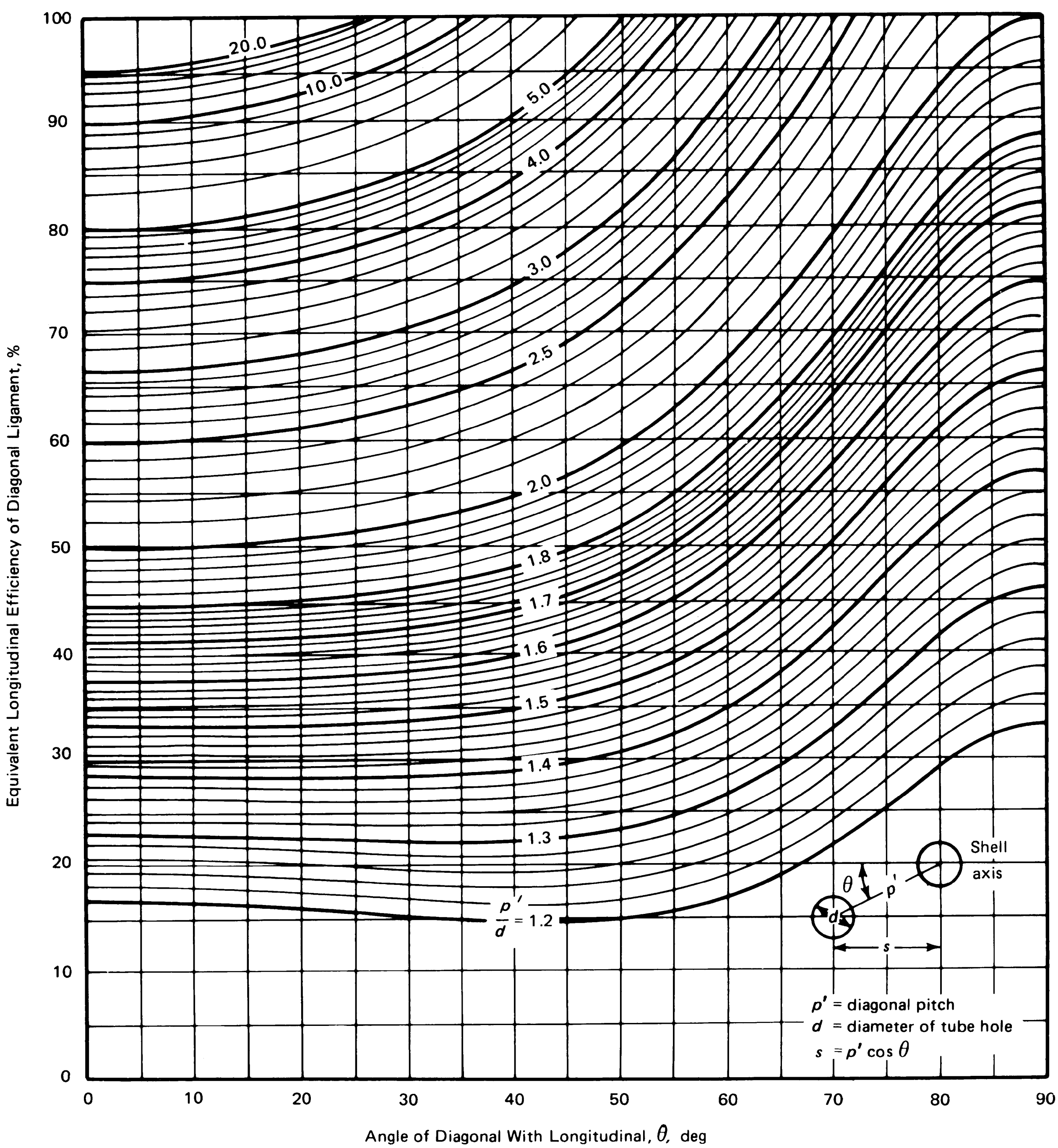


Figure NC-3329(g)-1
Diagram for Determining Equivalent Longitudinal Efficiency of Diagonal Ligaments



of the limits specified in NC-3334.2. Special consideration shall be given to the fabrication details used and examination employed. Reinforcement often may be advantageously obtained by use of heavier shell plate for a vessel course or inserted locally around the opening. Welds may be ground to concave contour and the inside corners of the opening rounded to a generous radius to reduce stress concentrations.

(d) All references to dimensions in NC-3330 apply to the finished dimensions, excluding material added as corrosion allowance.

(e) Any type of opening may be located in a welded joint.

NC-3332 Reinforcement Requirements for Openings in Shells and Formed Heads

NC-3332.1 Openings Not Requiring Reinforcement. Reinforcement shall be provided in amount and distribution such that the requirements for area of reinforcement are satisfied for all planes through the center of the opening and normal to the surface of the vessel, except that single circular openings need not be provided with reinforcement if the openings have diameters equal to or less than NPS 2 (DN 50).

NC-3332.2 Required Area of Reinforcement. The total cross-sectional area of reinforcement A, required in any given plane for a vessel under internal pressure, shall not be less than

$$A = dt_rF$$

where

d = finished diameter of a circular opening or finished dimension (chord length) of an opening on the plane being considered for elliptical and obround openings in corroded condition

F = a correction factor which compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations except that Figure NC-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.

t_r = the required thickness of a shell or head computed by the rules of this Article for the Design Pressure except that:

(a) when the opening and its reinforcement are entirely within the spherical portion of a torispherical head, t_r is the thickness required by NC-3324.8(b) using M = 1;

(b) when the opening is in a cone, t_r is the thickness required for a seamless cone of diameter D measured where the nozzle axis pierces the inside wall of the cone;

(c) when the opening and its reinforcement are in an ellipsoidal head and are located entirely within a circle, the center of which coincides with the center of the head and the diameter of which is equal to 80% of the shell diameter, t_r is the thickness required for a seamless sphere of radius K_1D, where D is the shell diameter and K_1 is given by Table NC-3332.2-1.

At least one-half of the required reinforcing shall be on each side of the center line of the opening.

NC-3332.3 Reinforcement for External Pressure. The reinforcement required for openings in vessels designed for external pressure need only be 50% of that required in the equation for area in NC-3332.2, except that t_r is the wall thickness required by the rules for vessels under external pressure.

NC-3332.4 Reinforcement for Both Internal and External Pressure. Reinforcement of vessels subject to both internal and external pressures shall meet the requirements of NC-3332.2 for internal pressure and of NC-3332.3 for external pressure.

Figure NC-3332.2-1
Chart for Determining the Value of *F*

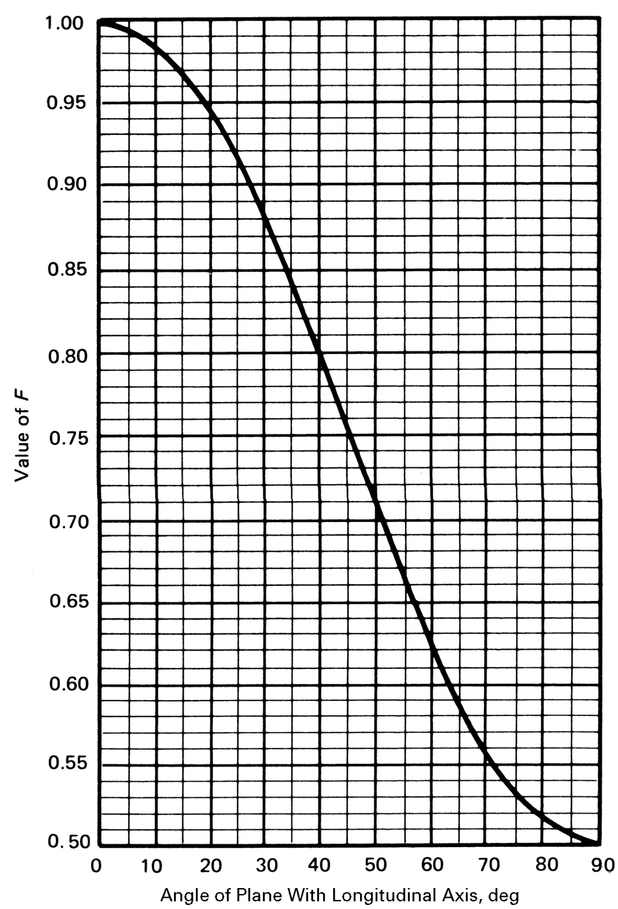


Table NC-3332.2-1
Values of Spherical Radius Factor K_1

$D/2h$	...	3.0	2.8	2.6	2.4	2.2
K_1	...	1.36	1.27	1.18	1.08	0.99
$D/2h$	2.0	1.8	1.6	1.4	1.2	1.0
K_1	0.90	0.81	0.73	0.65	0.57	0.50

GENERAL NOTE: Equivalent spherical radius = K_1D; $D/2h$ = axis ratio; interpolation is permitted for intermediate values.

NC-3333 Reinforcement Required for Openings in Flat Heads

(a) Flat heads that have an opening with a diameter that does not exceed one-half of the head diameter shall have a total cross-sectional area of reinforcement not less than that given by the equation

$$A = 0.5dt_r$$

where d is defined in NC-3332.2 and t_r is the thickness in inches which meets the requirements of NC-3325 in the absence of the opening.

(b) As an alternative to (a) above, the thickness of flat heads may be increased to provide the necessary opening reinforcement as follows:

(1) in eq. NC-3325.2(b)(5) by using $2C$ or 0.75 in place of C, whichever is less;

(2) in eq. NC-3325.2(b)(6), by doubling the quantity under the square root sign.

(c) Flat heads that have an opening with a diameter that exceeds one-half of the head diameter or shortest span, as defined in NC-3325.1, shall be designed as follows.

(1) When the opening is a single, circular, centrally located opening and when the shell–head juncture is integrally formed or integrally attached by a full penetration weld similar to those shown in Figure NC-3325-1, sketch (a), (b-1), (b-2), or (c), the head shall be designed according to Section III Appendices, Mandatory Appendix XIX and related parts of Section III Appendices, Mandatory Appendix XI. The required head thickness does not have to be calculated according to NC-3325, since the head thickness which satisfies all the requirements of Section III Appendices, Mandatory Appendix XIX also satisfies the intent of NC-3325. The opening in the head may have a nozzle which is integrally formed or integrally attached by a full penetration weld, or it may be an opening without an attached nozzle or hub.

(2) When the opening is of any other type than that described in (1) above, no specific rules are given. Consequently, the requirements of NC-1100(c) shall be met.

NC-3334 Limits of Reinforcement

The boundaries of the cross-sectional area in any plane normal to the vessel wall and passing through the center of the opening and within which metal shall be located in order to have value as reinforcement are designated as the limits of reinforcement for that plane and are given in the following subparagraphs.

NC-3334.1 Limits of Reinforcement Along the Vessel Wall. The limits of reinforcement, measured along the midsurface of the nominal wall thickness, shall meet the following:

(a) 100% of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) the diameter of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus the sum of the thicknesses of the vessel wall and the nozzle wall;

(b) two-thirds of the required reinforcement shall be within a distance on each side of the axis of the opening equal to the greater of the following:

(1) $r + 0.5\sqrt{Rt}$, where R is the mean radius of shell or head, t is the nominal vessel wall thickness, r is the radius of the finished opening in the corroded condition;

(2) the radius of the finished opening in the corroded condition plus two-thirds the sum of the thicknesses of the vessel wall and the nozzle wall.

NC-3334.2 Limits of Reinforcement Normal to the Vessel Wall. The limits of reinforcement, measured normal to the vessel wall, shall conform to the contour of the surface at a distance from each surface equal to the lesser of (a) or (b) below:

(a) $2^1/_2$ times the nominal shell thickness less corrosion allowance;

(b) $2^1/_2$ times the nozzle wall thickness less corrosion allowance, plus the thickness of any added reinforcement exclusive of weld metal on the side of the shell under consideration.

NC-3335 Metal Available for Reinforcement

NC-3335.1 Openings. Metal within the limits of reinforcement that may be considered to have reinforcing value shall be that given in (a) through (d) below:

(a) metal in the vessel wall over and above the thickness required to resist pressure and the thickness specified as corrosion allowance. The area in the vessel wall available as reinforcement is the larger of the values of A_1 given by:

$$A_1 = (t - Ft_r)d$$

or

$$A_1 = 2(t - Ft_r)(t + t_n)$$

(b) metal over and above the thickness required to resist pressure and the thickness specified as corrosion allowance in that part of a nozzle wall extending outside the vessel wall. The maximum area in the nozzle wall available as reinforcement is the lesser of the values of A_2 given by:

$$A_2 = (t_n - t_{rn})5t$$

or

$$A_2 = (t_n - t_{rn})(5t_n + 2t_e)$$

(c) all metal in the nozzle wall extending inside the vessel wall may be included after proper deduction for corrosion allowance on all the exposed surface is made. No allowance shall be taken for the fact that a differential pressure on an inwardly extending nozzle may cause opposing stress to that of the stress in the shell around the opening where

A_1 = area in excess thickness in the vessel wall available for reinforcement (NC-3334)
A_2 = area in excess thickness in the nozzle wall available for reinforcement (NC-3334)
d = diameter in the plane under consideration of the finished opening in its corroded condition (NC-3332.2)
F = a correction factor that compensates for the variation in pressure stresses on different planes with respect to the axis of a vessel. A value of 1.00 shall be used for all configurations, except that Figure NC-3332.2-1 may be used for integrally reinforced openings in cylindrical shells and cones.
t = nominal thickness of the vessel wall, less corrosion allowance
t_e = thickness of attached reinforcing pad or height of the largest 60 deg right triangle supported by the vessel and nozzle outside diameter projected surfaces and lying completely within the area of integral reinforcement [Figure NC-3335(b)-1]
t_n = nominal thickness of nozzle wall, less corrosion allowance
t_r = required thickness of a seamless shell or head as defined in NC-3332.2
t_{tn} = required thickness of a seamless nozzle wall

(d) metal added as reinforcement and metal in attachment welds.

NC-3335.2 Reinforcement of Multiple Openings.

(a) When any two openings in a group of two or more openings are spaced at less than two times their average diameter so that their limits of reinforcement overlap, the two openings shall be reinforced in the plane connecting the centers (Figure NC-3335.2-1) in accordance with NC-3330 through NC-3336, with a combined reinforcement that has an area equal to the combined area of the reinforcement required for separate openings. No portion of the cross section is to be considered as applying to more than one opening, or to be evaluated more than once in a combined area. The following additional requirements shall also apply.

(1) When the distance between the centers of the openings is greater than $1^1/_3$ times their average diameter, the area of reinforcement between them shall not be less than 50% of the total required for these openings.

(2) When the distance between the centers of the openings is less than $1^1/_3$ times their average diameter, no credit for reinforcement shall be taken for any of the material between these openings, and the openings shall be reinforced as described in (b) below.

(b) Any number of adjacent openings, in any arrangement, may be reinforced for an assumed opening of a diameter enclosing all such openings. The diameter of the assumed opening shall not exceed the following:

(1) for vessels 60 in. (1 500 mm) in diameter and less, one-half the vessel diameter, but not to exceed 20 in. (500 mm)

(2) for vessels over 60 in. (1 500 mm) in diameter, one-third the vessel diameter, but not to exceed 40 in. (1 000 mm)

(c) When a group of openings is reinforced by a thicker section butt welded into the shell or head, the edges of the inserted section shall be tapered as prescribed in NC-3361.

(d) When a series of two or more openings in a pressure vessel is arranged in a regular pattern, reinforcement of the openings may be provided in accordance with the requirements of NC-3329.

NC-3335.3 Flued Openings in Formed Heads.

(a) Flued openings in formed heads made by inward or outward forming of the head plate shall meet the requirements for reinforcement in NC-3332.

(b) The minimum depth of flange of a flued opening exceeding 6 in. (150 mm) in any inside dimension, when not stayed by an attached pipe or flue, shall equal $3t_r$ or $(t_r + 3)$ in. [$(t_r + 75)$ mm], whichever is less, where t_r is the required head thickness. The depth of flange shall be determined by placing a straight edge across the side opposite the flued opening along the major axis and measuring from the straight edge to the edge of the flanged opening [Figure NC-3335.3(b)-1].

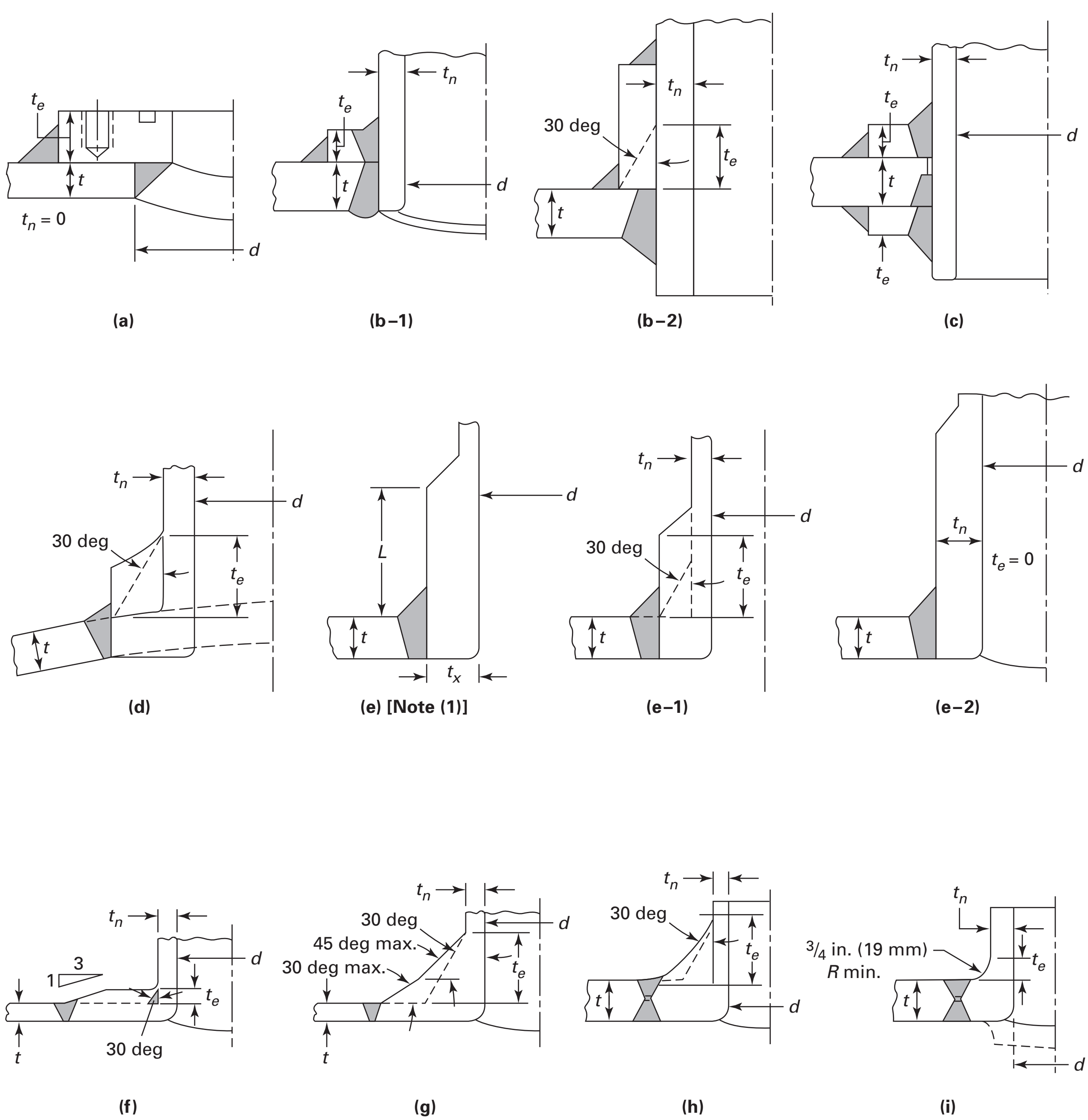
(c) The minimum width of bearing surface for a gasket on a self-sealing flued opening shall be in accordance with NC-3363.7.

NC-3336 Strength of Reinforcing Material

Material used for reinforcement shall preferably be the same as that of the vessel wall. If the material of the nozzle wall or reinforcement has a lower design stress value S than that for the vessel material, the amount of area provided by the nozzle wall or reinforcement in satisfying the requirements of NC-3332 shall be taken as the actual

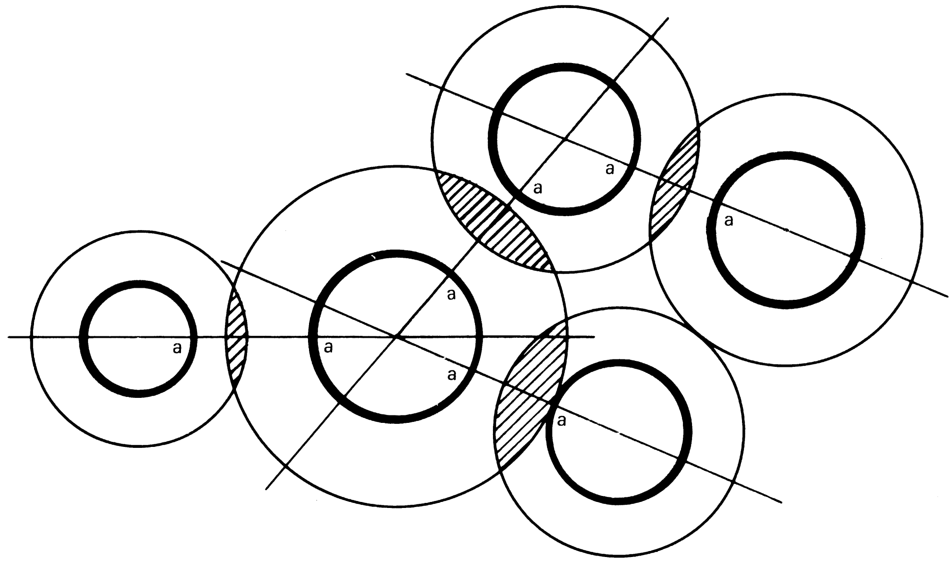
(15)

Figure NC-3335(b)-1
Some Representative Configurations Describing the t_e Reinforcement Dimension



NOTE:
(1) If $L < 2.5t_x$, use sketch (e-1). If $L \geq 2.5t_x$, use sketch (e-2).

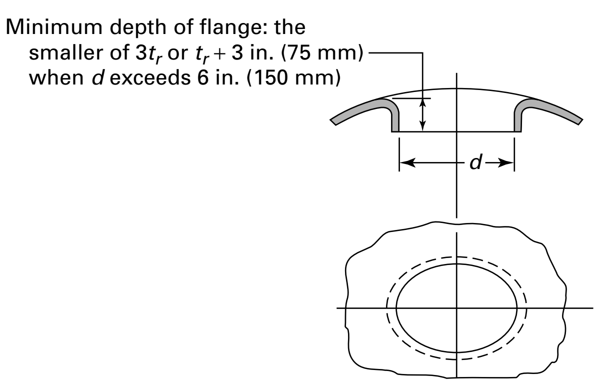
Figure NC-3335.2-1
Arrangement of Multiple Openings



GENERAL NOTES:
(a) Hatched area represents overlapping of the reinforcement limits.
(b) Each cross section indicated by a straight line a–a must be investigated for adequacy of reinforcement.
(c) Heavy circles represent openings, and light circles represent limits of reinforcement.

area provided multiplied by the ratio of the nozzle or reinforcement material design stress value to the vessel material design stress value. No reduction in the reinforcing required shall be taken for the increased strength of reinforcing material and weld metal having higher design stress values than that of the material of the vessel wall. Deposited weld metal outside of either the vessel wall or any reinforcing pad used as reinforcement shall be credited with an allowable stress value equivalent to the weaker of the materials connected by the weld. Vessel-to-nozzle or pad-to-nozzle attachment weld metal within the vessel wall or within the pad may be credited with a stress value equal to that of the vessel wall or pad, respectively.

Figure NC-3335.3(b)-1
Minimum Depth for Flange of Flued Openings



NC-3336.1 Strength of Weld. On each side of the plane defined in NC-3334, the strength of the attachment joining the vessel wall and reinforcement or any two parts of the attached reinforcement shall be at least equal to the lesser of (a) or (b) below:

(a) the strength in tension of the cross section of the element of reinforcement being considered;

(b) the strength in tension of the area defined in NC-3332 less the strength in tension of the reinforcing area which is integral in the vessel wall.

NC-3336.2 Strength of Attachment. The strength of the attachment joint shall be considered for its entire length on each side of the plane of the area of reinforcement defined in NC-3334. For obround openings, consideration shall also be given to the strength of the attachment joint on one side of the plane transverse to the parallel sides of the opening which passes through the center of the semicircular end of the opening.

NC-3350 DESIGN OF WELDED CONSTRUCTION

NC-3351 Welded Joint Categories

The term *category* defines the location of a joint in a vessel but not the type of joint. The categories are for use in specifying special requirements regarding joint type and method of examination for certain welded joints.

Since these special requirements, which are based on service, material, and thickness, do not apply to every welded joint, only those joints to which special requirements apply are included in the categories. The special requirements apply to joints of a given category only when specifically stated. The joints included in each category are designated as joints of Categories A, B, C, and D. Figure NC-3351-1 illustrates typical joint locations included in each category.

NC-3351.1 Category A. Category A comprises longitudinal welded joints within the main shell, communicating chambers,[23] transitions in diameter, or nozzles; any welded joint within a sphere, within a formed or flat head, or within the side plates[24] of a flat-sided vessel; circumferential welded joints connecting hemispherical heads to main shells, to transitions in diameters, to nozzles, or to communicating chambers.

(15) **NC-3351.2 Category B.** Category B comprises circumferential welded joints within the main shell, communicating chambers,[23] nozzles, or transitions in diameter including joints between the transition and a cylinder at either the large or small end; circumferential welded joints connecting formed heads other than hemispherical to main shells, to transitions in diameter, to nozzles, or to communicating chambers.

(15) **NC-3351.3 Category C.** Category C comprises welded joints connecting flanges, Van Stone laps, tubesheets, or flat heads to main shell, to formed heads, to transitions in diameter, to nozzles, or to communicating chambers[23] and any welded joint connecting one side plate[22] to another side plate of a flat-sided vessel.

(15) **NC-3351.4 Category D.** Category D comprises welded joints connecting communicating chambers[23] or nozzles to main shells, to spheres, to transitions in diameter, to heads, or to flat-sided vessels and those joints connecting nozzles to communicating chambers. For nozzles at the small end of a transition in diameter, see Category B.

NC-3352 Permissible Types of Welded Joints

The design of the vessel shall meet the requirements for each category of joint. Butt joints are full penetration joints between plates or other elements that lie approximately in the same plane. Category B angle joints between plates or other elements that have an offset angle α not exceeding 30 deg are considered as meeting the requirements for butt joints. Figure NC-3352-1 shows typical butt welds for each category joint.

NC-3352.1 Joints of Category A. All welded joints of Category A shall meet the fabrication requirements of NC-4241 and shall be capable of being examined in accordance with NC-5210.

NC-3352.2 Joints of Category B. All welded joints of Category B shall meet the fabrication requirements of NC-4242 and shall be capable of being examined in accordance with NC-5220.

NC-3352.3 Joints of Category C. All welded joints of Category C shall meet the fabrication requirements of NC-4243 and shall be capable of being examined in accordance with NC-5230.

NC-3352.4 Joints of Category D. All welded joints of Category D shall be in accordance with the requirements of NC-3359 and one of (a) through (e) below.

Figure NC-3351-1
Welded Joint Locations Typical of Categories A, B, C, and D

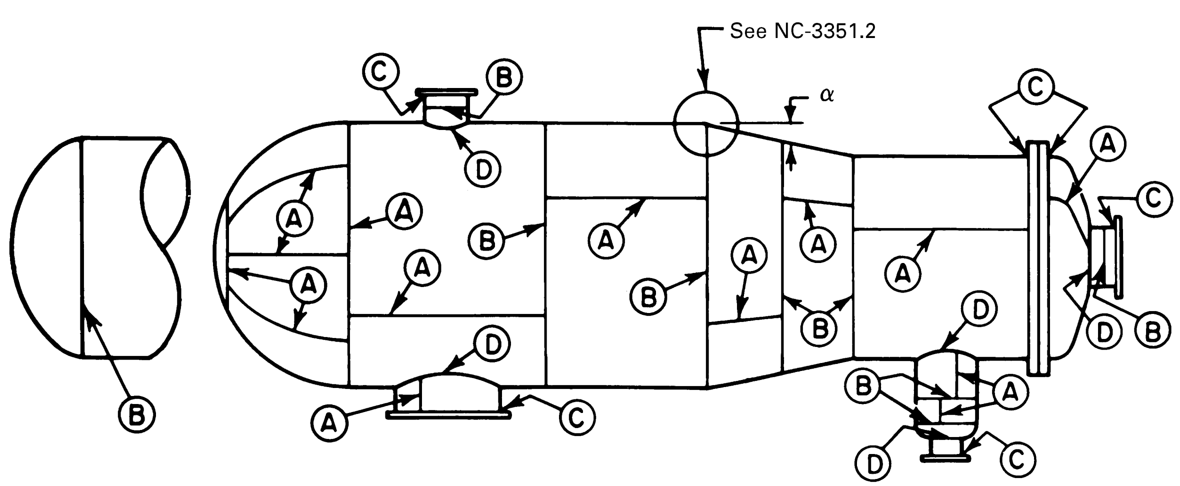
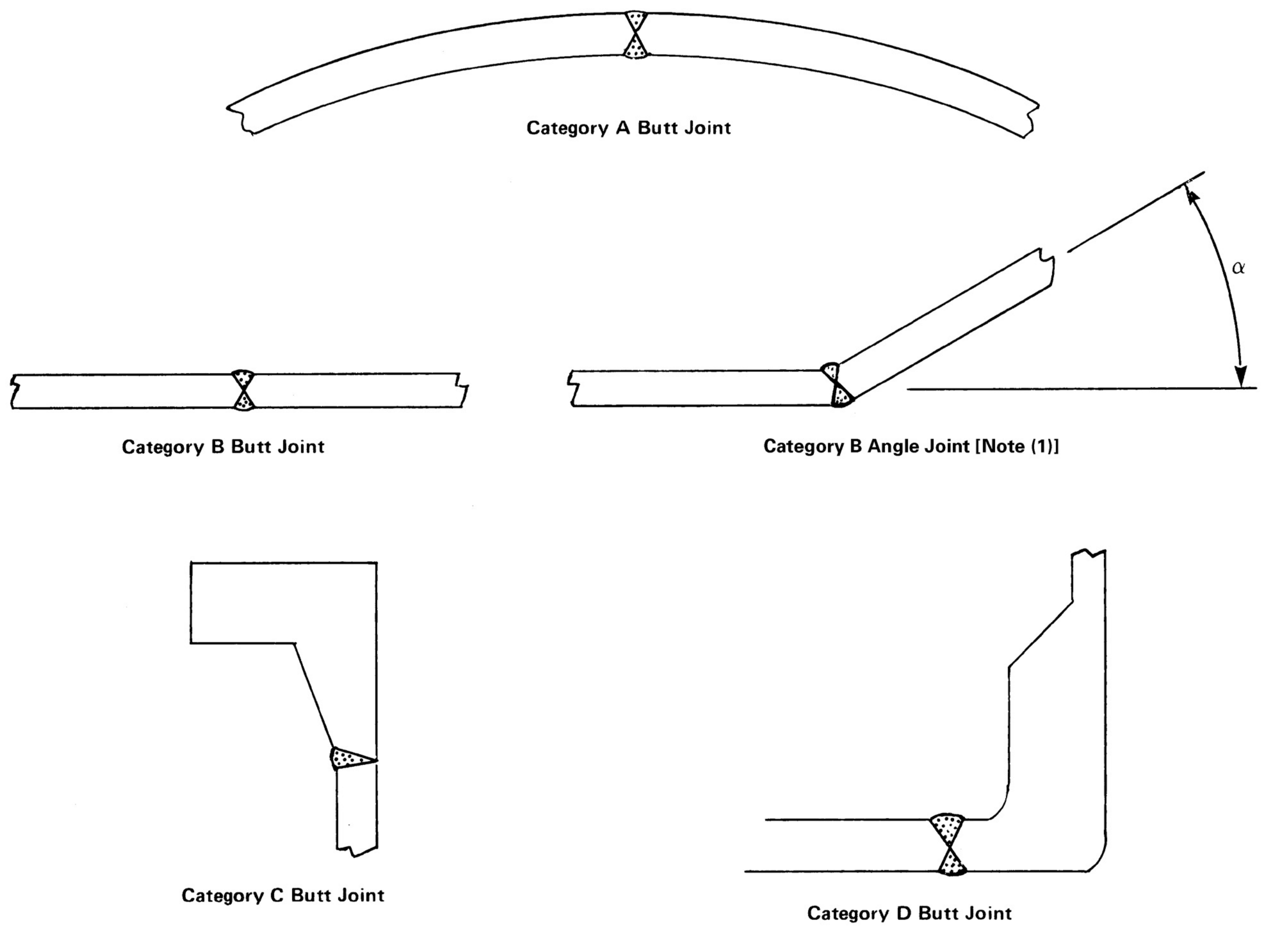


Figure NC-3352-1
Typical Butt Joints (15)



NOTE:
(1) When α does not exceed 30 deg, joint meets requirements for butt joints.

(a) Butt Welded Nozzles. Nozzles shall meet the fabrication requirements of NC-4244(a) and shall be capable of being examined in accordance with NC-5241. The minimum dimensions and geometrical requirements of Figure NC-4244(a)-1 shall be met where:

r_1 = $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2 = $\frac{1}{4}$ in. (6 mm), min.
t = nominal thickness of part penetrated
t_n = nominal thickness of penetrating part

(b) Full Penetration Corner Welded Nozzles. Nozzles shall meet the fabrication requirements of NC-4244(b) and shall be capable of being examined as required in NC-5241. Inserted type necks having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of $\frac{1}{2}t_{min}$. The minimum dimensions of Figure NC-4244(b)-1 shall be met where:

r_1 = $\frac{1}{4}t$ or $\frac{3}{4}$ in. (19 mm), whichever is less
r_2 = $\frac{1}{4}$ in. (6 mm), min.
t = nominal thickness of part penetrated
t_e = thickness of reinforcing element
t_{min} = the lesser of $\frac{3}{4}$ in. (19 mm) or the thickness of the thinner of the parts joined
t_n = nominal thickness of penetrating part
t_c = $0.7t_n$ or $\frac{1}{4}$ in. (6 mm), whichever is less

(c) Use of Deposited Weld Metal for Openings and Nozzles

(1) Nozzles shall meet the requirements of NC-4244(c) and shall be capable of being examined in accordance with NC-5241.

(2) When the deposited weld metal is used as reinforcement, the coefficients of thermal expansion of the base metal, the weld metal, and the nozzle shall not differ by more than 15% of the lowest coefficient involved.

(3) The minimum dimensions of Figure NC-4244(c)-1 shall be met where:

r_1 = $^1/_4 t$ or $^3/_4$ in. (19 mm), whichever is less
t = nominal thickness of part penetrated
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_n = nominal thickness of penetrating part

(4) The corners of the end of each nozzle, extending less than $\sqrt{dt_n}$ beyond the inner surface of the part penetrated, shall be rounded to a radius of one-half the thickness t_n of the nozzle or $^3/_4$ in. (19 mm), whichever is less.

(d) Attachment of Nozzles Using Partial Penetration Welds

(1) Partial penetration welds shall meet the requirements of NC-4244(d) and are limited to those used to connect nozzles NPS 2 (DN 50) or less, as shown in Figure NC-4244(d)-1. For inserted nozzles without reinforcing elements, two partial penetration welds may be used of any desired combination of fillet, single bevel, and single J-welds. Inserted-type nozzles having added reinforcement in the form of a separate reinforcing plate shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of $^1/_2 t_{min}$. The welds attaching the nozzle to the vessel wall and to the reinforcement shall consist of one of the combinations given in (-a) through (-c) below:

(-a) a single bevel or single J-weld in the shell plate and a single bevel and single J-weld in each reinforcement plate. The dimension t_w of each weld shall be not less than $0.7t_{min}$ [Figure NC-4244(d)-1 sketch (g)].

(-b) a full penetration groove weld in the shell plate and a fillet, single bevel, or single J-weld with a weld dimension t_w not less than $0.7t_{min}$ in each reinforcement plate [Figure NC-4244(d)-1 sketch (f)];

(-c) a full penetration groove weld in each reinforcement plate and a fillet, single bevel, or single J-weld with a weld dimension t_w not less than $0.7t_{min}$ in the shell plate [Figure NC-4244(d)-1 sketch (e)]. These welds shall be capable of being examined in accordance with the requirements of NC-5241.

(2) The minimum dimensions of Figure NC-4244(d)-1 shall be met where:

C = $^1/_2 t_{min}$
t = nominal thickness of part penetrated
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_e = thickness of reinforcement element
t_{min} = the lesser of $^3/_4$ in. (19 mm) or the thickness of the thinner of the parts joined
t_n = nominal thickness of penetrating part

$t_1 + t_2$ = $1^1/_4 t_{min}$; t_1 or t_2 not less than the lesser of $^1/_4$ in. (6 mm) or $0.7t_{min}$
t_w = $0.7t_n$ except $t_w = 0.7t_{min}$ for sketch (e)

(e) Attachment of Fittings With Internal Threads.[25] The attachment of internally threaded fittings shall meet the requirements of (1) through (3) below:

(1) Except as provided for in (2) and (3), the provisions of NC-4244(e) shall be met. The minimum weld dimensions shall be as shown in Figure NC-4244(e)-1 where:

t_{min} = lesser of $^3/_4$ in. (19 mm) or the thickness of the parts joined
t_c = $^1/_4$ in. (6 mm), min.

Sketches (a) and (b)

$$t_1 + t_2 = 1\frac{1}{4}t_{min}$$

Sketch (c)

t_w = thickness of Sch. 160 pipe (ASME B36.10M) $t_1 + t_2$ not less than the lesser of $^1/_4$ in. (6 mm) or $0.7t_{min}$

Sketch (d)

$t_w = 0.7t_{min}$

(2) Fittings shown in Figure NC-4244(e)-1 sketches (a-2), (b-2), (c-2), and (d) not exceeding NPS 2 (DN 50) may be attached by welds that are exempt from size requirements other than those specified in NC-3359;

(3) See below.

(-a) when internally threaded fittings and bolting pads not exceeding NPS 3 (DN 80) are attached to vessels having a wall thickness not greater than $^3/_8$ in. (10 mm) by a fillet weld deposited from the outside only, the welds shall comply with the dimensions shown in Figure NC-4244(e)-2. These openings do not require reinforcement other than that inherent in the construction as permitted in NC-3332.1.

(-b) if the opening exceeds $5^3/_8$ in. (135 mm) in any direction or is greater than one-half the vessel diameter, the opening shall be reinforced in accordance with NC-3332 with the nozzle or other connections attached, using a suitable detail in Figure NC-4244(e)-1.

NC-3354 Structural Attachment Welds

Welds for structural attachments shall meet the requirements of NC-4430.

NC-3355 Welding Grooves

The dimensions and shape of the edges to be joined shall be such as to permit complete fusion and complete joint penetration, except as otherwise permitted in NC-3352.4.

NC-3356 Fillet Welds

(a) Fillet welds may be used as strength welds within the limitations given in NC-3352 and Figure NC-4427-1. Particular care shall be taken in the layout of joints in which fillet welds are to be used in order to assure complete fusion at the root of the fillet.

(b) Corner or tee joints may be made with fillet welds, provided the plates are properly supported independently of such welds, except that independent supports are not required for joints used for lugs or clips.

(c) The allowable load on fillet welds shall equal the product of the weld area based on minimum leg dimensions, the allowable stress value in tension of the material being welded, and a joint efficiency of 0.55.

NC-3357 Welded Joints Subject to Bending Stresses

Except where specific details are permitted in other paragraphs, fillet welds shall be added where necessary to reduce stress concentration. The requirements of NC-3356(b) apply.

NC-3358 Design Requirements for Head Attachments

NC-3358.1 Skirt Length of Formed Heads.

(a) Ellipsoidal and other types of formed heads, concave or convex to the pressure, shall have a skirt length not less than that shown in Figure NC-3358.1(a)-1.

(b) A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections, as shown in Figure NC-3358.1(a)-1, shall be provided at joints between formed heads and shells that differ in thickness by more than one-fourth the thickness of the thinner section or by more than $^1/_8$ in. (3 mm), whichever is less. When a taper is required on any formed head thicker than the shell and intended for butt welded attachment [Figure NC-3358.1(a)-1], the skirt shall be long enough so that the required length of taper does not extend beyond the tangent line.

NC-3358.2 Unstayed Flat Heads Welded to Shells. The requirements for the attachment of unstayed flat heads welded to shells are given in NC-3325, NC-3358.3, and NC-3358.4.

NC-3358.3 Head Attachments Using Corner Joints. When shells, heads, or other pressure parts are welded to a forged or rolled plate to form a corner joint, as in Figures NC-4243-1 and NC-4243-2, the joint shall meet the applicable requirements of (a) through (f) below.

(a) On the cross section through the welded joint, the line of fusion between the weld metal and the forged or rolled plate being attached shall be projected on planes both parallel to and perpendicular to the surface of the plate being attached, in order to determine the dimensions a and b, respectively.

(b) For flange rings of bolted flanged connections and for flat heads and unsupported tubesheets with a projection having holes for a bolted connection, the sum of a and b shall be not less than three times the nominal thickness of the abutting pressure part.

(c) For supported tubesheets with a projection having holes for a bolted connection, the sum of a and b shall not be less than two times the nominal wall thickness of the abutting pressure part. A supported tubesheet is defined as one in which not less than 80% of the pressure load on the tubesheet is carried by tubes, stays, or braces.

(d) For other components, the sum of a and b shall be not less than two times the nominal wall thickness of the abutting pressure part. Examples of such components are flat heads and supported and unsupported tubesheets without a projection having holes for a bolted connection.

(e) Other dimensions of the joint shall be in accordance with details shown in Figures NC-4243-1 and NC-4243-2 where:

(1) Figure NC-4243-1

Sketches (a), (b), and (c)

(-a) for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle not greater than 45 deg measured from the face:

t, t_n = nominal thickness of welded parts
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_w = the lesser of $t_n/2$ or $t/4$

(-b) for all other material forms and for forged tubesheets, forged flat heads, and forged flanges with the weld preparation bevel angle greater than 45 deg measured from the face:

t, t_n = nominal thicknesses of welded parts
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_w = the lesser of t_n or $t/2$

Sketch (d)

t, t_n = nominal thickness of welded parts, in., either leg of fillet weld = 0.25 t_n but not less than $^1/_4$ in. (6 mm)

Sketches (e) and (f)

t, t_n = nominal thickness of welded parts
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less

(2) Figure NC-4243-2

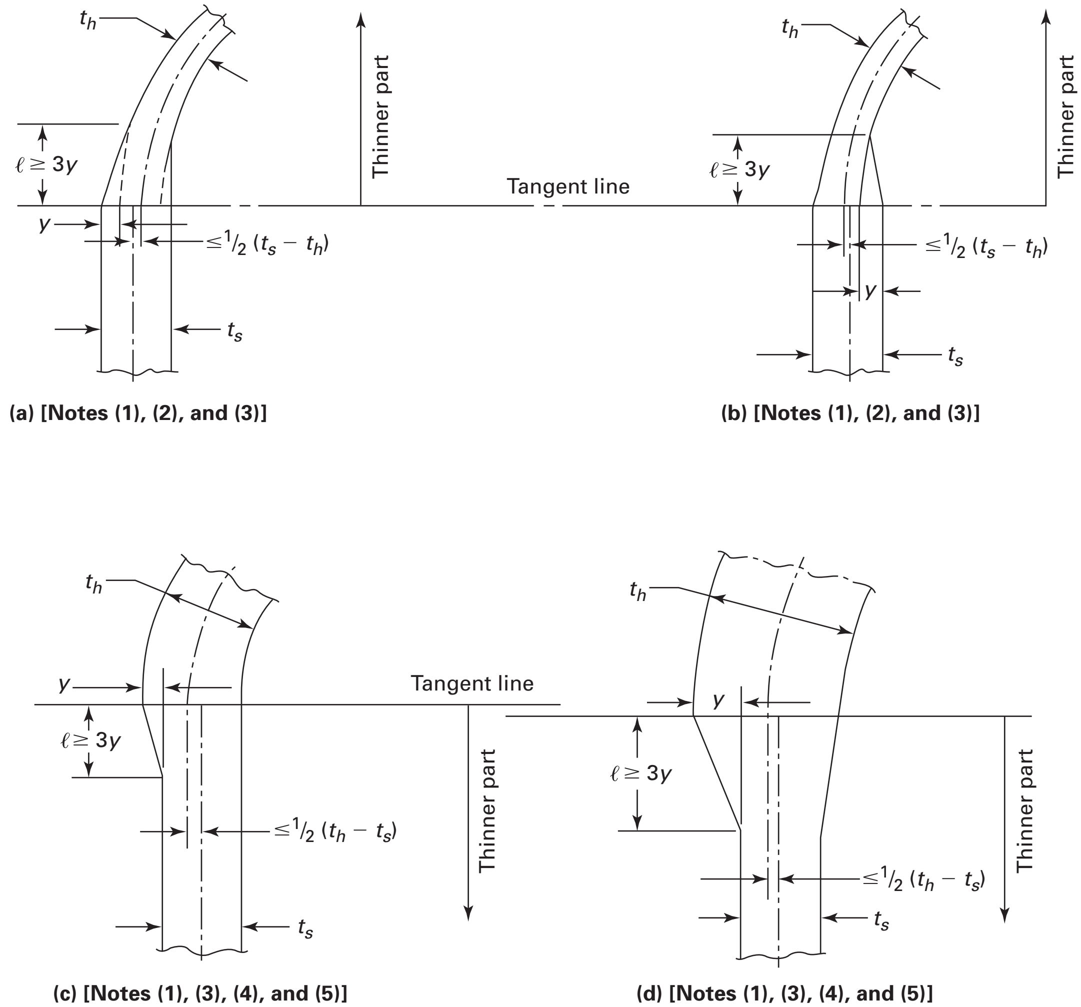
Sketch (a)
$a + b$ not less than $2t_s$
t_w not less than t_s
t_s = actual thickness of shell
t_p not less than t_s

Sketch (b)
$a + b$ not less than $2t_s$
t_s = actual thickness of shell

Sketch (c)
t_s = actual thickness of shell
t_r = required thickness of shell
for supported tubesheets:

(15)

Figure NC-3358.1(a)-1
Heads Attached to Shells



NOTES:
(1) Length of required taper ℓ may include the width of the weld.
(2) In all cases, the projected length of taper ℓ shall be not less than $3y$.
(3) The shell plate centerline may be on either side of the head plate centerline.
(4) In all cases, ℓ shall be not less than 3 times y when t_n exceeds $1.25t_s$; minimum length of skirt is $3t_h$, but need not exceed $1\frac{1}{2}$ in. (38 mm) except when necessary to provide required length of taper.
(5) When t_h is equal to or less than $1.25t_s$, length of skirt shall be sufficient for any required taper.

c not less than $0.7t_s$ or $1.4t_r$, whichever is less
$a + b$ not less than $2t_s$

for flange rings, flat heads, and unsupported tubesheets:

c not less than t_s or $2t_r$, whichever is less
$a + b$ not less than $3t_s$

Sketch (d)

t_s = actual thickness of shell
t_r = required thickness of shell
$a + b$ not less than $3t_s$
c not less than t_s

(f) In Figure NC-4243-1,

t, t_n = nominal thicknesses
t_c = $0.7t_n$ or $^1/_4$ in. (6 mm), whichever is less
t_w = the lesser of t_n or $t/2$

(g) Joint details that have a dimension through the joint less than the thickness of the shell, head, or other pressure part, or that provide eccentric attachment are not permissible.

NC-3358.4 Flat Heads and Tubesheets With Hubs. Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Figure NC-4243.1-1, shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize if necessary) taken in this direction and as close to the hub as is practical. In Figure NC-4243.1-1, the minimum dimensions are as follows:

Sketch (a)
r not less than $1.5t_s$

Sketch (b)
r not less than $1.5t_s$ and e not less than t_s

Sketch (c)
h not less than $1.5t_s$

Sketch (d)
t_f not less than $2t_s$
r not less than $3t_f$

Sketch (e)
t_f not less than $2t_s$
r not less than $3t_f$
e not less than t_f

NC-3359 Design Requirements for Nozzle Attachment Welds

In addition to the requirements of NC-3352.4, the minimum design requirements for nozzle attachment welds are given in (a) and (b) below.

(a) Required Weld Strength. Sufficient welding shall be provided on either side of the line through the center of the opening parallel to the longitudinal axis of the shell to develop the strength of the reinforcing parts as required in NC-3336, through shear or tension in the weld, whichever is applicable. The strength of groove welds shall be based on the area subjected to shear or to tension. The strength of fillet welds shall be based on the area subjected to shear, computed on the minimum leg dimension. The inside diameter of a fillet weld shall be used in figuring its length. Calculations are not required when full penetration welds are used.

(b) Allowable Stress Values for Welds. The allowable stress values for groove and fillet welds and for shear in nozzles, in percentage of stress values for the vessel material, are as follows:

(1) nozzle wall shear, 70%

(2) groove weld tension, 74%

(3) groove weld shear, 60%

(4) fillet weld shear, 49%

NC-3360 SPECIAL VESSEL REQUIREMENTS

NC-3361 Tapered Transitions

A tapered transition having a length not less than three times the offset between the adjacent surfaces of abutting sections (Figure NC-3361-1) shall be provided at joints between sections that differ in thickness by more than one-fourth of the thickness of the thinner section or by more than $^1/_8$ in. (3 mm), whichever is less. The transition may be formed by any process that will provide a uniform taper. The weld may be in the tapered section or adjacent to it. This also applies when there is a reduction in thickness within a spherical shell or cylindrical shell course and to a taper at a Category A joint within a formed head. Provisions for tapers at circumferential butt welded joints connecting formed heads to main shells are contained in NC-3358.1(b).

NC-3362 Bolted Flange and Studded Connections

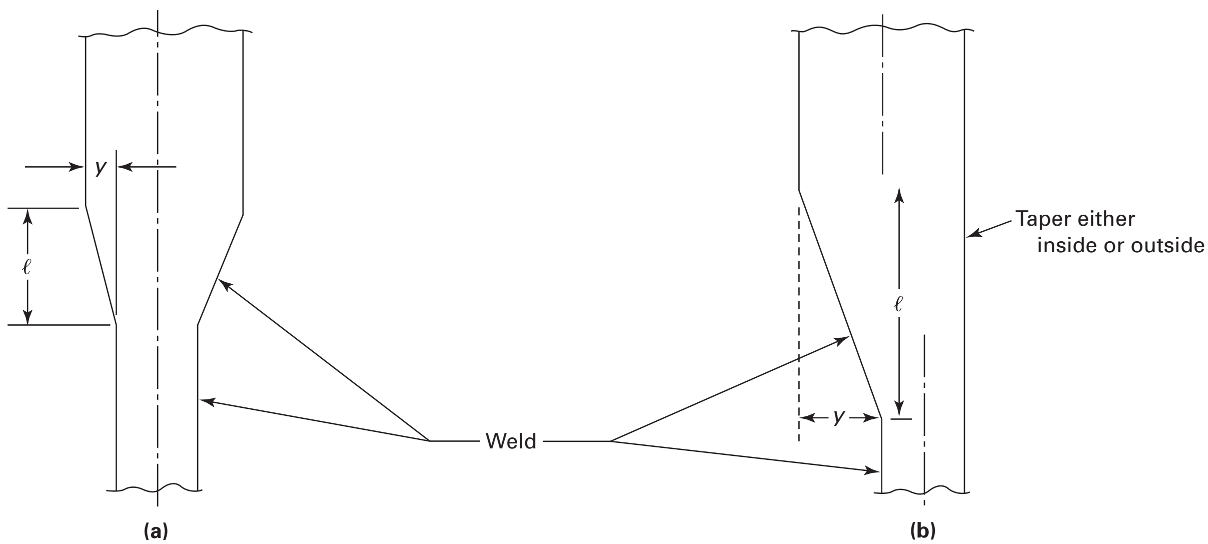
(a) It is recommended that the dimensional requirements of bolted flange connections to external piping conform to ASME B16.5, Steel Pipe Flanges and Flanged Fittings or ASME B16.47, Large Diameter Steel Flanges. Such flanges and flanged fittings may be used for the pressure–temperature ratings given in the appropriate standard. Flanges and flanged fittings to other standards may be used, provided they have been designed in accordance with the rules of Section III Appendices, Mandatory Appendix XI for the vessel design loadings and are used within the pressure–temperature ratings so determined.

(b) Where tapped holes are provided for studs, the threads shall be full and clean and shall engage the stud for a length not less than the larger of d_s or

$$0.75d_s \times \frac{\text{Maximum allowable stress value of stud material at Design Temperature}}{\text{Maximum allowable stress value of tapped material at Design Temperature}}$$

in which d_s is the diameter of the stud. The thread engagement need not exceed $1^1/_2 d_s$.

Figure NC-3361-1
Butt Welding of Sections of Unequal Thicknesses



GENERAL NOTES:
(a) In all cases ℓ shall be not less than $3y$.
(b) $\ell \geq 3y$, where ℓ is required length of taper and y is the offset between the adjacent surfaces of abutting sections.
(c) Length of required taper, ℓ, may include the width of the weld.

NC-3363 Access or Inspection Openings[26]

NC-3363.1 General Requirements.

(a) All vessels for use with compressed air, except as otherwise permitted, and those subject to internal corrosion or having parts subject to erosion or mechanical abrasion shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning.

(b) Vessels over 12 in. (300 mm) inside diameter under air pressure which also contain other substances which will prevent corrosion need not have openings for inspection only, provided the vessel contains suitable openings through which inspection can be made conveniently and provided such openings are equivalent in size and number to the requirements for inspection openings in NC-3363.3.

(c) Compressed air is not intended to include air which has had moisture removed to the degree that it has an atmospheric dew point of −50°F (−45°C) or less. The Certificate Holder's Data Report shall include a statement "for noncorrosive service" when inspection openings are not provided.

(d) When provided with telltale holes complying with the provisions of (e) below, inspection openings as required in NC-3363 may be omitted in vessels subject only to corrosion. This provision does not apply to vessels for compressed air.

(e) Telltale holes may be used to provide some positive indication when the thickness has been reduced to a dangerous degree. When telltale holes are provided, they shall be at least $^{3}/_{16}$ in. (5 mm) in diameter and have a depth not less than 80% of the thickness required for a seamless shell of like dimensions. These holes shall be provided in the surface opposite to that where deterioration is expected.

NC-3363.2 Requirements for Vessels 12 in. (300 mm) Inside Diameter and Smaller. For vessels 12 in. (300 mm) or less in inside diameter, openings for inspection only may be omitted if there are at least two removable pipe connections not less than NPS $^{3}/_{4}$ (DN 20).

NC-3363.3 Requirements for Vessels Over 12 in. (300 mm), but Not Over 16 in. (400 mm) Inside Diameter. Vessels over 12 in. (300 mm) but not over 16 in. (400 mm) inside diameter, that are to be installed so that they may be disconnected from an assembly to permit inspection, need not be provided with openings for inspection only, if there are at least two removable pipe connections not less than NPS $1^{1}/_{2}$ (DN 40).

NC-3363.4 Equipment of Vessels Requiring Access or Inspection Openings. Vessels that require access or inspection openings shall be equipped as required in (a) through (f) below.

(a) All vessels less than 18 in. (450 mm) and over 12 in. (300 mm) inside diameter shall have at least two handholes or two plugged, threaded inspection openings of not less than NPS $1^{1}/_{2}$ (DN 40).

(b) All vessels 18 in. to 36 in. (450 mm to 900 mm), inclusive inside diameter, shall have a manhole or at least two handholes or two threaded pipe plug inspection openings of not less than NPS 2 (DN 50).

(c) All vessels over 36 in. (900 mm) inside diameter shall have a manhole, except that those whose shape or use makes one impracticable shall have at least two handholes 4 in. × 6 in. (100 mm × 150 mm) or two equal openings of equivalent area.

(d) When handholes or pipe plug openings are permitted for inspection openings in place of a manhole, one handhole or one pipe plug opening shall be in each head or in the shell near each head.

(e) Openings with removable heads or cover plates intended for other purposes may be used in place of the required inspection openings, provided they are equal at least to the size of the required inspection openings.

(f) A single opening with removable head or cover plate may be used in place of all the smaller inspection openings, provided it is of such size and location as to afford at least an equal view of the interior.

NC-3363.5 Size and Type of Access and Inspection Openings. When inspection or access openings are required, they shall comply at least with the requirements of (a) and (b) below.

(a) An elliptical or obround manhole shall be not less than 11 in. × 15 in. (275 mm × 375 mm) or 10 in. × 16 in. (250 mm × 400 mm). A circular manhole shall be not less than 15 in. (375 mm) inside diameter.

(b) A handhole opening shall be not less than 2 in. × 3 in. (50 mm × 75 mm) but should be as large as is consistent with the size of the vessel and the location of the opening.

NC-3363.6 Design of Access and Inspection Openings in Shells and Heads. All access and inspection openings in a shell or unstayed head shall be designed in accordance with the rules for openings.

NC-3363.7 Minimum Gasket Bearing Width for Manhole Cover Plates. Manholes of the type in which the internal pressure forces the cover plate against a flat gasket shall have a minimum gasket bearing width of $^{11}/_{16}$ in. (17 mm).

NC-3363.8 Threaded Openings. When a threaded opening is to be used for inspection or cleaning purposes, the closing plug or cap shall be of a material suitable for the pressure and no material shall be used at a temperature exceeding the maximum temperature allowed for that material. The thread shall be a standard taper pipe thread, except that a straight thread of equal strength may be used if other sealing means to prevent leakage are provided.

NC-3364 Attachments

Attachments used to transmit support loads shall meet the requirements of NC-3135.

NC-3365 Supports

All vessels shall be so supported and the supporting members shall be arranged or attached to the vessel wall in such a way as to withstand the maximum imposed loadings (NC-3111 and Subsection NF).

NC-3366 Bellows Expansion Joints

Expansion joints of the bellows type may be used to provide flexibility for vessels. Expansion joints in piping portions of vessels shall meet the requirements of NC-3649. The design, material, fabrication, examination, and testing of expansion joints which are constructed as a part or appurtenance of a vessel shall comply with the requirements of (a) through (i) below.

(a) Bellows may be used to absorb axial movement, lateral deflection, angular rotation, or any combination of these movements. They are not normally designed for absorbing torsion. The layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

(b) In all systems containing bellows, the hydrostatic end force caused by either pressure or the bellows spring force or both shall be resisted by rigid anchors, cross connections of the expansion joint ends, or other means.

(c) The expansion joint shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up for deficiencies in length or offset to accommodate connecting parts which are not properly aligned, unless such movements have been specified by the system designer or can be justified by the expansion joint manufacturer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Internal sleeves shall be provided for expansion joints over 6 in. (150 mm) diameter when flow velocities exceed the following values:

(1) air, steam, and other gases — 25 ft/sec (7.5 m/s);

(2) water and other liquids — 10 ft/sec (3.0 m/s).

(g) Pressure-retaining materials in the expansion joint shall comply with the requirements of Article NC-2000.

(h) All welded joints shall comply with the requirements of NC-4400.

(i) Design of bellows type expansion joints shall comply with the requirements of NC-3649.4.

NC-3400 PUMP DESIGN

NC-3410 GENERAL REQUIREMENTS FOR CENTRIFUGAL PUMPS

NC-3411 Scope

NC-3411.1 Applicability. The rules of NC-3400 apply to (a) through (j) below:

(a) pump casings
(b) pump inlets and outlets
(c) pump covers
(d) clamping rings
(e) seal housings, seal glands, and packing glands
(f) related bolting
(g) pump internal heat exchanger piping
(h) pump auxiliary nozzle connections up to the face of the first flange or circumferential joint in welded connections excluding the connecting weld
(i) piping identified with the pump and external to and forming part of the pressure-retaining boundary and supplied with the pump
(j) external and internal integral attachments to the pressure-retaining boundary

Hydrostatic test of seal glands and packing glands is not required.

NC-3411.2 Exemptions. The rules of NC-3400 do not apply to (a) through (c) below:

(a) pump shafts and impellers (shafts may be designed in accordance with Section III Appendices, Nonmandatory Appendix S)
(b) nonstructural internals
(c) seal packages

NC-3412 Acceptability

The requirements for the design of pumps are given in (a) and (b) below.

(a) The design shall be such that the requirements of NC-3100 are satisfied.
(b) The rules of this subarticle are met.

NC-3413 Design Specification

Design and Service Conditions (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). Loads from thermal expansion, deadweight, and applicable seismic forces from the connected piping shall be included in the Design Specification.

NC-3414 Design and Service Conditions

The general design considerations, including definitions, of NC-3100 plus the requirements of NC-3320, NC-3330, NC-3361, and NC-3362 are applicable to pumps. The pump shall conform to the requirements of NC-3400. The stress limits listed in NC-3416 shall be used for the specified Design and Service Conditions. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, or any design equations, which have been demonstrated to be satisfactory, may be used.

NC-3415 Loads From Connected Piping

Loads imposed on pump inlets and outlets by connected piping shall be considered in the pump casing design.

NC-3416 Stress and Pressure Limits for Design and Service Conditions

Stress[20] limits for Design and Service Conditions are specified in Table NC-3416-1. The symbols used in Table NC-3416-1 are defined as follows:

S = allowable stress value, given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3. The allowable stress shall correspond to the highest metal temperature of the section under consideration during the condition under consideration.

σ_b = bending stress. This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress. This stress is the same as σ_m except that it includes the effect of discontinuities.

σ_m = general membrane stress. This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

NC-3417 Earthquake Loadings

(a) The effects of earthquake shall be considered in the design of pumps, pump supports, and restraints. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

(b) Where pumps are provided with drivers on extended supporting structures and these structures are essential to maintaining pressure integrity, an analysis shall be performed when required by the Design Specifications.

NC-3418 Corrosion

The requirements of NC-3121 apply.

NC-3419 Cladding

Cladding dimensions used in the design of pumps shall be required as in NC-3122.

Table NC-3416-1
Stress and Pressure Limits for Design and Service Loadings

Service Limit	Stress Limits [Note (1)]	P_{max} [Note (2)]
Level A	$\sigma_m \leq S$ $(\sigma_m$ or $\sigma_L) + \sigma_b \leq 1.5S$	1.0
Level B	$\sigma_m \leq 1.1S$ $(\sigma_m$ or $\sigma_L) + \sigma_b \leq 1.65S$	1.1
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m$ or $\sigma_L) + \sigma_b \leq 1.8S$	1.2
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m$ or $\sigma_L) + \sigma_b \leq 2.4S$	1.5

NOTES:
(1) These requirements for acceptability of pump design are not intended to ensure the operability of the pump.
(2) The maximum pressure shall not exceed the tabulated factors listed under P_{max} times the Design Pressure.

NC-3420 DEFINITIONS

NC-3421 Radially Split Casing

A radially split casing shall be interpreted as one in which the primary sealing joint is radially disposed around the shaft.

NC-3422 Axially Split Casing

An axially split casing shall be interpreted as one in which the primary sealing joint is axially disposed with respect to the shaft.

NC-3423 Single and Double Volute Casings

Figures NC-3423-1 and NC-3423-2 show typical single and double volute casings, respectively.

NC-3424 Seal Housing

A seal housing is defined as that portion of the pump cover or casing assembly which contains the seal and forms a part of the primary pressure boundary.

NC-3425 Typical Examples of Pump Types

Figures NC-3441.1-1 through NC-3441.9-2 are intended to be typical examples to aid in the determination of a pump type and are not considered as limiting.

NC-3430 DESIGN REQUIREMENTS FOR CENTRIFUGAL PUMPS

NC-3431 Design of Welded Construction

(a) The design of welded construction shall be in accordance with NC-3350.

Figure NC-3423-1
Typical Single Volute Casing

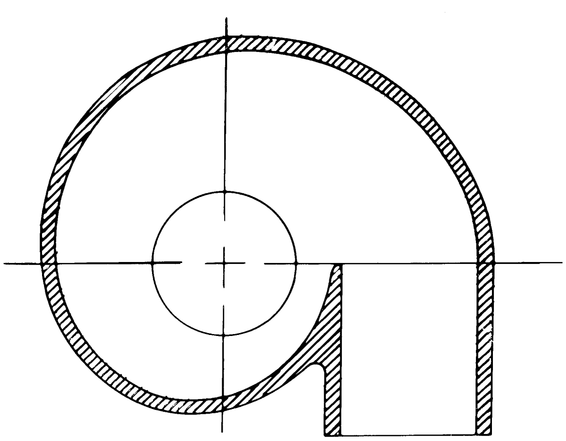
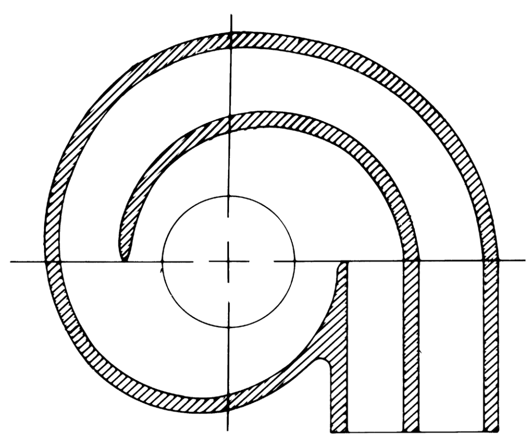


Figure NC-3423-2
Typical Double Volute Casing



(b) Partial penetration welds, as shown in Figure NC-4244(e)-1 sketch (c-3) and Figure NC-4266(d)-1 sketches (a) and (b), are allowed for nozzles such as vent and drain connections and openings for instrumentation. Nozzles shall not exceed NPS 2 (DN 50). For such nozzles, all reinforcement shall be integral with the portion of the shell penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles.

NC-3432 Flanged Connections

(15) **NC-3432.1 Pressure Design.**

(a) Pumps with flanged connections that are cast integrally with the casing and meet all dimensional requirements (including tolerances) of flanged fittings (as shown in Table NCA-7100-1) with regard to the flange dimensions and required wall thicknesses, shall be considered to meet the pressure design requirements of this subarticle and are suitable for use within the pressure–temperature range shown in Section III Appendices, Mandatory Appendix I for the material utilized.

(b) Flanged connections not meeting the requirements of (a) shall be designed in accordance with Section III Appendices, Mandatory Appendix XI, Article XI-3000 or Section III Appendices, Nonmandatory Appendix L, Article L-3000.

(c) Pump flanges meeting all requirements of Table NCA-7100-1 and welded onto the integral inlets and outlets of the casing, shall be considered as meeting the pressure design requirements of this subarticle, provided that the inlet and outlet wall thicknesses comply with the standard flanged fitting. However, the nozzle-to-flange welds shall meet the requirements of NC-1130.

NC-3432.2 External Loads. When external nozzle loads interact with pumps, it is very likely that operability will dictate the maximum allowable loads. The major areas of concern are distortion of the casing and misalignment of driver and driven equipment. The casing shall be capable of withstanding the external loading plus the design pressure, provided in the Design Specification, without distortion that would impair the operation of the pump. In addition, the pump supports shall be capable of accomodating the external loads without sustaining any significant displacements that would cause unacceptable misalignment of rotating parts.

(a) Flanged connections meeting the requirements of NC-3432.1 do not require futher analysis when all requirements of NC-3658.2 or NC-3658.3 are met. All other flanged connections shall all meet the requirements of (b) below.

(b) Flanged connections shall meet the requirements of NC-3658.1.

NC-3433 Reinforcement of Pump Casing Inlets and Outlets

NC-3433.1 Axially Oriented Inlets and Outlets.

(a) An axially oriented pump casing inlet or outlet shall be considered similar to an opening in a vessel and shall be reinforced. It shall be treated as required in NC-3330.

(b) To avoid stress concentrations, the outside radius r_2 of Figures NC-3441.1(a)-1 and NC-3441.3-2 shall not be less than one-half the thickness of the inlets and outlets as reinforced.

NC-3433.2 Radially Oriented Inlets and Outlets. Reinforcement of radially oriented inlets and outlets is required. The applicable portions of NC-3330 shall apply.

NC-3433.3 Tangential Inlets and Outlets. Except as modified in NC-3433.4, any design method which has been demonstrated to be satisfactory for the specified Design Loadings may be used.

NC-3433.4 Minimum Tangential Inlet and Outlet Wall Thicknesses. In Figure NC-3433.4-1, the value of l, in. (mm), shall be determined from the relationship

$$l = 0.5\sqrt{r_m t_m}$$

where

r_i = maximum inlet or outlet inside radius, in. (mm)
= $d_i/2$
r_m = $r_i + 0.5t_m$, in. (mm)
t_m = mean inlet or outlet wall thickness, in. (mm), taken between section x–x and a parallel section y–y tangent to crotch radius

The wall thickness of the inlet and outlet shall not be less than the minimum wall thickness of the casing for a distance l as shown in Figure NC-3433.4-1. The wall thickness beyond the distance l may be reduced to the minimum wall thickness of the connected piping. The change in wall thickness shall be gradual and have a maximum slope as indicated in Figure NC-4250-1.

NC-3434 Bolting

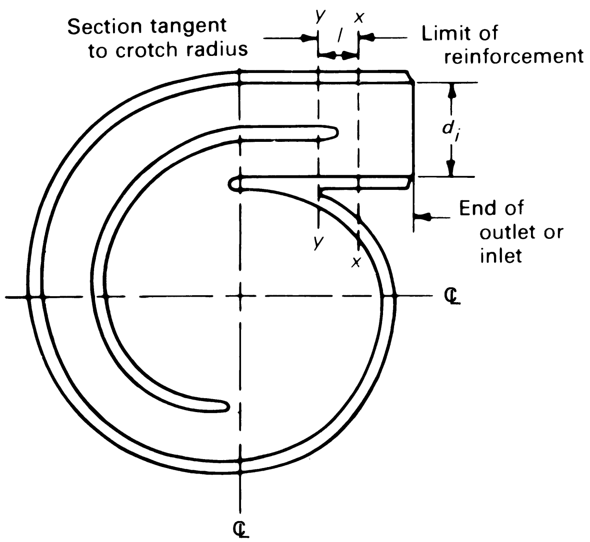
NC-3434.1 Radially Split Configurations. Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Section III Appendices, Mandatory Appendix XI.

NC-3434.2 Axially Split Configurations. Bolting in axially split configurations shall be designed in accordance with the procedure given in NC-3441.7 for Type G pumps.

NC-3435 Piping

NC-3435.1 Piping Under External Pressure. Piping located within the pressure-retaining boundary of the pump shall be designed in accordance with NC-3640.

Figure NC-3433.4-1
Minimum Tangential Inlet and Outlet Wall Thickness



NC-3435.2 Piping Under Internal Pressure. Piping identified with the pump and external to or forming a part of the pressure-retaining boundary, such as auxiliary water connections, shall be designed in accordance with NC-3640.

NC-3436 Attachments

(a) External and internal attachments to pumps shall be designed so as not to cause excessive localized bending stresses or harmful thermal gradients in the pump. The effects of stress concentrations shall be considered.

(b) Attachments shall meet the requirements of NC-3135.

NC-3437 Pump Covers

Pump covers shall be designed in accordance with NC-3325 or NC-3326. Covers for which specific design rules are not given in NC-3325 or NC-3326 shall be designed by any method shown by analysis or experience to be satisfactory.

NC-3438 Supports

Pump supports shall be designed in accordance with the requirements of Subsection NF, unless included under the rules of NC-3411.1(j).

NC-3440 DESIGN OF SPECIFIC PUMP TYPES

NC-3441 Standard Pump Types

NC-3441.1 Design of Type A Pumps. Type A pumps are those having single volutes and radially split casings with a single suction as illustrated in Figures NC-3441.1-1 and NC-3441.1-2. Pumps with nozzle sizes NPS 4 (DN 100) discharge and smaller shall be constructed in accordance with (a) through (e). Larger pumps are permitted as stipulated in (f).

(a) Casing Wall Thickness. Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t which is determined as follows:

$$t = (PA)/S$$

or 0.25 in. (6 mm), whichever is greater, where

A = scroll dimension, in. (mm), inside casing as shown in Figure NC-3441.1(a)-1. If the value of dimension A exceeds 20 in. (500 mm), the equation shall not be used and (f) below applies.
P = Design Pressure, psig (MPa gage)
S = allowable stress, including casting factor, psi (MPa) (NC-2571 and Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)
t = minimum allowable wall thickness, in. (mm)

(b) Cutwater Tip. The cutwater tip radius shall not be less than 0.05t.

(c) Cutwater Fillets. All cutwater fillets, including the tips, where they meet the casing wall, shall have a minimum radius of 0.10t or 0.25 in. (6 mm), whichever is greater.

(d) Crotch Radius [*Figure NC-3441.1(a)-1*]. The crotch radius shall not be less than 0.3t.

(e) Bottom of Casing. That section of the pump casing within the diameter defined by dimension A in Figure NC-3441.1(a)-1 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness the greater of t from (a) or t_b. The value of t_b shall be determined by methods of NC-3300 or Section III Appendices, Nonmandatory Appendix A using the appropriate equations for the casing shape or by methods permitted in Section III Appendices, Mandatory Appendix XIII.

Figure NC-3441.1-1
Type A Pump

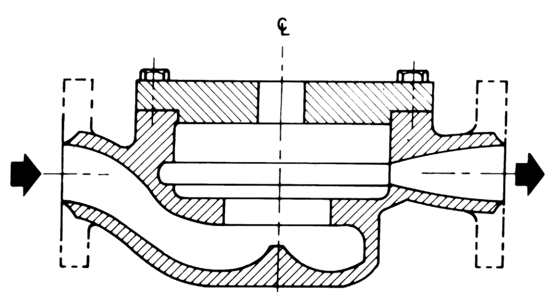
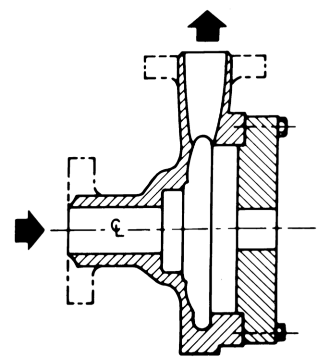


Figure NC-3441.1-2
Type À Pump



(f) Pumps with an "A" dimension greater than 20 in. (500 mm) or nozzles larger than NPS 4 (DN 100) discharge are permitted. Design of these larger pumps must be performed in accordance with Section III Appendices, Mandatory Appendix II, Experimental Stress Analysis, or Section III Appendices, Mandatory Appendix XIII, Design Based on Stress Analysis for Vessels. If the design is qualified by analysis, the analysis shall be certified in accordance with NCA-3551.1.

NC-3441.2 Design of Type B Pumps. Type B pumps are those having single volutes and radially split casings with double suction as illustrated in Figure NC-3441.2-1. Any design method that has been demonstrated to be satisfactory for the specified design conditions may be used.

NC-3441.3 Design of Type C Pumps. Type C pumps are those having double volutes and radially split casings with single suction as illustrated in Figures NC-3441.3-1 and NC-3441.3-2. The splitter is considered a structural part of the casing. Their design shall be in accordance with the requirements of this subarticle and with those given in (a) through (e) below.

(a) Casing Wall Thickness. Except where specifically indicated in these rules, no portion of the casing wall shall be thinner than the value of t determined as follows:

$$t = (0.5PA)/S$$

where

A = scroll dimension inside casing as shown in Figure NC-3441.3-2, in. (mm)
P = Design Pressure, psig (MPa gage)
S = allowable stress, including casting factor, psi (MPa) (NC-2571 and Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)
t = minimum allowable wall thickness, in. (mm)

Figure NC-3441.1(a)-1
Type A Pump

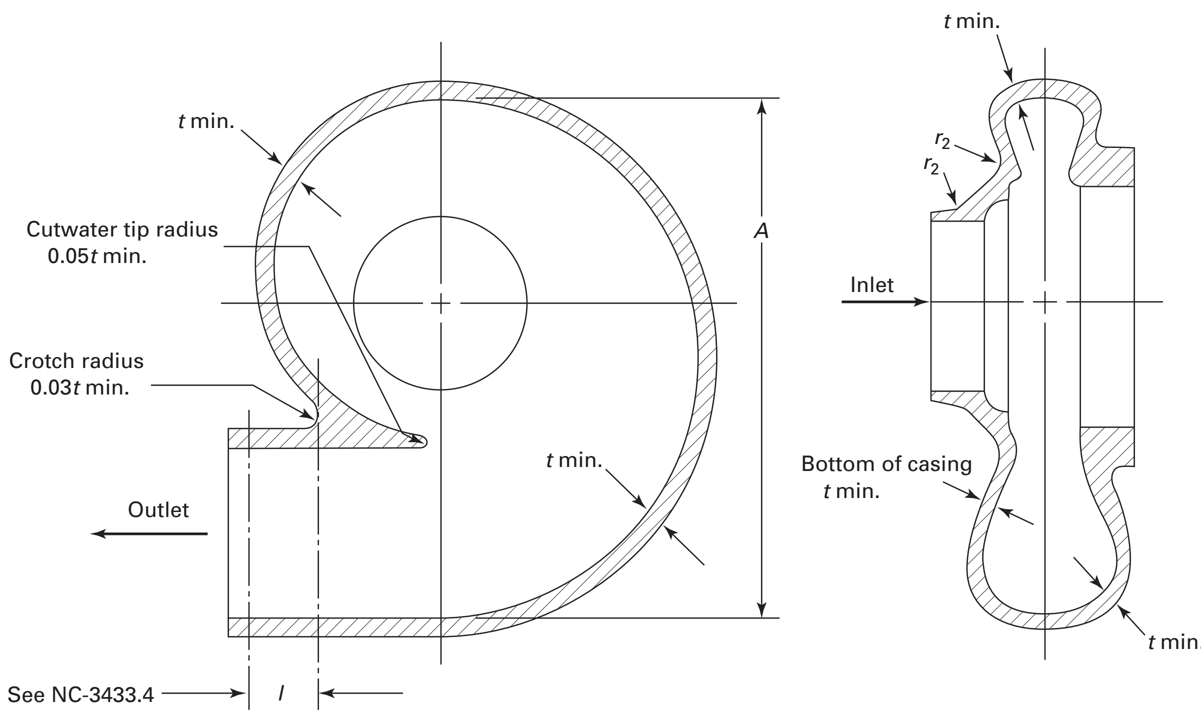
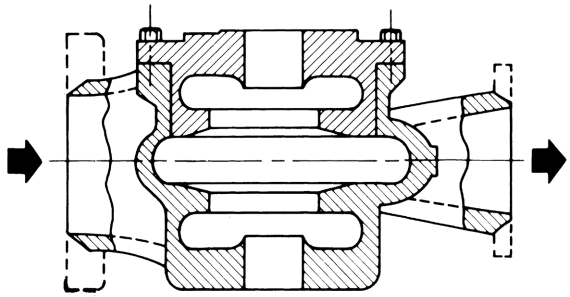


Figure NC-3441.2-1
Type B Pump



(b) Splitter Wall Thickness

(1) The splitter, which is considered a structural part of the casing, shall have a minimum wall thickness of 0.7t as determined above for the casing wall and shall extend from point B in Figure NC-3441.3-2 sketch (a) through a minimum angle of 135 deg to point C. Beyond point C, the splitter wall may be reduced in thickness and tapered to blend with the cutwater tip radius.

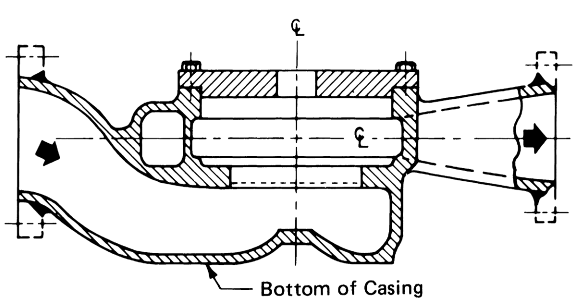
(2) Cutwater tip and splitter tip radii shall not be less than 0.05t.

(3) All cutwater and splitter fillets, including the tips, where they meet the casing wall, shall have a minimum radius of 0.10t or 0.25 in. (6 mm), whichever is greater.

(c) Crotch Radius (Figure NC-3441.3-2). The crotch radius shall not be less than 0.3t.

(d) Bottom of Casing. That section of the pump casing within the diameter defined by dimension A in Figure NC-3441.3-2 on the inlet side of the casing, normally referred to as the bottom of the casing, shall have a wall thickness no less than the value of t determined in (a) above.

Figure NC-3441.3-1
Type C Pump



(e) Alternative Rules for Casing Wall Thickness and Splitter Wall Thickness. As an alternative to (a) and (b) above, it is permissible to use a smaller casing wall thickness and a larger splitter wall thickness when requirements of (1) through (3) below are met.

(1) The casing wall thickness, as determined by (a) above, shall be maintained at a minimum t between the tangent point of the crotch radius to a point D radially opposite the splitter tip [Figure NC-3441.3-2 sketch (b)]. The casing wall shall be decreased uniformly to point E from which point a minimum thickness of 0.7t shall be continued around the casing wall to a point on the discharge nozzle a distance l from the crotch, where l is defined in Figure NC-3433.4-1.

(2) The splitter wall thickness shall be as defined in (b) above, except that the splitter shall have a minimum thickness t instead of 0.7t.

(3) The requirements of (b)(2) and (b)(3) above shall apply.

NC-3441.4 Design of Type D Pumps.

(a) Type D pumps are those having double volutes and radially split casings with double suction as illustrated in Figure NC-3441.4(a)-1. Their design shall be in accordance with the applicable requirements of NC-3400.

(b) The requirements of NC-3441.3(a), NC-3441.3(b), and NC-3441.3(c), governing casing wall thickness, splitter wall thickness, and crotch radius, apply.

(c) In the casing portion between the cover and the casing wall, a wall thickness in excess of t may be required.

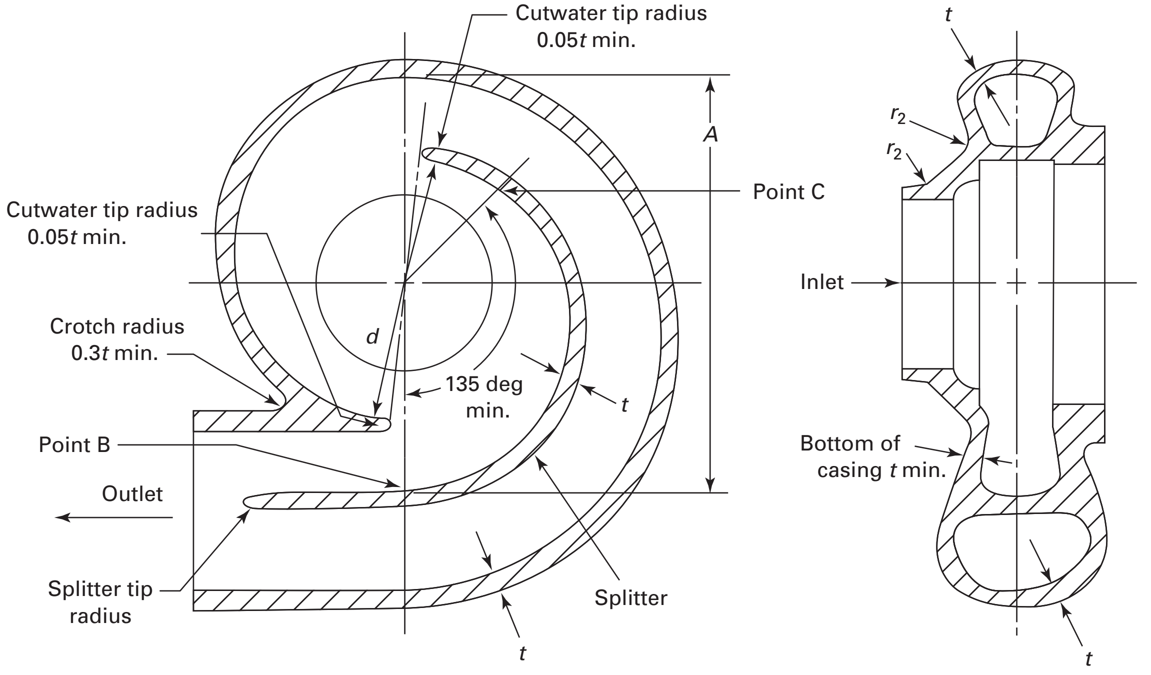
NC-3441.5 Design of Type E Pumps. Type E pumps are those having volute-type radially split casings and multivane diffusers which form structural parts of the casing as illustrated in Figure NC-3441.5-1. The design shall be in accordance with the applicable requirements of NC-3400.

NC-3441.6 Design of Type F Pumps.

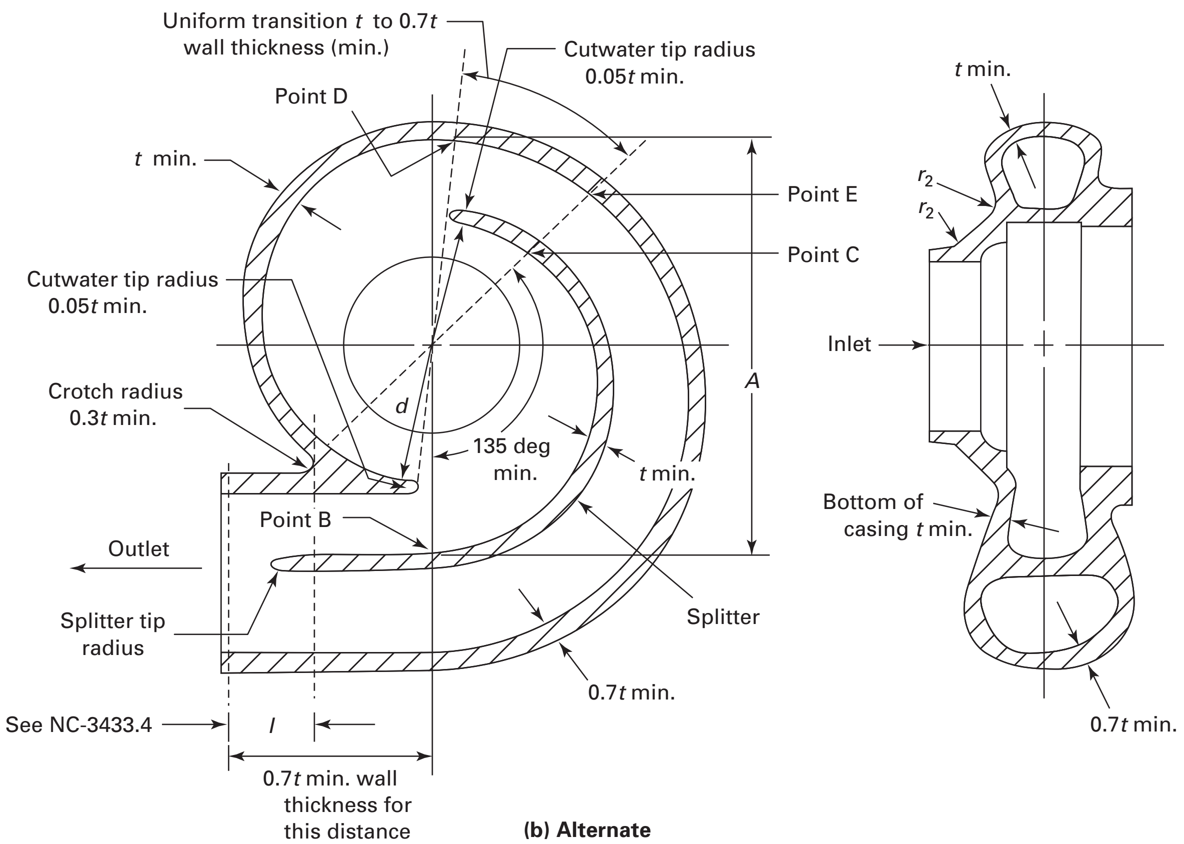
(a) Type F pumps are those having radially split, axisymmetric casings with either tangential or radial outlets as illustrated in Figure NC-3441.6(a)-1. The basic configuration of a Type F pump casing is a shell with a dished head attached at one end and a bolting flange at the other. The outlet may be either tangent to the side or normal to the center line of the casing. Variations of these inlet and outlet locations are permitted.

(b) The design of Type F pumps shall be in accordance with the applicable requirements of NC-3400.

Figure NC-3441.3-2
Type C Pump

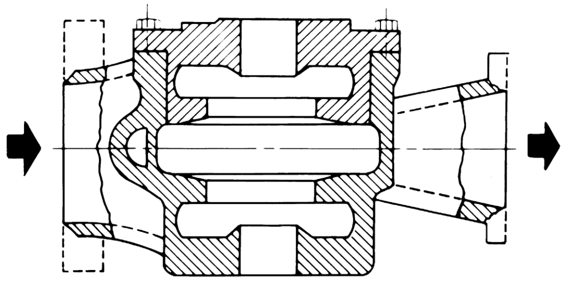


(a) Standard



(b) Alternate

Figure NC-3441.4(a)-1
Type D Pump



NC-3441.7 Design of Type G Pumps.[27]

(a) Type G pumps are those having axially split, single or double volute casings [Figures NC-3441.7(a)-1 and NC-3441.7(a)-2].

(b) Manufacturers proposing this design should thoroughly review nondestructive examination requirements for compatibility.

(c) An acceptable method for calculating the stress in the most highly stressed section of the pump case, such as the section with the greatest span, is given in (1) and (2) below. This method is not acceptable for those designs in which more than one bolt falls within a given section [Figure NC-3441.7(c)-1, Section B–B].

(1) The following assumptions are made:

(-a) assign one bolt to Section *X*; assign one-half bolt to Section *Y*, and one-half bolt to Section *Z* (Section *Z* is identical to Section *Y*);

(-b) the flange and bolts act together in bending;

Figure NC-3441.5-1
Type E Pump

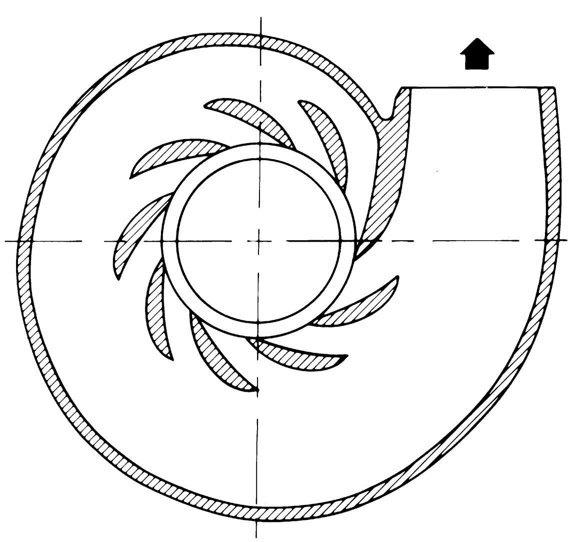
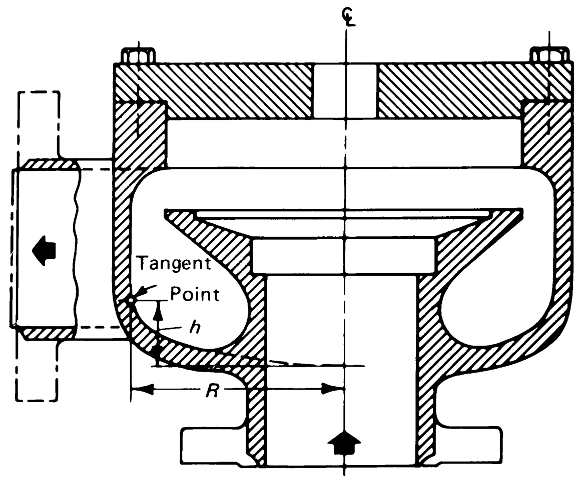


Figure NC-3441.6(a)-1
Type F Pump



(-c) the maximum moment occurs at the bolt;

(-d) the total moment is distributed between the flange and case in proportion to their moments of inertia.

(2) Typical sections are shown in Figures NC-3441.7(c)(2)-1, NC-3441.7(c)(2)-2, and NC-3441.7(c)(2)-3. The procedure for the calculation is given in(-a) through (-o) below.

(-a) Establish the Design Pressure *P*, psi (MPa). Establish dimensions *A*, *B*, *C*, *F*, *R*, t_c, t_f, *w*, and *b* from Figures NC-3441.7(c)(2)-1, NC-3441.7(c)(2)-2, and NC-3441.7(c)(2)-3 and determine the following:

A_b = bolt root area, in.^{2} (mm^2)
A_G = effective gasket area, in.^{2} (mm^2)
D = diameter of bolt hole, in. (mm)
d = bolt root diameter, in. (mm)

Figure NC-3441.7(a)-1
Axially Split Casing, Volute Pump, Type G

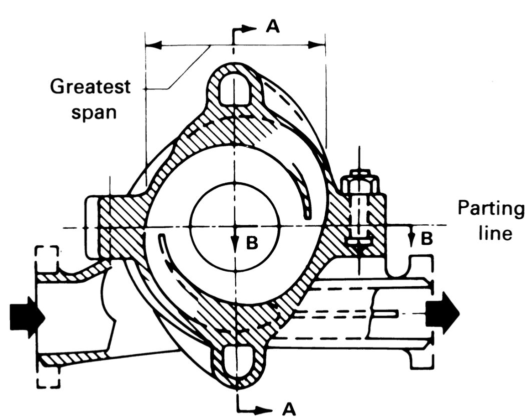
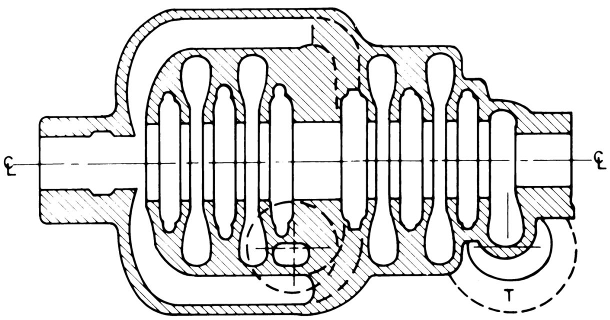


Figure NC-3441.7(a)-2
Axially Split Casing, Volute Pump, Type G



Section A–A

DTF = Design Temperature, °F (°C)
E = modulus of elasticity of bolt at service temperature, psi (MPa)
e = unit thermal elongation of bolt, 1/°F (1/°C)
G = $B + 0.5t_c$, in. (mm)
m = gasket factor (Section III Appendices, Mandatory Appendix XI, Table XI-3221.1-1)
R = $C - (B + t_c)$, in. (mm)
S_b = allowable stress, bolt, psi (MPa)
S_c = allowable stress, case, psi (MPa)
W = load used in calculating preliminary bolt stress, lb (N)
= W_X, W_Y, W_Z
w = section width, in. (mm)
y = gasket design seating stress, psi (MPa) (Section III Appendices, Mandatory Appendix XI, Table XI-3221.1-1)

(-b) Determine the effective gasket area A_G, in.^{2} (mm^2), for Sections X and Y:

$$A_G = \left[(A - F)w - \frac{\pi D^2}{4}\right] \times K$$

For the factor K, use 0.20 if case face is crowned for greatest contact pressure at inner edge and use 0.50 for flat surfaces.

Figure NC-3441.7(c)-1
Axially Split Casing, Volute Pump, Type G
Section B–B Typical Highly Stressed Sections of Pump Case

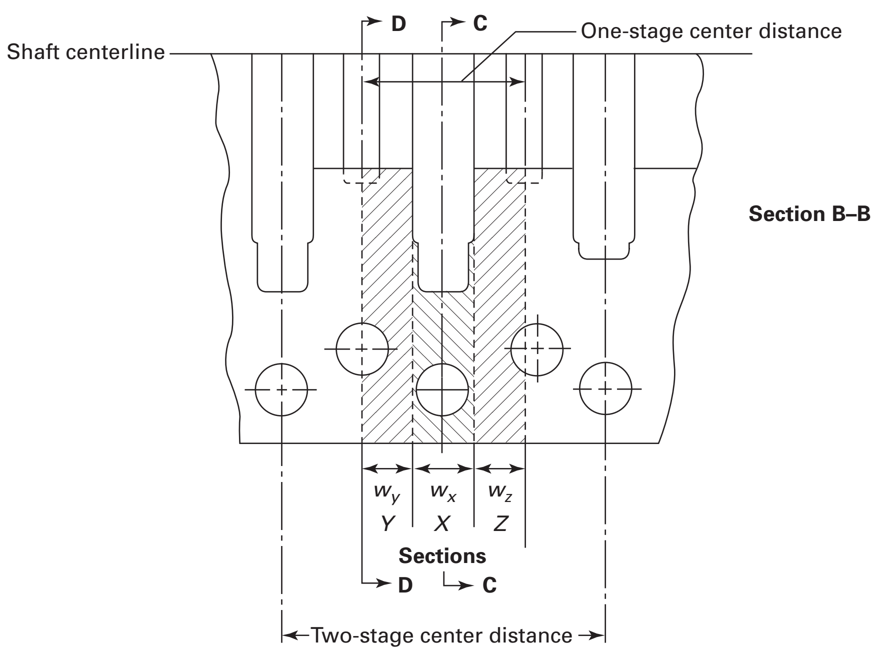


Figure NC-3441.7(c)(2)-1
Typical Section of Type G Pumps

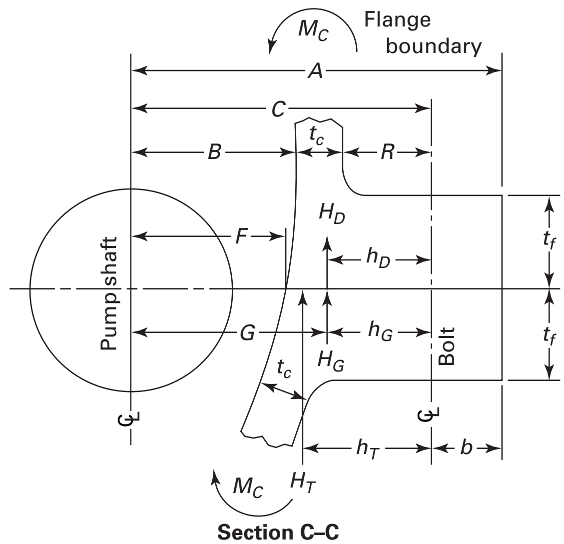


Figure NC-3441.7(c)(2)-2
Typical Section of Type G Pumps

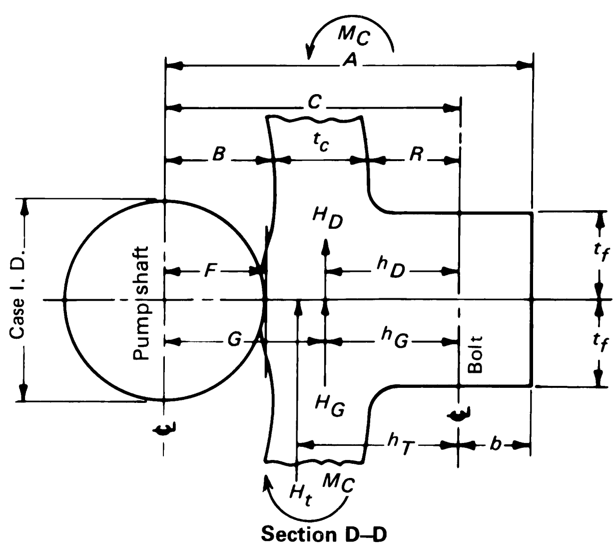
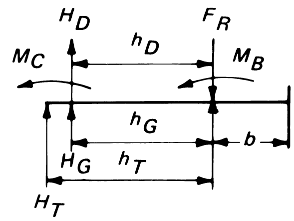


Figure NC-3441.7(c)(2)-3 Typical Loads on Type G Pumps



Equivalent Beam

(-c) Determine bolt load, lb (N), and preliminary bolt stress σ_{PRE}, psi (MPa):

$$H = G \times w \times P$$

$$H_p = A_G \times m \times P$$

$$W_{m1} = H + H_p$$

$$W_{m2} = 0.5 A_G y$$

$$W = \text{greator of } W_{m1} \text{ or } W_{m2}$$

$$\sigma_{PRE} = W / A_b$$

(-d) Determine the total load H_o, lb (N):

$$H_D = B \times w \times P$$

$$H_G = H_p$$

$$H_T = H - H_D$$

$$H_o = H_D + H_G + H_T$$

(-e) Determine the lever arms h_D, h_G, and h_T, in. (mm):

$$h_D = R + 0.5 t_c$$

$$h_G = h_D$$

$$h_T = 0.5(R + t_c + h_G)$$

(-f) Determine the total moment M_o, in.-lb (N·mm):

$$M_D = H_D h_D$$

$$M_G = H_G h_G$$

$$M_T = H_T h_T$$

$$M_o = M_D + M_G + M_T$$

(-g) Determine the moments of inertia, in.^{4} (mm^4), I_F (flange) I_B (bolt), I_C (case), and I_T (total):

$$I_F = \left[w(t_f)^3 / 12 \right] - \left[D(t_f)^3 / 12 \right]$$

$$I_B = 0.049 d^4$$

$$I_C = w(t_c)^3 / 12$$

$$I_T = I_F + I_B + I_C$$

(-h) Determine the moments, in.-lb (N·mm), carried M_F (flange), M_B (bolt), and M_C (case):

$$M_F = M_o I_F / I_T$$

$$M_B = M_o I_B / I_T$$

$$M_C = M_o I_C / I_T$$

(-i) Determine the resultant bolt load F_R, lb (N):

$$F_R = \left[H_D \left(b + h_D \right) + H_G \left(b + h_G \right) + H_T \left(b + h_T \right) - M_C - M_B \right] / b$$

or

$$F_R = H_o + \left[\left(M_o - M_C - M_B \right) / b \right]$$

(-j) Determine the resultant bolt stresses, psi (MPa)

$$\sigma_{Load} = F_R / A_b$$

$$\sigma_{Temp} = eE$$

$$\sigma_{Tensile} = \sigma_{Load} + \sigma_{Temp}$$

$$\sigma_{Bending} = M_B d / 2I_B$$

(-k) Determine the shear and bending flange stresses σ_s', psi (MPa), and σ_b', psi (MPa), respectively

$$\sigma_s' = H_o / wt_f$$

$$\sigma_b' = M_F t_f / 2I_F$$

(-l) Determine the tensile and bending case stresses σ_t'', psi (MPa), and σ_b'', psi (MPa), respectively

$$\sigma_t'' = H_D / wt_c$$

$$\sigma_b'' = M_C t_C / 2I_C$$

(-m) Use the following method for combining stress in combined sections:

Let F_X = load on Section X,
F_Y = load on Section Y, etc.

Let S_X = stress on Section X,
F_Y = stress on Section Y, etc.

Then the combined stress S_{COMB} is as follows:

$$S_{COMB} = \left(F_X + F_Y \right) / \left[\left(F_X / S_X \right) + \left(F_Y / S_Y \right) \right], \text{etc.}$$

(-n) Determine the maximum stresses using (-1) through (-4) below.

(-1) To determine the preliminary bolt stress, establish the load W and the stress σ_{PRE} for Section X and for Section $(Y + Z)$

$$\sigma_{PRE_{COMB}} = \frac{W_X + W_{(Y+Z)}}{\dfrac{W_X}{\sigma_{PRE_X}} + \dfrac{W_{(Y+Z)}}{\sigma_{PRE_{(Y+Z)}}}}$$

The allowable limit for this stress is S_b.

(-2) To determine the resultant bolt stress, establish the load F_R and the stresses σ_t and σ_b for Section X and for Section $(Y + Z)$

$$\sigma_{t_{COMB}} = \frac{F_{R_X} + F_{R_{(Y+Z)}}}{\dfrac{F_{R_X}}{\sigma_{t_X}} + \dfrac{F_{R_{(Y+Z)}}}{\sigma_{t_{(Y+Z)}}}}$$

The allowable limit for $\sigma_{t_{COMB}}$ is $2S_b$.

$$\sigma_{b_{COMB}} = \frac{F_{R_X} + F_{R_{(Y+Z)}}}{\dfrac{F_{R_X}}{\sigma_{b_X}} + \dfrac{F_{R_{(Y+Z)}}}{\sigma_{b_{(Y+Z)}}}}$$

The allowable limit for $\sigma_{t_{COMB}} + \sigma_{b_{COMB}}$ is $3S_b$.

(-3) To determine the flange stresses, establish the load H_o, the shear stress σ'_s, and the bending stress σ_b' for Section X and for Section $(Y + Z)$

$$\sigma'_{s_{COMB}} = \frac{H_{o_X} + H_{o_{(Y+Z)}}}{\dfrac{H_{o_X}}{\sigma'_{s_X}} + \dfrac{H_{o_{(Y+Z)}}}{\sigma'_{s_{(Y+Z)}}}}$$

$$\sigma'_{b_{COMB}} = \frac{H_{o_X} + H_{o_{(Y+Z)}}}{\dfrac{H_{o_X}}{\sigma'_{b_X}} + \dfrac{H_{o_{(Y+Z)}}}{\sigma'_{b_{(Y+Z)}}}}$$

$$\sigma'_{s_{max}} = \left[\left(\sigma'_{s_{COMB}} \right)^2 + \left(\sigma'_{b_{COMB}} / 2 \right)^2 \right]^{1/2}$$

$$\sigma'_{n_{\max}} = \sigma'_{s_{\max}} + \left(\sigma'_{b_{\rm COMB}}/2\right)$$

where $\sigma'_{n_{\max}}$ is the maximum normal stress. The allowable limit for $\sigma_{s_{\max}}$ is S_c and the allowable limit for $\sigma'_{n_{\max}}$ is $1.5S_c$.

(-4) To determine the case stresses, establish the load H_D, the tensile stress σ_t'', and the bending stress σ_b'' for Section X and for Section $(Y + Z)$

$$\sigma''_{t_{\rm COMB}} = \frac{H_{D_X} + H_{D_{(Y+Z)}}}{\dfrac{H_{D_X}}{\sigma''_{t_X}} + \dfrac{H_{D_{(Y+Z)}}}{\sigma''_{t_{(Y+Z)}}}}$$

$$\sigma''_{b_{\rm COMB}} = \frac{H_{D_X} + H_{D_{(Y+Z)}}}{\dfrac{H_{D_X}}{\sigma''_{b_X}} + \dfrac{H_{D_{(Y+Z)}}}{\sigma''_{b_{(Y+Z)}}}}$$

The allowable limit for $\sigma''_{t_{\rm COMB}}$ is S_c. The total stress is $\sigma''_{t_{\rm COMB}} + \sigma''_{b_{\rm COMB}}$. The allowable limit for total stress is $1.5S_c$.

(-o) The above procedure will generally show some bolt stresses in excess of the indicated allowable values. Under these circumstances it is permissible to average bolt stresses between adjacent bolts. Such averaged stresses shall not exceed the specified allowables.

NC-3441.8 Design of Type H Pumps. Type H pumps are those having axially split, barrel-type casings (Figures NC-3441.8-1 and NC-3441.8-2) and radially split covers. The axially split casing shall be designed in accordance with the rules of NC-3441.7 for Type G pumps. The radially split cover shall be designed in accordance with the rules of NC-3437.

Figure NC-3441.8-1
Longitudinal Section Through Type H Pump

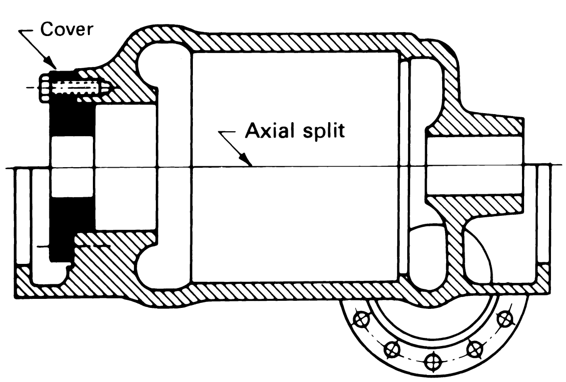
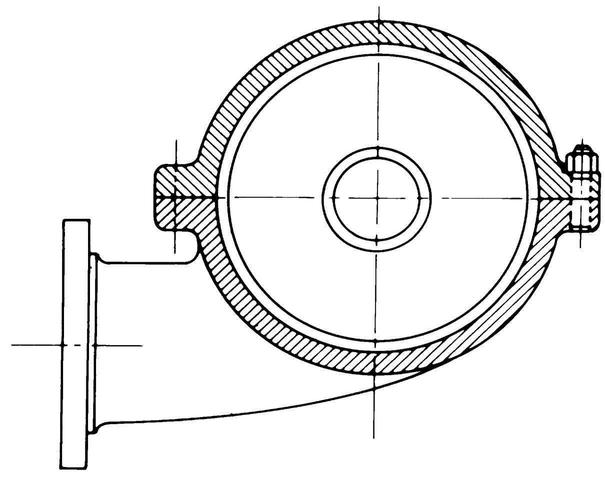


Figure NC-3441.8-2
Transverse Section Through Type H Pump



NC-3441.9 Design of Type K Pumps. Type K pumps (15) are vertical pumps of one or more stages having a radially split casing as illustrated in Figures NC-3441.9-1 and NC-3441.9-2. The basic configuration is a casing consisting of a barrel and a head joined by bolted flanges and an inner assembly consisting of internal chambers of the head, one or more bowls and columns, and a suction bell, all joined by flanges and arranged so that the external surfaces of these parts are subjected to inlet pressure. These pumps may be furnished with or without column (s) and with or without lateral restraints between the inner assembly and outer casing.

(a) Casing. The barrel and head of the casing shall be designed in accordance with the requirements of NC-3400 and with those given in (1) through (3) below.

(1) Barrel. The Design Pressure for the barrel shall be the pump inlet pressure or as otherwise stated in the Design Specification (NCA-3250), but in no case shall it be less than the maximum pressure at the pump inlet under any Service Condition. The static head shall be considered in the selection of the Design Pressure.

(2) Head

(-a) The external walls of the head, which form the pressure-containing boundary to the atmosphere, shall be designed for the pressures specified in (-b) and (-c) below. The Design Pressure for the internal chambers shall be as specified under the inner assembly rules.

(-b) The Design Pressure for the portions of the head that form the pressure-containing boundary between the outlet pressure and the atmosphere shall be the outlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump outlet under any Service Condition.

Figure NC-3441.9-1
Type K Pump

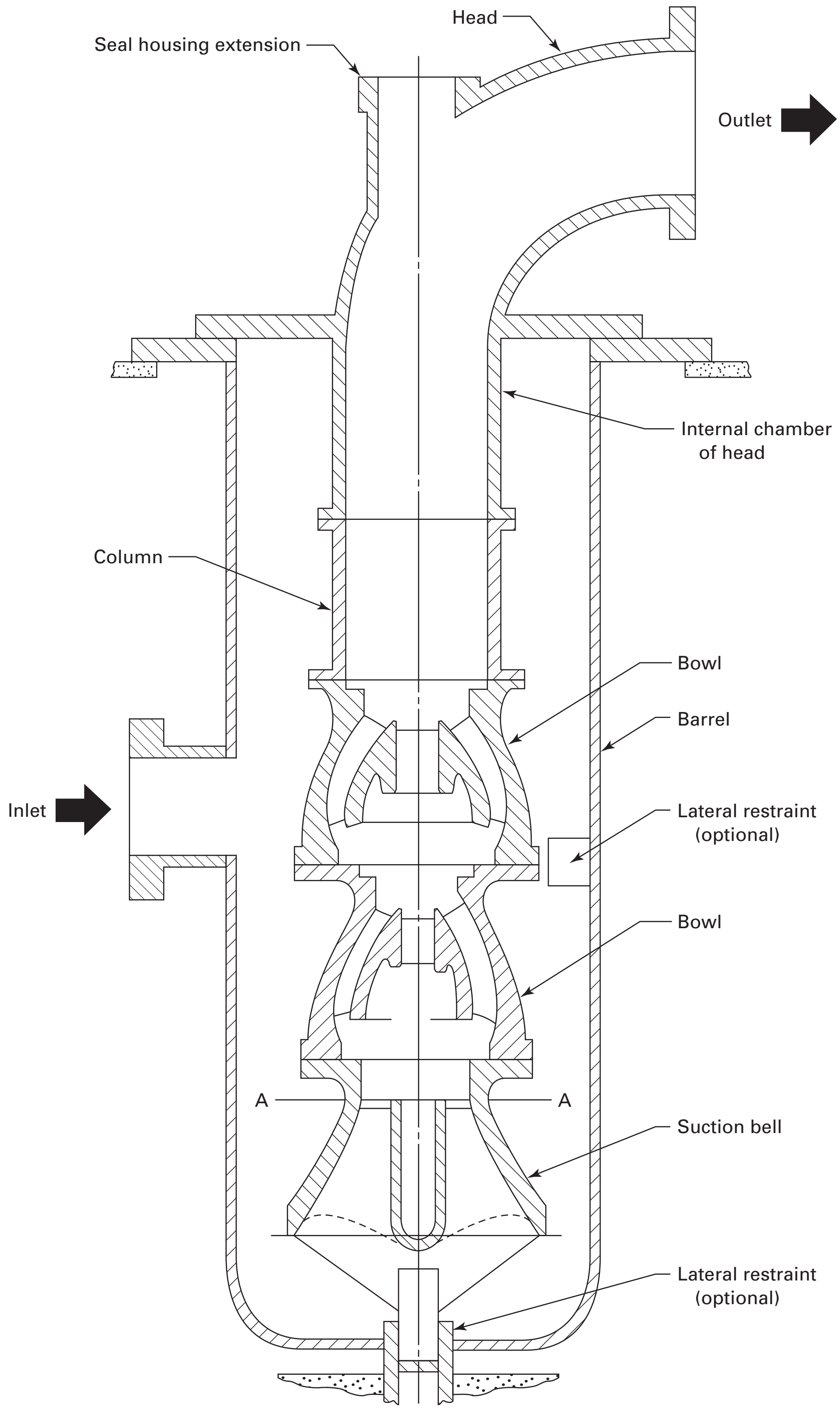
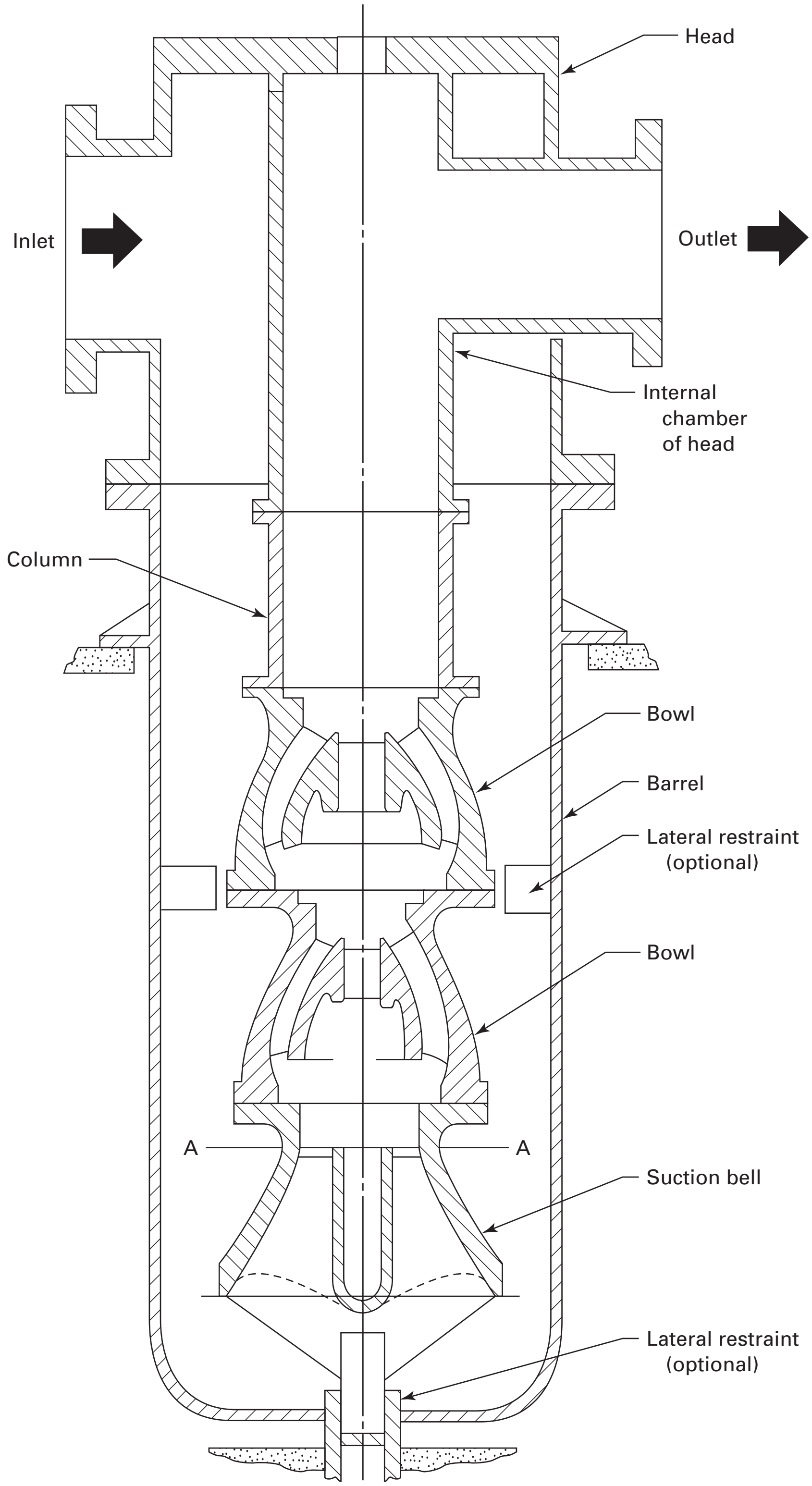


Figure NC-3441.9-2
Type K Pump



(-c) The Design Pressure for the portions of the head that form the pressure-containing boundary between the inlet pressure and the atmosphere shall be the inlet pressure or as otherwise stated in the Design Specification, but in no case shall it be less than the maximum pressure at the pump inlet under any Service Condition.

(3) Flanged Joints. Flanged joints may be analyzed and the stresses evaluated by using methods given in Section III Appendices, Mandatory Appendix XI if of the "RF" type and in accordance with Section III Appendices, Nonmandatory Appendix L if of the "FF" type, as modified by (-a) through (-d) below or by (-e) below.

(-a) The Design Pressure to be used for the calculation of H in Section III Appendices, Mandatory Appendix XI or Nonmandatory Appendix L shall be replaced by the flange design pressure

$$P_{FD} = P + P_{eq} \tag{1}$$

where

P = design or Service Condition Pressure as defined in NCA-2140, psi (MPa)
P_{eq} = equivalent pressure to account for the axial force and moments applied to the flange joint, psi (MPa)

The equivalent pressure, P_{eq}, shall be determined from the seismic and external loads acting on the flanged joint using the equation

$$P_{eq} = \frac{KM_f}{\pi G^3} + \frac{4F}{\pi G^2} \tag{2}$$

where

F = the axial load at the flange, lbf (N)
G = the diameter at the location of the gasket load reaction, in. (mm)
K = If the loads include dynamic loads the value of this coefficient shall be 8. If the loads are static the value shall be 16.
M_f = the resultant bending moment on the flange as taken from paragraph NC-3658, in.-lbf (N·mm)

(-b) Section III Appendices, Mandatory Appendix XI, XI-3223, eqs. (3) and (4) or Section III Appendices, Nonmandatory Appendix L, L-3221 shall be used to establish minimum bolt area required using allowable stress values given in Section II, Part D, Subpart 1, Tables 1A and 1B.

(-c) Equation (6) in Section III Appendices, Mandatory Appendix XI, XI-3240 for longitudinal hub stress shall be revised to include primary axial membrane stress as follows:

$$S_H = \frac{fM_o}{Lg_1{}^2B} + \frac{PB}{4g_o} \tag{3}$$

where P is the Design or Service Pressure as defined in NCA-2140, psi (MPa). Other terms are defined in Section III Appendices, Mandatory Appendix XI, XI-3130.

(-d) The allowable stress limits shall be

– S_H not greater than 1.5S
– S_R not greater than 1.5S
– S_T not greater than 1.5S

(-e) If the flanged joint conforms to one of the standards listed in Table NCA-7100-1 and if each P_{FD} as calculated by eq. (-a)(1) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of this subparagraph are satisfied.

(b) Inner Assembly. The inner assembly consists of internal chambers of the head, the bowls and columns, and the upper flange of the suction bell. It comprises those elements of the pump subjected to differential pressure within the pump and those which do not form part of the pressure boundary to the atmosphere. Design rules are under development. Until they are available, the design shall be by analysis or any procedure which can be shown to have been satisfactory by actual service experience. However, their design shall meet the rules of NC-3400 and the rules given in (1) and (2) below.

(1) Columns and Internal Chambers of the Head. The Design Pressure for columns and internal chambers of the head shall be not less than the maximum differential pressure which can be developed across the wall of that column or chamber under any Service Condition.

(2) Bowls and Suction Bell

(-a) The Design Pressure for the bowl(s) shall be not less than the maximum differential pressure to which each respective bowl may be subjected under any Service Condition. Potential for interchangeability of bowls of different design ratings shall be taken into consideration.

(-b) The Design Pressure for the upper flange of the suction bell (section above line A–A in Figures NC-3441.9-1 and NC-3441.9-2) shall be not less than the maximum pressure differential developed by the first stage of the pump under any Service Condition. The remaining portion of the bell is not considered to be subject to pressure loads.

(-c) Each bowl and suction bell shall be manufactured of material meeting the rules of NC-2190 and designed using the casting quality factors listed in Note (4) of Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NC-3441.10 Type N Pumps.

(a) Type N pumps have radially split, multistage barrel type casings with single nozzles each for suction and discharge, radially disposed with respect to the shaft axis [Figure NC-3441.10-1, sketch (a)].

The design shall be in accordance with the applicable requirements of NC-3400.

(b) Minimum transition radii at critical sections of the barrel shall be limited to 0.2 in.

(c) The circumferential pitch between drilled and tapped holes shall be a minimum of 2*d* where *d* is the nominal diameter of the bolt or stud [Figure NC-3441.10-1, sketch (b)].

(d) The minimum distance, *X*, between the bottom of the hole and the nozzle opening shall be greater than or equal to the greater of the minimum, nozzle, wall thickness or 50% of the hole diameter as shown [Figure NC-3441.10-1, sketch (c)].

NC-3442 Special Pump Types

NC-3442.1 Design of Type J Pumps (Centrifugal).

(a) Type J pumps are those that cannot logically be classified with any of the preceding types of centrifugal pumps.

(b) It is not planned to establish rules for Type J pumps. Any design method which has been demonstrated to be satisfactory for the specified Design Conditions may be used.

NC-3442.2 Design of Reciprocating Pumps. See NC-3450.

NC-3450 DESIGN OF CLASS 2 RECIPROCATING PUMPS

NC-3451 Scope

(a) These rules cover the strength and pressure integrity of the structural parts of the liquid end [Figure NC-3451(a)-1], whose failure would violate the pressure boundary. Such parts include:

(1) liquid cylinder and valve chambers

(2) valve covers

(3) liquid cylinder heads

(4) stuffing boxes

(5) packing glands

(6) manifolds

(7) piping and nozzles normally identified with the pump and furnished by the pump supplier

(8) related bolting

(9) external and internal integral attachments to the pressure-retaining boundary

(b) These rules do not apply to the plunger or piston, nonstructural internals, including valves, valve seats, gaskets, packing, and cylinder mounting bolting. Hydrostatic testing of packing glands is not required.

NC-3452 Acceptability

The pressure boundary parts shall be capable of withstanding the specified Design Pressures, and the design shall be such that the requirements of NC-3100 are satisfied in addition to these rules.

NC-3453 Material and Stresses

Material and allowable stresses shall conform to the requirements of Article NC-2000.

NC-3454 Design Requirements

NC-3454.1 Design of Welded Construction.

(a) Design of welded construction shall be in accordance with NC-3350.

(b) Partial penetration welds, as shown in Figure NC-4244(e)-1 sketch (c-3) and Figure NC-4266(d)-1 sketches (a) and (b), are allowed for nozzles such as vent and drain connections and openings for instrumentation. Nozzles shall not exceed NPS 2 (DN 50). For such nozzles, all reinforcement shall be integral with the portion of the shell penetrated. Partial penetration welds shall be of sufficient size to develop the full strength of the nozzles.

NC-3454.2 Piping. Piping located within the pressure-retaining boundary of the pump, and identified with the pump, shall be designed in accordance with NC-3600.

NC-3454.3 Liquid End. Any design method which has been demonstrated to be satisfactory for the specified design may be used.

NC-3454.4 Fatigue. The liquid cylinder and pressure-retaining bolting are exposed to significant fatigue loadings which shall be considered in the design. Any design method which has been demonstrated to be satisfactory for the specified design may be used.

NC-3454.5 Earthquake Loadings. The effects of earthquake shall be considered in the design of pumps. The stresses resulting from these earthquake effects shall be included with the stresses resulting from pressure or other applied loads.

NC-3454.6 Corrosion. In designs where corrosion of material is a factor, allowances shall be made.

NC-3454.7 Bolting. Bolting in axisymmetric arrangements involving the pressure boundary shall be designed in accordance with the procedure described in Section III Appendices, Mandatory Appendix XI.

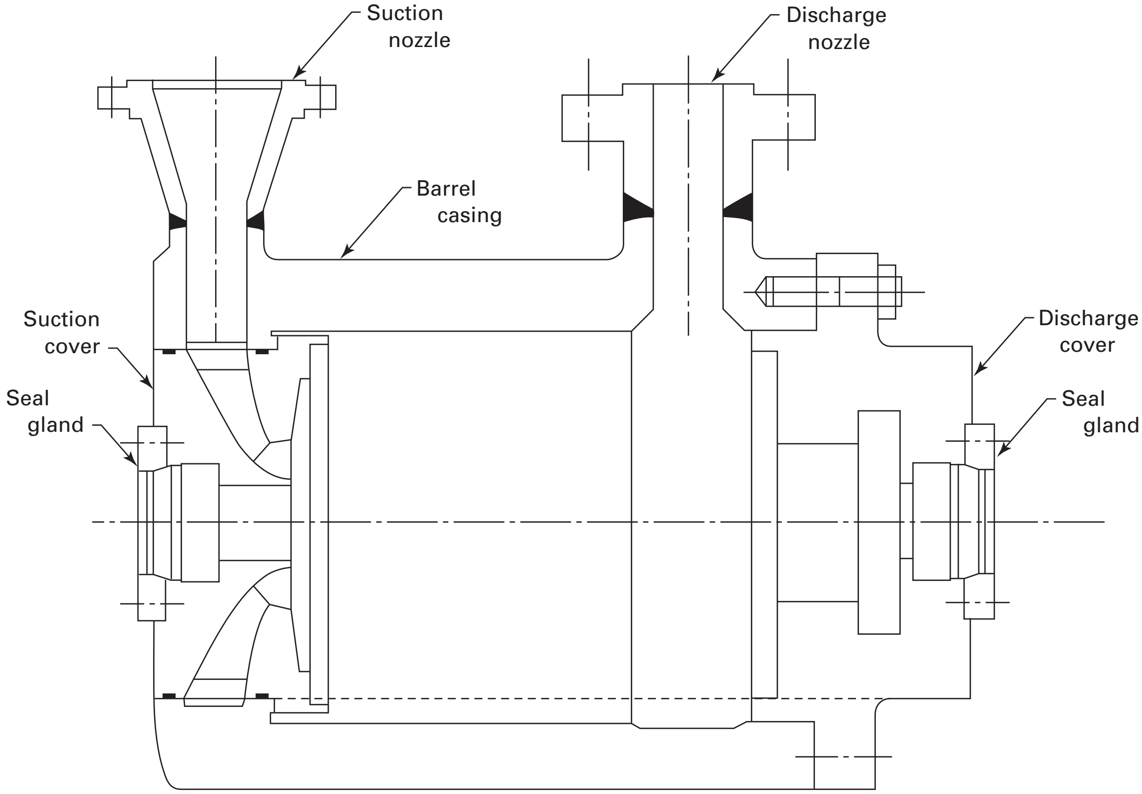
NC-3500 VALVE DESIGN

NC-3510 GENERAL REQUIREMENTS

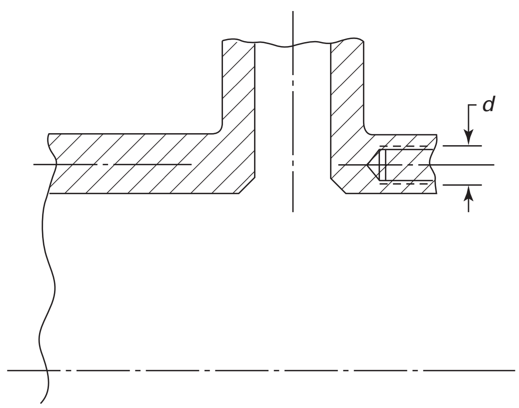
NC-3511 Design Specification

Design and Service Conditions (NCA-2142) shall be stipulated in the Design Specification (NCA-3250). The requirements of NCA-3254(a) for specifying the location

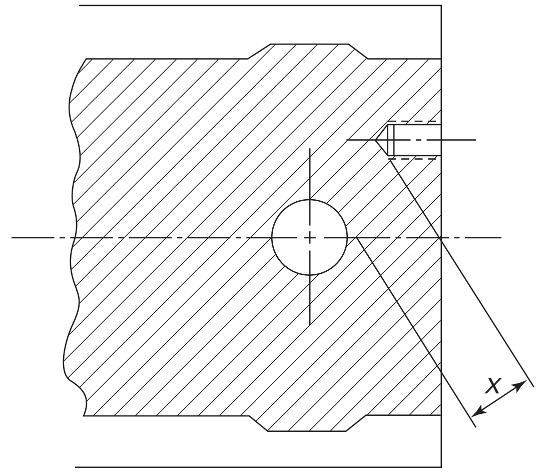
Figure NC-3441.10-1
Type N Pump



(a)

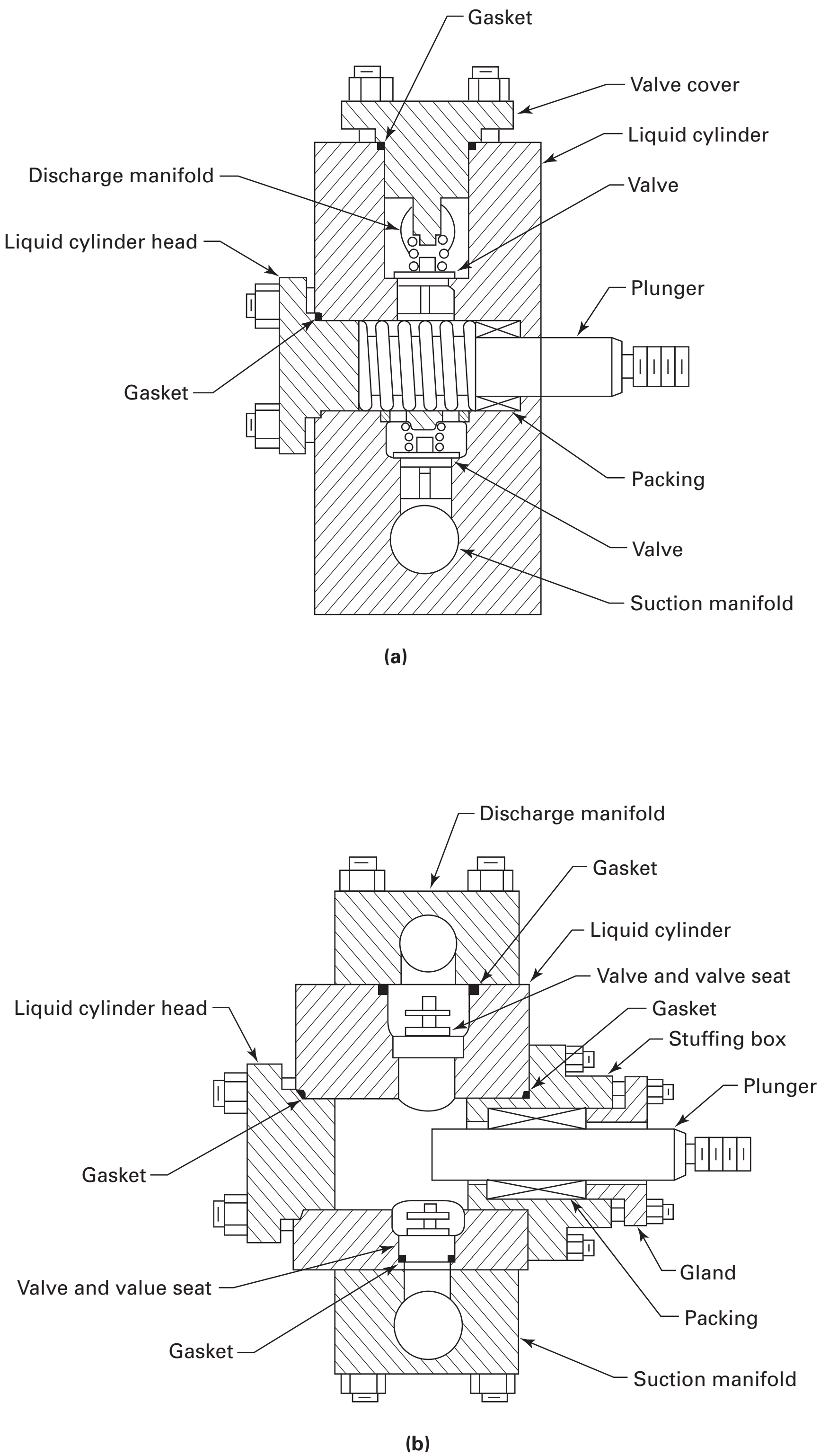


(b)



(c)

Figure NC-3451(a)-1
Horizontal Single-Acting Power Pump Liquid Ends



of valve boundary jurisdiction may be considered to have been met by employing the minimum limits of NC-1131, unless the Design Specification extends the boundary of jurisdiction beyond these minimum limits. The requirements of NCA-3254(b) for specifying the boundary conditions are not applicable to valve end connections.

CAUTION: Certain types of double-seated valves have the capability of trapping liquid in the body or bonnet cavity in the closed position. If such a cavity accumulates liquid and is in the closed position at a time when adjacent system piping is increasing in temperature, a substantial and uncontrolled increase in pressure in the body or bonnet cavity may result. Where such a condition is possible, it is the responsibility of the Owner or his designee to provide, or require to be provided, protection against harmful overpressure in such valves.

NC-3512 Standard Design Rules

NC-3512.1 Flanged and Butt Welded End Valves. The design of valves with flanged and butt welded ends shall conform to the applicable requirements for Standard Class category valves of ASME B16.34, except as provided in (a) and (b) below.

(a) Valves with flanged and butt welded ends may be designated as Class 75 in sizes larger than NPS 24 (DN 600), provided that the following additional requirements are met.

(1) The maximum rated pressure shall be 75 psi (520 kPa) for fluid temperatures from −20°F to 350°F (−30°C to 175°C).

(2) The minimum valve body wall thickness, exclusive of corrosion allowance, shall be in accordance with the following:

$$t_m = 0.4t_o + 0.2 \text{ for } d \leq 50 \text{in.} (1,270 \text{mm})$$

or

$$t_m = 0.008d + 0.2 \text{ for } d > 50 \text{in.} (1,270 \text{mm})$$

where

d = inside diameter, in. (mm)
t_m = minimum body wall thickness, in. (mm)
t_o = minimum body wall thickness as tabulated in ASME B16.34 for Class 150, in. (mm)

(3) Flanges shall be designed in accordance with the requirements of Section III Appendices, Mandatory Appendix XI, ANSI/AWWA C207 Class E, or ASME B16.47.

(4) The minimum hydrostatic shell test pressure shall be 125 psi (860 kPa) and shall be maintained for a minimum of 10 min.

(5) The minimum valve closure test pressure shall be 85 psi (590 kPa) and shall be maintained for a minimum of 10 min.

(b) Valves with flanged ends in sizes larger than NPS 24 (DN 600) may be used, provided that the following additional requirements are met.

(1) For ASME B16.47, the Pressure Class shall be limited to Class 150 and Class 300.

(2) The operating temperatures shall be limited to the range of −20°F to 650°F (−30°C to 345°C).

(3) Flanges are designed in accordance with the requirements of Section III Appendices, Mandatory Appendix XI or ASME B16.47.

NC-3512.2 Socket Welded End and Nonwelded End Valves. The design of valves with socket welded end connections and nonwelded piping end connections other than ASME B16.5 flanges shall conform to the applicable requirements for Standard Class category butt welding end valves of ASME B16.34, except that the end connections shall conform to the applicable requirements of NC-3661 or NC-3671. (15)

Instrument, control, and sampling line valves, NPS 1 (DN 25) and smaller, with welded or nonwelded piping or tubing end connections other than flanges, and with body wall thickness not meeting Standard Class category valves of ASME B16.34, are acceptable, provided that the following additional requirements of (a) through (g) are met:

(a) The valve design shall meet one or more of the following:

(1) the pressure design rules of NC-3324

(2) an experimental stress analysis (Section III Appendices, Mandatory Appendix II)

(3) design based on stress analysis (Section III Appendices, Mandatory Appendix XIII) and meeting the limits of Section III Appendices, Mandatory Appendix XIII

(b) The end connections shall meet the requirements of NC-3661, NC-3671.3, or NC-3671.4 for welded, threaded, and flared, flareless, and compression-type fitting tube ends.

(c) Valve loadings, including but not limited to operation, closure, and assembly, shall be accounted for by one of the following methods:

(1) experimental stress analysis (Section III Appendices, Mandatory Appendix II), or

(2) design based on stress analysis (Section III Appendices, Mandatory Appendix XIII).

(d) All valves shall meet the requirements of NC-3521.

(e) Valve bonnets threaded directly into valve bodies shall have a lock weld or locking device to ensure that the assembly does not disengage through either stem operation or vibration.

(f) The valve's design shall be qualified and a maximum pressure–temperature rating determined in accordance with the requirements of MSS SP-105, Section 5. A lesser pressure–temperature rating may be applied to the valve.

(g) Valves shall be hydrostatic tested per the requirements of NC-3531 at pressures appropriate for the valve's applied pressure rating.

NC-3512.3 Wafer or Flangeless Valves. The design of valves that can be bolted between flanges (i.e., butterfly valves) shall conform to the applicable requirements of Standard Class category valves of ASME B16.34 and the requirements of (a) through (e) below.

(a) The design shall provide for bolt-up using all of the bolt holes and the bolt circle of the specified flange.

(b) Bolt holes parallel to the body run may be either threaded or unthreaded. Threaded holes may be blind holes suitable for use with bolt studs.

(c) The required minimum valve body wall thickness shall be measured from the valve inside circumference to either the valve outside circumference or the circumference of a circle inscribed about the inner tangents to the bolt holes, whichever is smaller.

(d) The inner ligament of either a through hole or a blind threaded hole in the vicinity of a stem penetration shall not be less than 25% of the required body neck thickness.

(e) The inner ligament for singular holes parallel to the body run shall not be less than 25% of the required valve body wall thickness. Such holes shall not be larger than $^3/_8$ in. (10 mm) diameter.

NC-3512.4 Design and Service Loadings. The design requirements of NC-3512.1 and NC-3512.2 include pressure–temperature ratings for Design Loadings and Service Loadings for which Level A Limits are designated. When any Service Loadings are stipulated for which Level B, Level C, or Level D Limits are designated in the Design Specification, the requirements of NC-3520 shall be met.

NC-3512.5 Openings for Auxiliary Connections. Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ASME B16.34 and the applicable requirements of NC-3330.

NC-3513 Alternative Design Rules

For butt welding end valves and for socket welding end valves whose end connections conform to the requirements of NC-3661, the design requirements for Special Class category valves of ASME B16.34 may be used in place of NC-3512 when permitted by the Design Specification, provided that the following requirements are met.

(a) The nondestructive examination requirements of ASME B16.34, Special Class, shall be met for all sizes of butt welding and socket welding end valves in accordance with the examination methods and acceptance standards of NC-2500.

(b) When any Service Loadings are stipulated for which Level B, Level C, or Level D Limits are designated in the Design Specification, the requirements of NC-3520 shall be met.

(c) Openings for auxiliary connections, such as for drains, bypasses, and vents, shall meet the requirements of ASME B16.34 and the applicable reinforcement requirements of NC-3330.

NC-3515 Acceptability of Metal Bellows and Metal Diaphragm Stem Sealed Valves

Valves using metal bellows or metal diaphragm stem seals shall be constructed in accordance with the rules of this subarticle, based on the assumption that the bellows or diaphragms do not retain pressure and Design Pressure is imposed on a required backup stem seal such as packing. The bellows or diaphragms need not be constructed in accordance with the requirements of this Section.

NC-3516 Acceptability of Elastomer Diaphragm Valves

Valves using elastomer diaphragms, wherein the diaphragm performs the function of a disc or plug, shall be constructed in accordance with NC-3500. This is based on the assumptions that the diaphragms do not retain pressure, design pressure is imposed on the backup stem seal, and the additional requirements below.

(a) Design temperature shall not exceed 350°F (175°C).

(b) Valve size and Pressure Class shall not exceed NPS 12 (DN 300) for Class 150 (PN 20) and NPS 4 (DN 100) for Class 300 (PN 50).

(c) A backup seal stem shall be provided.

(d) Diaphragms shall meet the requirements of MSS SP-100.

NC-3520 LEVEL B, C, AND D SERVICE LIMITS

NC-3521 Design Requirements

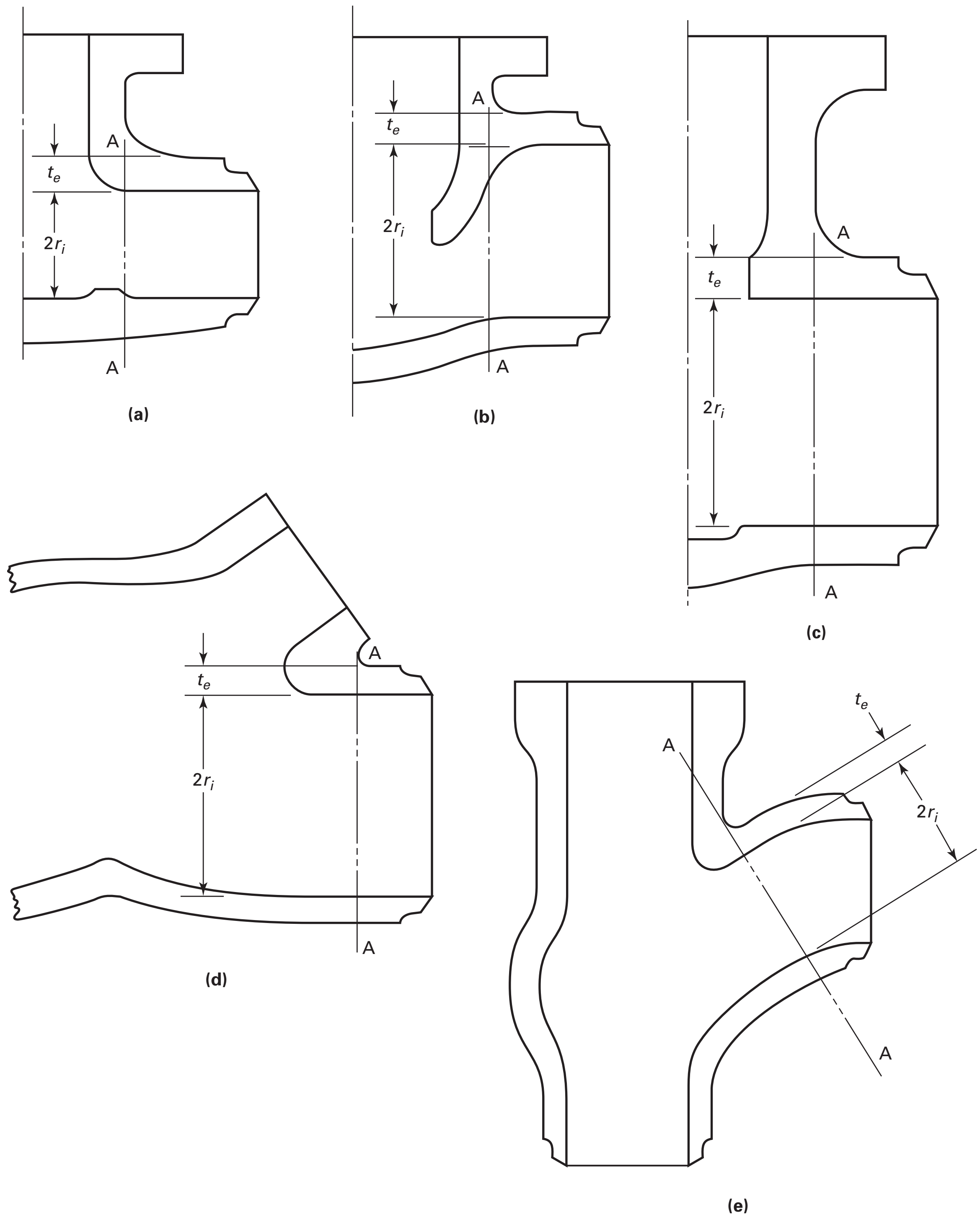
(a) When the piping system in which the valve is located is designed to the requirements of NC-3600, the valve body is considered adequate to withstand piping end loads, provided that conditions (1) and (2) below are satisfied. In lieu of (1) and (2), the design procedure of NB-3545.2 is acceptable.

(1) The section modulus and metal area at a plane normal to the flow passage through the region at the valve body crotch, that is, in the plane A–A of Figure NC-3521-1, shall be not less than 110% of the section modulus and metal area of the piping connected to the valve body inlet and outlet nozzles.

(2) The allowable stress for valve body material is equal to or greater than the allowable stress of the connected piping material. If the valve body material allowable stress is less than that of the connected piping material, the valve section modulus and metal area shall be not less than 110% of the section modulus and metal area of the connected piping multiplied by the ratio $S_{\text{pipe}}/S_{\text{valve}}$.

(b) The maximum internal pressure resulting from Service Loadings for which Level A, Level B, Level C, or Level D limits are designated shall not exceed the tabulated factors in Table NC-3521-1 times the Design Pressure or the rated pressure at the applicable service temperature. If these pressure limits are met, loadings for the stress

Figure NC-3521-1
Typical Sections of Valve Bodies



limits in Table NC-3521-1 are considered to be satisfied. Conversely, if the stress limits in Table NC-3521-1 are met, the factored pressure limit, P_{max}, need not be met.

(c) Where valves are provided with operators having extended structures and these structures are essential to maintaining pressure integrity, an analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses. The valve bodies shall conform to the stress limits listed in NC-3522. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

NC-3522 Stress and Pressure Limits

Stress limits for service loadings are specified in Table NC-3521-1. The symbols used in Table NC-3521-1 are defined as follows:

S = allowable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, psi (MPa). The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

σ_b = bending stress, psi (MPa). This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress, psi (MPa). This stress is the same as σ_m except that it includes the effect of discontinuities.

σ_m = general membrane stress, psi (MPa). This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

NC-3530 GENERAL RULES

NC-3531 Hydrostatic Tests

The following requirements apply to valves designated to either NC-3512 or NC-3513.

NC-3531.1 Shell Hydrostatic Test. A shell hydrostatic test shall be made using either water or air in accordance with the requirements of ASME B16.34. Stem seal leakage during this test is permissible. Hydrostatic tests for metal bellows of metal diaphragm stem sealed valves shall include hydrostatic testing of the valve body, bonnet, body-to-bonnet joint, and either the bellows or diaphragm or the required backup stem seal. End closure seals for retaining fluid at test pressure in welding end valves may be positioned in the welding end transitions as defined in ASME B16.34 in reasonable proximity to the end plane of the valve so as to ensure safe application of the test pressure.

NC-3531.2 Valve Closure. After the shell hydrostatic test, a valve closure test shall be performed in accordance with ASME B16.34, except that all valve sizes shall be subjected to a test differential pressure across the valve disk

Table NC-3521-1
Level A, B, C, and D Service Limits

Service Limit	Stress Limits [Note (1)]–[Note (4)]	P_{max} [Note (5)]
Level A	$\sigma_m \leq S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.5S$	1.0
Level B	$\sigma_m \leq 1.1S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$	1.1
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$	1.2
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$	1.5

NOTES:
(1) A casting quality factor of 1 shall be assumed in satisfying these stress limits.
(2) These requirements for the acceptability of valve design are not intended to ensure the functional adequacy of the valve.
(3) Design requirements listed in this Table are not applicable to valve disks, stems, seat rings, or other parts of the valves that are contained within the confines of the body and bonnet.
(4) These rules do not apply to safety relief valves.
(5) The maximum pressure shall not exceed the tabulated factors listed under P_{max} times the Design Pressure or times the rated pressure at the applicable service temperature.

not less than 110% of the 100°F (38°C) pressure rating. During this test, seat leakage value is defined by the Design Specification.

NC-3531.3 Time at Pressure. The duration of the shell hydrostatic test shall meet the requirements of NC-6223. The duration of the valve closure test shall be the greater of either 1 min/in. (2.5 sec/mm) of minimum wall thickness t_m or the testing time requirement of ASME B16.34, but not less than 1 min.

NC-3531.4 Exemptions to the Valve Closure Test.

(a) For valves that are designed for Service Conditions that have the pressure differential across the closure member limited to values less than the 100°F (38°C) pressure rating, or that have closure members or actuating devices (direct, mechanical, fluid, or electrical) that would be subject to damage at high differential pressures, the test pressure may be reduced to 110% of the maximum specified differential pressure in the closed position. This exception shall be identified in the Design Specification, and this maximum specified differential pressure shall be noted on the valve nameplate and the N Certificate Holder's Data Report Form.

(b) For valves designed for nonisolation service, the primary function of which is to modulate flow, and which by their design are prevented from providing full closure, the valve closure test defined in NC-3531.2 is not required. This exception shall be identified in the Design Specification and noted on the valve nameplate and the N Certificate Holder's Data Report Form.

NC-3590 PRESSURE RELIEF VALVE DESIGN

NC-3591 Acceptability

NC-3591.1 General. The rules of this subsubarticle constitute the requirements for the design acceptability of spring loaded pressure relief valves. The design rules for pilot operated and power-actuated pressure relief valves are covered by NC-3500. The rules of this subsubarticle cover the pressure-retaining integrity of the valve inlet and outlet connections, nozzle, disk, body structure, bonnet (yoke), and body-to-bonnet (yoke) bolting. The rules of this subsubarticle also cover other items such as the spring, spindle (stem), spring washers, and set pressure adjusting screw. The rules of this subsubarticle do not apply to guides, control rings, bearings, set screws, and other nonpressure-retaining items. Figures NC-3591.1-1 and NC-3591.1-2 are illustrations of typical pressure relief valves.

NC-3591.2 Definitions. The definitions for pressure relief valve terms used in this subsubarticle are given in the American National Standard ANSI B95.1-1977, Terminology for Pressure Relief Devices, and also in Article NC-7000. Pressure relief valves characteristically have multipressure zones within the valve, that is, a primary pressure zone and a secondary pressure zone as illustrated by Figures NC-3591.1-1 and NC-3591.1-2.

NC-3591.3 Acceptability of Small Pressure Relief Valves. Pressure relief valves having inlet piping connections NPS 2 (DN 50) and under shall comply with the wall thickness requirements of NC-3595.1. Other elements of the valve shall be designed to ensure pressure integrity, in accordance with appropriate design practices based on successful experience in comparable service conditions.

NC-3591.4 Acceptability of Large Pressure Relief Valves. The design shall be such that the requirements of this subsubarticle are met.

NC-3592 Design Considerations

NC-3592.1 Design Conditions. The general design requirements of NC-3100 are applicable, with consideration for the design conditions of the primary and secondary pressure zones. In case of conflict between NC-3100 and NC-3590, the requirements of NC-3590 shall apply. Mechanical loads for both the closed and open (full discharge) positions shall be considered in conjunction with the service conditions. In addition, the requirements of Article NC-7000 shall be met.

NC-3592.2 Stress Limits for Specified Service Loadings.

(a) Level A Service Loadings. Stress limits for Level A service loadings for the valve shall be as follows.

(1) The general membrane stress shall not exceed S.

(2) The general membrane stress plus bending stress shall not exceed 1.5S.

(3) Substantiation by analysis of localized stresses associated with contact loading of bearing or seating surfaces is not required.

(4) The values of S shall be in accordance with Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

(b) Level B, C, and D Service Loadings. Stress limits for Level B, C, and D service loadings are specified in Table NC-3592.2(b)-1. The symbols used in Table NC-3592.2(b)-1 are defined in NC-3522.

NC-3593 Special Rules

NC-3593.1 Hydrostatic Test. Pressure relief valve shell hydrostatic tests shall be made in accordance with NC-3531.1 and NC-3531.3 except that the inlet (primary pressure-containing) portion of the pressure relief valve shall be shell tested at a pressure at least equal to 1.5 times the set pressure marked on the valve. For closed system application, the outlet portion of the pressure relief valve shall be shell tested to 1.5 times the design secondary pressure (NC-7111).

NC-3593.2 Marking. In addition to marking required by NCA-8220 and Article NC-7000, the secondary Design Pressure shall be marked on the valve or valve nameplate.

Figure NC-3591.1-1
Typical Pressure Relief Devices

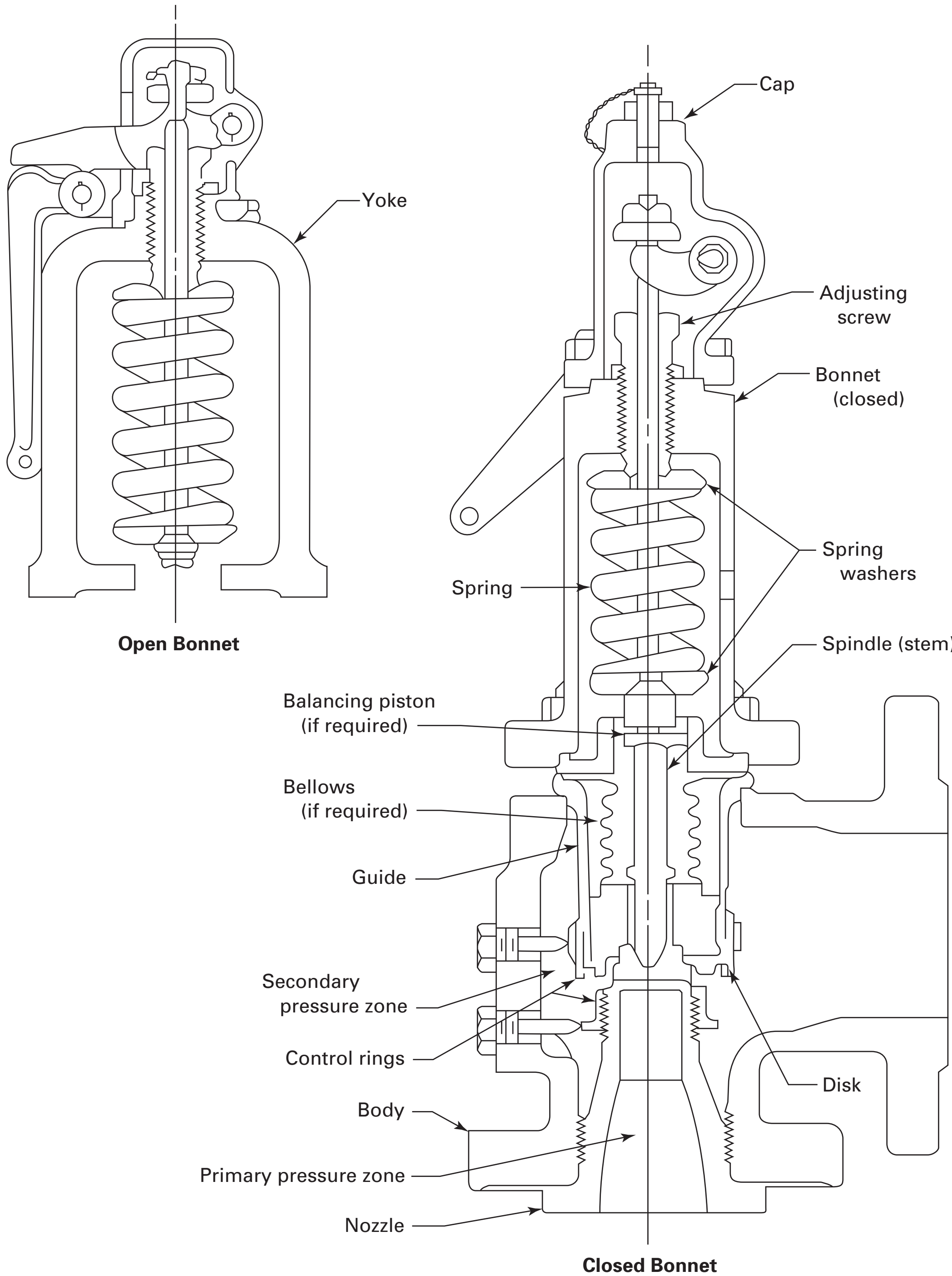
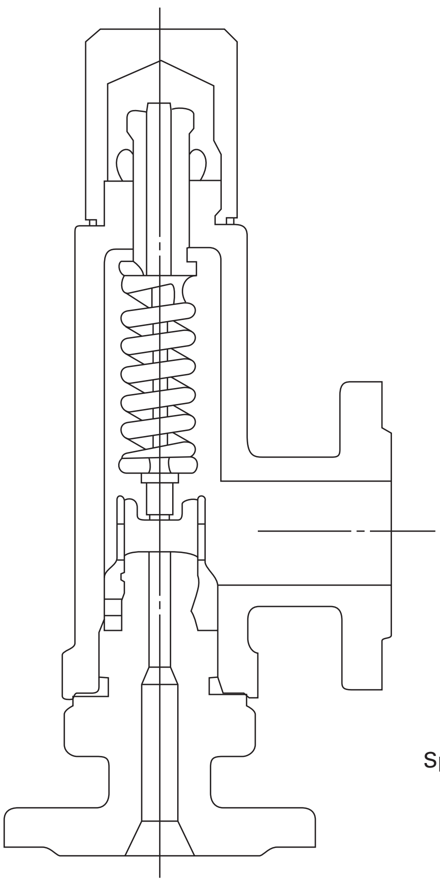


Figure NC-3591.1-2
Typical Pressure Relief Devices



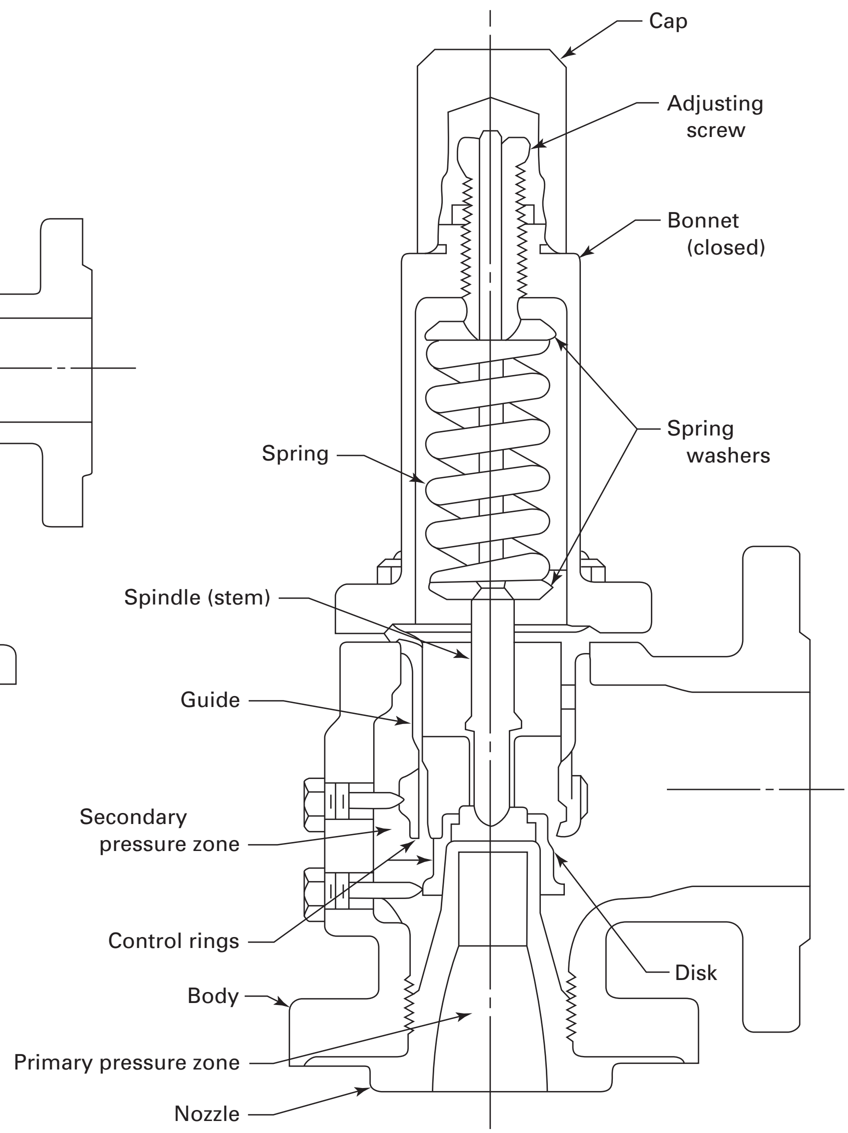


Table NC-3592.2(b)-1
Class 2 Pressure Relief Devices:
Level B, C, and D Service Loadings

Service Loading	Stress Limits
Level B	$\sigma_m \leq 1.1S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.65S$
Level C	$\sigma_m \leq 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 1.8S$
Level D	$\sigma_m \leq 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \leq 2.4S$

GENERAL NOTES:
(a) A casting quality factor is not required to satisfy these limits.
(b) These requirements for the acceptability of valve design are not intended to ensure the functional adequacy of the valve. However, the designer is cautioned that the requirements of Article NC-7000 relative to set pressure, lift, blowdown, and closure shall be met.
(c) Design requirements listed in this Table are applicable to those portions of the valves that are pressure retaining or affect pressure-retaining items of these valves.

NC-3594 Design Requirements for Level B, C, and D Service Loadings

(a) When the piping system in which the valve is located is designed to the requirements of NC-3600, the valve body may be considered adequate to withstand piping end loads, provided that conditions (1) and (2) below are satisfied.

(1) The section modulus and metal area at a plane normal to the flow passage through the region at the valve inlet and outlet (Figures NC-3591.1-1 and NC-3591.1-2) shall be not less than 110% of the section modulus and metal area of the piping connected (or joined) to the valve inlet and outlet.

(2) The allowable stress for valve body material shall be equal to or greater than the allowable stress of the connected piping material. If the valve body material allowable stress is less than that of the connected piping material, the valve section modulus and metal area shall be not less than 110% of the section modulus and metal area of the connecting pipe multiplied by the ratio $S_{\text{pipe}}/S_{\text{valve}}$.

(b) The pressure-retaining portions of pressure relief valves shall conform to the stress limits listed in Table NC-3592.2(b)-1 for those Service Loadings stipulated as Level B, C, or D.

(c) Pressure relief valves have extended structures, and these structures are essential to maintaining pressure integrity. An analysis, when required by the Design Specification, shall be performed based on static forces resulting from equivalent earthquake accelerations acting at the centers of gravity of the extended masses. Classical bending and direct stress equations, where free body diagrams determine a simple stress distribution that is in equilibrium with the applied loads, may be used.

NC-3595 Design of Pressure Relief Valve Parts

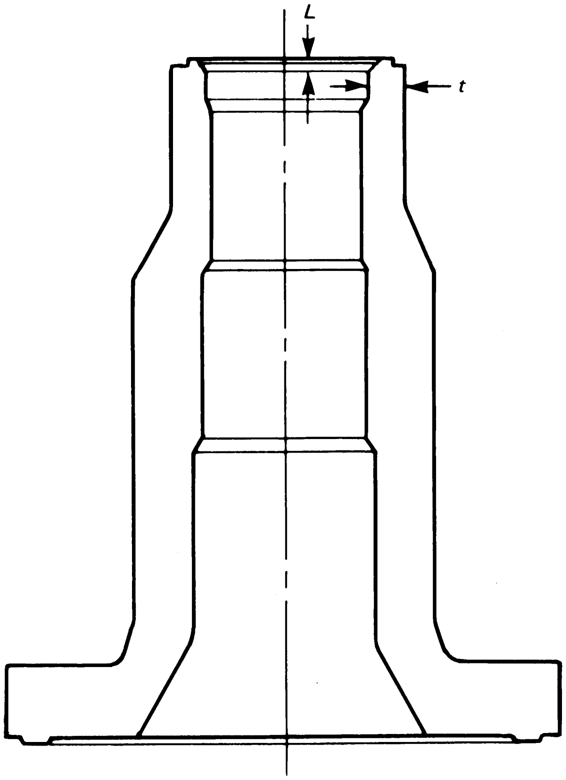
NC-3595.1 Body. Minimum wall thicknesses of valve bodies shall conform to the applicable requirements for Standard Class category valves of ASME B16.34, taking into account the dimensional and pressure conditions of the primary and secondary zones. Minimum wall thickness adjacent to the inlet nozzle and for a distance equal to that minimum wall thickness from the plane of the back face of the inlet flange shall be that required for Standard Class category valves of ASME B16.34 for the inlet flange size and pressure class. Minimum wall thicknesses elsewhere in the secondary zone shall be determined by the requirements for Standard Class category valves of ASME B16.34 for the outlet flange size and pressure class, including such other rules and considerations of ASME B16.34 as may be applicable. In valve design where the outlet flange is an extension of the bonnet, the bonnet design shall conform to these rules. Where the inlet flange geometry involves inside contours encroaching on the metal section boundary represented by dimension B in Tables 9, 12, 15, 18, 21, 24, or 27 in ASME B16.5, adequacy of the design shall be proven by stress calculation in accordance with NC-3658. Additional metal thickness needed for operating stresses, shapes other than circular, stress concentrations, and adequate structural strength of the crotch area of the neck of the valve for bending stresses and installation stress that may be imposed on the valve must be determined by the manufacturer.

NC-3595.2 Bonnet (Yoke). The bonnet (yoke) may be analyzed using classic bending and direct stress equations, with appropriate free body diagrams. The general membrane stress and the general membrane stress plus bending stress shall not exceed the stress limits of NC-3592.2.

NC-3595.3 Nozzle. The minimum wall thickness of the nozzle shall be determined from the limit on general membrane stress. Alternatively, the rules of NB-3594.3 may be used. These requirements are not applicable to the transition region to the seat contacting area of the nozzle defined by L in Figure NC-3595.3-1, provided the dimension L is less than the nominal wall thickness t.

NC-3595.4 Body-to-Bonnet Joint. For valves having inlet piping connections NPS 2 (DN 50) and less, body-to-bonnet connections may be threaded. The thread shear stress, considering all loadings, shall not exceed 0.6 times the allowable stress S. The body-to-bonnet bolting shall be designed to resist the hydrostatic end force of the rated maximum secondary Design Pressure combined with the total spring load to full lift, and to maintain sufficient compression for a tight joint on the gasket or joint

Figure NC-3595.3-1
Valve Nozzle



Legend:

L = length of seal transition region, in. (mm); ≤ t

t = nozzle wall thickness, in. (mm)

contact surface. The bolt stresses for these loadings shall not exceed the allowable stress values of Section II, Part D, Subpart 1, Table 3.

NC-3595.5 Disk. The stress evaluation shall be made for the condition which results in the maximum stress in the disk. The bending stress shall not exceed the stress limits of NC-3592.2.

NC-3595.6 Spring Washer. The shear stress shall not exceed 0.6S. The bending stress shall not exceed the stress limits of NC-3592.2.

NC-3595.7 Spindle (Stem). The general membrane stress shall not exceed the stress limits of NC-3592.2.

NC-3595.8 Adjusting Screw. The adjusting screw shall be analyzed for thread stress in accordance with the method of ASME B1.1, and this stress shall not exceed 0.6S. The general membrane stress of the adjusting screw shall not exceed the stress limits of NC-3592.2, based on the root diameter of the thread.

NC-3595.9 Spring. The valve spring shall be designed so that the full lift spring compression shall be no greater than 80% of the nominal solid deflection. The permanent set of the spring (defined as the difference between the free height and the height measured a minimum of 10 min after the spring has been compressed solid three additional times after presetting at room temperature) shall not exceed 1.0% of the free height.

NC-3596 Design Reports

NC-3596.1 General Requirements. The manufacturer shall certify compliance with the requirements of this subarticle in accordance with the provisions of NCA-3570.

NC-3600 PIPING DESIGN

NC-3610 GENERAL REQUIREMENTS

NC-3611 Acceptability

The requirements for acceptability of a piping system are given in the following subparagraphs.

NC-3611.1 Allowable Stress Values. Allowable stress values to be used for the design of piping systems are given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

NC-3611.2 Stress Limits.

(a) Design and Service. Loadings shall be specified in the Design Specification.

(b) Design Loadings. The sum of stresses due to design internal pressure, weight, and other sustained loads shall meet the requirements of eq. NC-3652(8).

(c) Service Loadings. The following service limits shall apply to Service Loadings as designated in the Design Specifications.

(1) Level A and B Service Limits. For Service Loadings for which Level A and B Service Limits are designated in the Design Specification, the requirements of NC-3653 shall be met. When Level B Limits apply, the peak pressure P_{max} alone shall not exceed 1.1 times the pressure P_a calculated in accordance with eq. NC-3641.1(5). The calculation of P_a shall be based on the maximum allowable stress for the material at the coincident temperature.

(2) Level C Service Limits. For Service Loadings for which Level C Service Limits are designated in the Design Specification, the sum of stresses shall meet the requirements of NC-3654.

(3) Level D Service Limits. For Service Loadings for which Level D Service Limits are designated in the Design Specification, the sum of stresses shall meet the requirements of NC-3655.

(4) Test Conditions. Testing shall be in accordance with Article NC-6000. Occasional loads shall not be considered as acting at time of test.

(d) External Pressure Stress. Piping subject to external pressure shall meet the requirements of NC-3641.2.

(e) Allowable Stress Range for Expansion Stresses. The allowable stress range S_A is given by eq. (1):

$$S_A = f(1.25S_c + 0.25S_h) \quad (1)$$

where

f = stress range reduction factor for cyclic conditions for total number N of full temperature cycles over total number of years during which system is expected to be in service from Table NC-3611.2(e)-1
S_c = basic material allowable stress at minimum (cold) temperature, psi (MPa)
S_h = basic material allowable stress at maximum (hot) temperature, psi (MPa)

(1) In determining the basic material allowable stresses S_c and S_h, joint efficiencies need not be applied.

(2) Stress reduction factors apply essentially to noncorrosive service and to corrosion resistant materials, where employed to minimize the reduction in cyclic life caused by corrosive action.

(3) If the range of temperature change varies, equivalent full temperature cycles may be computed as follows:

$$N = N_E + r_1^5 N_1 + r_2^5 N_2 + \ldots + r_n^5 N_n \quad (2)$$

where

N_E = number of cycles at full temperature change ΔT_E for which expansion stress S_E has been calculated
$N_1, N_2, \ldots, N_n$ = number of cycles at lesser temperature changes, $\Delta T_1, \Delta T_2, \ldots, \Delta T_n$
$r_1, r_2, \ldots, r_n$ = $(\Delta T_1)/(\Delta T_E), (\Delta T_2)/(\Delta T_E), \ldots, (\Delta T_n)/(\Delta T_E)$
= the ratio of any lesser temperature cycles for which the expansion stress S_E has been calculated

(f) Allowable Stress for Nonrepeated Stresses. The allowable stress due to any single nonrepeated anchor movement (e.g., predicted building settlement) calculated in accordance with eq. NC-3653.2(b)(10b) shall be $3.0S_c$.

Table NC-3611.2(e)-1
Stress Range Reduction Factors

Number of Equivalent Full Temperature Cycles, N	f
7,000 and less	1.0
7,000 to 14,000	0.9
14,000 to 22,000	0.8
22,000 to 45,000	0.7
45,000 to 100,000	0.6
100,000 and over	0.5

NC-3611.3 Alternative Analysis Methods. The specific design requirements of NC-3600 are based on a simplified engineering approach. A more rigorous analysis such as described in NB-3600 or NB-3200 may be used to calculate the stresses required to satisfy these requirements. These calculated stresses must be compared to the allowable stresses in this Subsection. In such cases, the designer shall include appropriate justification for the approach taken in the Certified Design Report.

NC-3612 Pressure–Temperature Ratings for Piping Products

NC-3612.1 Piping Products Having Specific Ratings.

(a) Pressure–temperature ratings for certain piping products have been established and are contained in some of the standards listed in Table NCA-7100-1. The pressure ratings at the corresponding temperatures given in the standards listed in Table NCA-7100-1 shall not be exceeded, and piping products shall not be used at temperatures in excess of those given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 for the materials of which the products are made.

(b) Where piping products have established pressure–temperature ratings which do not extend to the upper material temperature limits permitted by this Subsection, the pressure–temperature ratings between those established and the upper material temperature limit may be determined in accordance with the rules of this Subsection.

NC-3612.2 Piping Products Not Having Specific Ratings. Should it be desired to use methods of manufacture or design of piping products not now covered by this Subsection, it is intended that the manufacturer shall comply with the requirements of NC-3640 and NC-3690 and other applicable requirements of this Subsection for the Design Loadings involved. The manufacturer's recommended pressure ratings shall not be exceeded.

NC-3612.4 Considerations for Local Conditions and Transients.

(a) Where piping systems operating at different pressures are connected by a valve or valves, the valve or valves shall be designed for the higher pressure system requirements of pressure and temperature. The lower pressure system shall be designed in accordance with (1), (2), or (3) below.

(1) The requirement of the higher pressure system shall be met.

(2) Pressure relief devices or safety valves shall be included to protect the lower pressure system in accordance with NC-7311 and NC-7321.

(3) Assure compliance with all the conditions of (-a) through (-e) below.

(-a) Redundant check or remote actuated valves shall be used in series at the interconnection, or a check in series with a remote actuated valve.

(-b) When mechanical or electrical controls are provided, redundant and diverse controls shall be installed which will prevent the interconnecting valves from opening when the pressure in the high pressure system exceeds the Design Pressure of the low pressure system.

(-c) Means shall be provided such that operability of all components, controls, and interlocks can be verified by test.

(-d) Means shall be provided to assure that the leakage rate of the interconnecting valves does not exceed the relieving capacity of the relief devices on the low pressure system.

(-e) Adequate consideration shall be given to the control of fluid pressure caused by heating of the fluid trapped between two valves.

The low pressure system relieving capacity may be determined in accordance with NC-7311 and NC-7321, on the basis of the interconnecting valve being closed but leaking at a specified rate, when (3)(-a) through (3)(-e) above are met. The pressure relief devices or safety valves shall adjoin or be as close as possible to the interconnecting valve and shall relieve preferably to a system where the relieved effluent may be contained. The design of the overpressure protection system shall be based on pressure transients that are specified in the Design Specification, and all other applicable requirements of Article NC-7000 shall be met.

(b) When pressure reducing valves are used and one or more pressure relief devices or safety valves are provided, bypass valves may be provided around the pressure reducing valves. The combined relieving capacity of the pressure relief devices, safety valves, and relief piping shall be such that the lower pressure system service pressure will not exceed the lower pressure system Design Pressure by more than 10% if the pressure reducing valve fails in the open position and the bypass valve is open at the same time. If the pressure reducing valve and its bypass valve are mechanically or electrically interlocked so that only one may be open at any time, the high pressure system is at a pressure higher than the Design Pressure of the low pressure system, the relieving capacity of the pressure relief devices, safety valves, and relief piping shall be at least equal to the maximum capacity of the larger of the two valves. The interlocks shall be redundant and diverse.

(c) Exhaust and pump suction lines for any service and pressure shall have relief valves of a suitable size, unless the lines and attached equipment are designed for the maximum pressure and temperature to which they may be accidentally or otherwise subjected.

(d) The effluent from relief devices may be discharged outside the containment only if provisions are made for the disposal of the effluent.

(e) Drip lines from steam headers, mains, separators, or other equipment operating at different pressures shall not discharge through the same trap. Where several traps discharge into a single header that is or may be under pressure, a stop valve and a check valve shall be provided in the discharge line from each trap. The Design Pressure of trap discharge piping shall not be less than the maximum discharge pressure to which it may be subjected. Trap discharge piping shall be designed for the same pressure as the trap inlet piping, unless the discharge piping is vented to a system operated under lower pressure and has no intervening stop valves.

(f) Blowdown, dump, and drain piping from water spaces of a steam generation system shall be designed for saturated steam at the pressures and temperatures given below.

Vessel Pressure, psi (MPa)	Design Pressure, psi (MPa)	Design Temperature, °F (°C)
600 (4) and below	250 (1.7)	410 (210)
601 to 900 (4 to 6)	400 (3)	450 (230)
901 to 1,500 (6.01 to 10)	600 (4)	490 (250)
Over 1,500 (10)	900 (6)	535 (280)

These requirements for blowdown, dump, and drain piping apply to the entire system beyond the blowdown valves to the blowdown tank or other points where the pressure is reduced to approximately atmospheric and cannot be increased by closing a valve. When pressures can be increased because of calculated pressure drop or otherwise, this shall be taken into account in the design. Such piping shall be designed for the maximum pressure to which it may be subjected.

(g) Pump discharge piping shall be designed for the maximum pressure exerted by the pump at any load and for the highest corresponding temperature actually existing.

(h) Where a fluid passes through heat exchangers in series, the Design Temperature of the piping in each section of the system shall conform to the most severe temperature condition expected to be produced by heat exchangers in that section.

NC-3613 Allowances

NC-3613.1 Corrosion or Erosion. When corrosion or erosion is expected, the wall thickness of the piping shall be increased over that required by other design requirements. This allowance shall be consistent with the specified design life of the piping.

NC-3613.2 Threading and Grooving. The calculated minimum thickness of piping that is to be threaded or grooved shall be increased by an allowance equal to the depth of the cut.

NC-3613.3 Mechanical Strength. When necessary to prevent damage, collapse, or buckling of pipe due to superimposed loads from supports or other causes, the wall thickness of the pipe shall be increased, or, if this is impractical or would cause excessive local stresses, the superimposed loads or other causes shall be reduced or eliminated by other design methods.

NC-3613.4 Steel Casting Quality Factors. The quality factors for castings required in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 apply to castings which are designed using the stresses contained in this Subsection. The minimum examination required for these castings is that stipulated in the applicable material specification and in NC-2570. Castings satisfying these minimum requirements shall be designed with a quality factor of 1.00.

NC-3620 DESIGN CONSIDERATIONS

NC-3621 Design and Service Loadings

The provisions of NC-3110 shall apply, except as modified in this subarticle.

NC-3621.1 Cooling Effects on Pressure. When the cooling of a fluid may reduce the pressure in the piping to below atmospheric, the piping shall be designed to withstand the external pressure or provision shall be made to break the vacuum.

NC-3621.2 Fluid Expansion Effects. When the expansion of a fluid may increase the pressure, the piping system shall be designed to withstand the increased pressure or provision shall be made to relieve the excess pressure.

NC-3622 Dynamic Effects

NC-3622.1 Impact. Impact forces caused by either external or internal loads shall be considered in the piping design.

NC-3622.2 Reversing Dynamic Loads. Reversing dynamic loads are those loads which cycle about a mean value and include building filtered loads and earthquake loads. A reversing dynamic load shall be treated as a nonreversing dynamic load in applying the rules of NC-3600 when the number of reversing dynamic load cycles, exclusive of earthquake, exceeds 20.

NC-3622.3 Vibration. Piping shall be arranged and supported so that vibration will be minimized. The designer shall be responsible, by design and by observation under startup or initial service conditions, for ensuring that vibration of piping systems is within acceptable levels.

NC-3622.4 Exposed Piping. Exposed piping shall be designed to withstand wind loadings, using meteorological data to determine wind forces. When State, Province, or Municipal ordinances covering the design of building structures are in effect and specify wind loadings, these values shall be considered the minimum design values. However, it is not necessary to consider earthquake and wind loadings to be acting concurrently.

NC-3622.5 Nonreversing Dynamic Loads. Nonreversing dynamic loads are those loads which do not cycle about a mean value and include the initial thrust force due to sudden opening or closure of valves and waterhammer resulting from entrapped water in two-phase flow systems (see Figure NC-3622-1). Reflected waves in a piping system due to flow transients are classified as nonreversing dynamic loads.

NC-3623 Weight Effects

Piping systems shall be supported to provide for the effects of live and dead weights, as defined in the following subparagraphs, and they shall be arranged or properly restrained to prevent undue strains on equipment.

NC-3623.1 Live Weight. The live weight shall consist of the weight of the fluid being handled or of the fluid used for testing or cleaning, whichever is greater.

NC-3623.2 Dead Weight. The dead weight shall consist of the weight of the piping, insulation, and other loads permanently imposed upon the piping.

NC-3624 Thermal Expansion and Contraction Loads

NC-3624.1 General Requirements.

(a) The design of piping systems shall take account of the forces and moments resulting from thermal expansion and contraction and from the effects of expansion joints.

(b) Thermal expansion and contraction shall be provided for, preferably by pipe bends, elbows, offsets, or changes in direction of the pipeline.

(c) Hangers and supports shall permit expansion and contraction of the piping between anchors.

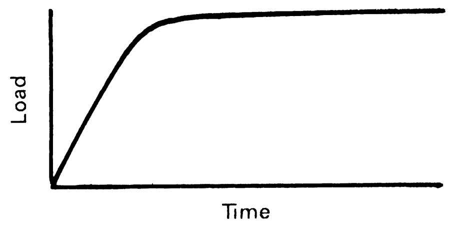
NC-3624.2 Expansion Joints. Expansion joints of the corrugated slip sleeve, ball, or swivel types may be used if they conform to the requirements of NC-3649.1 through NC-3649.4; their structural and working parts are designed for the maximum pressure and temperature of the piping system; and their design prevents the complete disengagement of working parts while in service.

NC-3640 PRESSURE DESIGN OF PIPING PRODUCTS

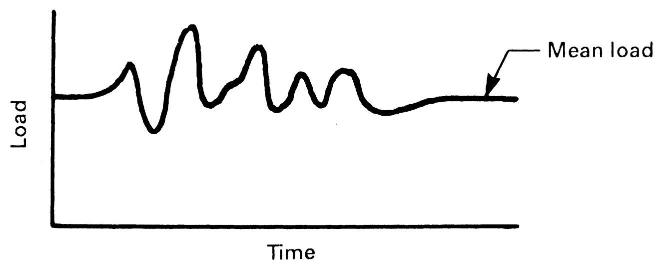
NC-3641 Straight Pipe

NC-3641.1 Straight Pipe Under Internal Pressure. The minimum thickness of pipe wall required for Design Pressures and for temperatures not exceeding those for the various materials listed in Section II, Part D, Subpart

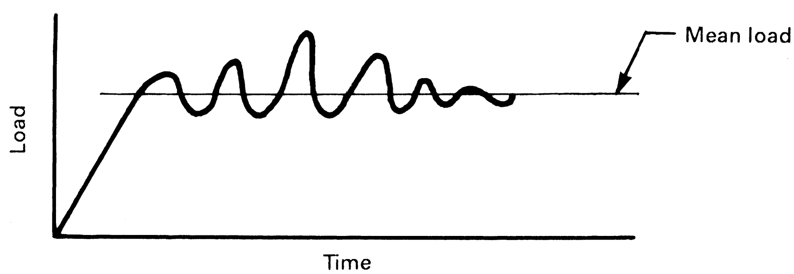
Figure NC-3622-1
Examples of Reversing and Nonreversing Dynamic Loads



(a) Nonreversing Dynamic Load
(Relief/Safety Valve Open End Discharge)



(b) Reversing Dynamic Load
(Earthquake Load Cycling About Normal Operating Condition)



(c) Nonreversing Dynamic Load
(Initial Water Slug Followed By Reflected Waves)

1, Tables 1A, 1B, and 3, including allowances for mechanical strength, shall not be less than that determined by eq. (3) as follows:

$$t_m = \frac{PD_o}{2(S + Py)} + A \quad (3)$$

$$t_m = \frac{Pd + 2SA + 2yPA}{2(S + Py - P)} \quad (4)$$

where

A = an additional thickness, in. (mm):

(a) to compensate for material removed or wall thinning due to threading or grooving, required to make a mechanical joint. The values of A listed in Table NC-3641.1(a)-1 are minimum values for material removed in threading

(b) to provide for mechanical strength of the pipe. Small diameter, thin wall pipe or tubing is susceptible to mechanical damage due to erection, operation, and maintenance procedures. Accordingly, appropriate means must be employed to protect such piping against these types of loads if they are not considered as Design Loads. Increased wall thickness is one way of contributing to resistance against mechanical damage.

(c) to provide for corrosion or erosion. Since corrosion and erosion vary widely from installation to installation, it is the responsibility of designers to determine the proper amounts which must be added for either or both of these conditions.

d = inside diameter of pipe, in. (mm). In using eq. (4) the value of d is for the maximum possible inside diameter allowable under the purchase specifications.

D_o = outside diameter of pipe, in. (mm). For design calculations, the outside diameter of pipe as given in tables of standards and specifications shall be used in obtaining the value of t_m. When calculating the allowable pressure of pipe on hand or in stock, the actual measured outside diameter and actual measured minimum wall thickness at the thinner end of the pipe may be used to calculate this pressure.

P = internal Design Pressure, psi (MPa)

S = maximum allowable stress for the material at the Design Temperature, psi (MPa) (Section II, Part D, Subpart 1, Tables 1A and 1B)

t_m = minimum required wall thickness, in. (mm). If pipe is ordered by its nominal wall thickness, the manufacturing tolerance on wall thickness must be taken into account. After the minimum pipe wall thickness t_m is determined by eq. (4), this minimum thickness shall be increased by an amount sufficient to provide the manufacturing tolerance allowed in the applicable pipe specification or required by the process. The next heavier commercial wall thickness shall then be selected from standard thickness schedules such as contained in ASME B36.10M or from manufacturers' schedules for other than standard thickness.

The allowable working pressure of pipe may be determined from the following equation:

$$P_a = \frac{2St}{D_o - 2yt} \quad (5)$$

where

P_a = the calculated maximum allowable internal pressure, psi (MPa), for straight pipe which shall at least equal the Design Pressure.

(a) P_a may be used for piping products with pressure ratings equal to that of straight pipe (see ASME B16.9).

(b) For standard flanged joints, the rated pressure shall be used instead of P_a.

(c) For reinforced branch connections (NC-3643) where part of the required reinforcement is in the run pipe, the Design Pressure shall be used instead of P_a.

(d) For other piping products where the pressure rating may be less than that of the pipe (for example, flanged joints designed to Section III Appendices, Mandatory Appendix XI), the Design Pressure shall be used instead of P_a.

(e) P_a may be rounded out to the next higher unit of 10 psi (0.1 MPa).

t = the specified or actual wall thickness minus, as appropriate, material removed in threading, corrosion or erosion allowance, material manufacturing tolerances, bending allowance (NC-3642.1), and material to be removed by counterboring, in. (mm)

y = a coefficient having a value of 0.4, except that, for pipe with a D_o/t_m ratio less than 6, the value of y shall be taken as

$$y = \frac{d}{d + D_o} \quad (6)$$

Table NC-3641.1(a)-1
Values of *A*

Type of Pipe	*A*, in. (mm)
Threaded steel and nonferrous pipe:	
NPS $^3/_4$ (DN 20) and smaller	0.065 (1.65)
NPS 1 (DN 25) and larger	Depth of thread
Grooved steel and nonferrous pipe	Depth of groove plus $^1/_{64}$ in. (0.40)

NC-3641.2 Straight Pipe Under External Pressure. For determining wall thickness and stiffening requirements for straight pipe under external pressure, the procedures outlined in NC-3133 shall be followed.

NC-3642 Curved Segments of Pipe

(15) **NC-3642.1 Pipe Bends.** Pipe bends shall be subject to the limitations in (a), (b), and (c) below.

(a) The minimum wall thickness after bending shall not be less than the minimum wall thickness required for straight pipe.

(b) The ovality shall meet the requirements of NC-4223.2.

(c) The information in Section III Appendices, Nonmandatory Appendix GG is given to guide the designer when ordering pipe.

NC-3642.2 Elbows. Flanged elbows manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use at the pressure–temperature ratings specified by such standards. In the case of standards under which butt welding elbows are made to a nominal wall thickness, the elbows shall be considered suitable for use with pipe of the same nominal thickness and of the same material.

NC-3643 Intersections

NC-3643.1 General Requirements.

(a) NC-3643 gives acceptable rules governing the design of branch connections to sustain internal and external pressure in cases where the axes of the branch and the run intersect, the angle between the axes of the branch and of the run is between 45 deg and 90 deg, inclusive, and no allowance is required for corrosion or erosion.

(b) Branch connections in which the smaller angle between the axes of the branch and the run is less than 45 deg impose special design and fabrication problems. The rules given for angles of 45 deg and 90 deg, inclusive, may be used as a guide, but sufficient additional strength must be provided to assure safe service. Such branch connections shall be designed to meet the requirements of NC-3649.

(c) Branch connections in piping may be made by using one of the products or methods given in (1) through (5) below:

(1) flanged, butt welding, socket welding, or screwed fittings made in accordance with the applicable standards listed in Table NCA-7100-1;

(2) welded outlet fittings, such as cast or forged nozzles; couplings, including ASME B16.11 couplings, to a maximum nominal size of 3 in. (DN 80); and adaptors or similar items having butt welding, socket welding, threaded, or flanged ends for attachment of the branch pipe. Such outlet fittings shall be attached to the main pipe

(-a) by a full penetration weld; or

(-b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Figure NC-3643.2(b)-2 sketch (e) or (f), provided the requirements of (-1) through (-4) below are met:

(-1) the nominal size of the branch shall not exceed 2 in. (50 mm) or one-quarter of the nominal size of the run, whichever is less;

(-2) the minimum size of the weld, X_{min}, shall not be less than $1\frac{1}{4}$ times the fitting wall thickness in the reinforcement zone;

(-3) the groove angle, θ, shall be equal to or greater than 45 deg;

(-4) except for attaching ASME B16.11 couplings, the requirements of NC-3643.3 shall be met.

(3) extruded outlets at right angles to the run pipe, in accordance with NC-3643.4, where the attachment of the branch pipe is by butt welding;

(4) by attaching the branch pipe directly to the run pipe by welding or threading as stipulated in (-a)), (-b), or (-c) below:

(-a) right angle branch connections may be made by attaching the branch pipe to the run pipe by socket welding, provided the requirements of (-1) through (-5) below are met:

(-1) the nominal size of branch does not exceed 2 in. (50 mm) or one-quarter the nominal size of the run, whichever is less;

(-2) the depth of the socket in the run is at least equal to that shown in ASME B16.11 with a minimum shoulder of $\frac{1}{16}$ in. (1.5 mm) between the bottom of the socket and the inside diameter of the run pipe; weld metal may be deposited on the run pipe to provide the required socket depth and to provide any reinforcement required;

(-3) a minimum of $\frac{1}{16}$ in. (1.5 mm) clearance shall be provided between the bottom of the socket and the end of the inserted pipe;

(-4) the size of the fillet weld shall not be less than $1\frac{1}{4}$ times the nominal branch wall thickness;

(-5) the requirements of NC-3643.3 shall be met.

(-b) right angle branch connections may be made by attaching the branch pipe directly to the run by threading within the provisions of NC-3671.3 and provided the requirements of (-1) and (-2) below are met:

(-1) the nominal size of the branch does not exceed 2 in. (50 mm) or one-quarter of the nominal size of the run, whichever is less;

(15) **Table NC-3642.1(c)-1**

DELETED

(-2) minimum thread engagement shall be six full threads for $^1/_2$ in. (DN 15) and $^3/_4$ in. (DN 20) branches; seven for 1 in. (DN 25), $1^1/_4$ in. (DN 32), and $1^1/_2$ in. (DN 40) branches; and eight for 2 in. (DN 50) branches; weld metal may be deposited on the run pipe to provide sufficient thickness for required thread engagement;

(5) branch connections may be made by attaching the branch pipe directly to the run pipe:

(-a) by a full penetration weld as shown in Figure NC-3643.2(b)-1, with or without pad or saddle reinforcement as shown in Figure NC-3643.3(c)(1)-1 or Figure NC-3643.3(c)(1)-2, provided the requirements of NC-3643.3 are met; or

(-b) for right angle branch connections, by a fillet weld or partial penetration weld as shown in Figure NC-3643.2(b)-2, sketches (a) through (d), provided the requirements of (-1) through (-4) below are met:

(-1) the nominal size of the branch shall not exceed 2 in. (DN 50) or one-quarter of the nominal size of the run, whichever is less;

(-2) the minimum size of the weld, X_{min}, shall not be less than $1^1/_4$ times the nominal branch wall thickness;

(-3) the groove angle, θ, shall be equal to or greater than 45 deg;

(-4) the requirements of NC-3643.3 shall be met.

NC-3643.2 Branch Connections Not Requiring Reinforcement. Reinforcement need not be provided if the branch connection is made in accordance with the requirements of (a) through (c) below:

(a) by the use of a fitting manufactured in accordance with one of the standards listed in Table NCA-7100-1 and used within the limits of pressure–temperature ratings specified in such standard, a butt welding fitting made in accordance with ASME B16.9 or MSS SP-97 shall be of nominal thickness not less than the nominal thickness required for the adjoining pipe;

(b) by welding a coupling or half coupling directly to the run pipe, provided the nominal diameter of the branch does not exceed NPS 2 (DN 50) or one-quarter the nominal diameter of the run, whichever is less; the wall thickness of the coupling is not less than that of the branch pipe; the coupling is joined to the run pipe by one of the methods shown in Figure NC-3643.2(b)-1, sketch (c)(1) or Figure NC-3643.2(b)-2, sketch (e); and in no case is the thickness of the coupling less than extra heavy or 3,000 lb nominal rating;

(c) by using an extruded outlet, provided the nominal diameter of the branch does not exceed NPS 2 (DN 50) or one-quarter of the nominal diameter of the pipe, whichever is less, and the minimum wall thickness at the abutting end of the outlet is not less than required for the branch pipe wall.

NC-3643.3 Branch Connections Requiring Reinforcement.

(a) Calculations shall be made to determine the adequacy of reinforcement in branch connections, except as exempted in NC-3643.2.

(b) A branch connection may be made by extruding an integrally reinforced outlet on the run pipe. The reinforcement requirements shall be in accordance with NC-3643.4.

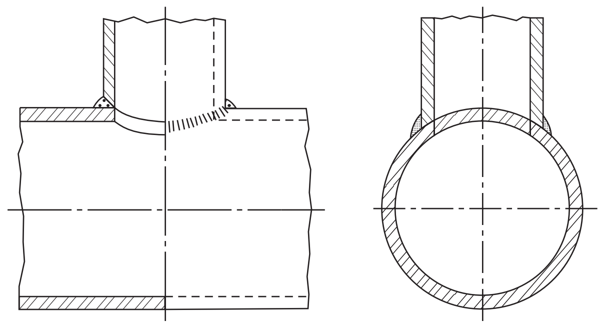
(c) A branch connection may be made by welding a pipe or fitting directly to the run pipe with or without added reinforcement, provided the pipe or fitting, deposited weldment, and other reinforcing devices meet the requirements of this subparagraph. This subparagraph gives rules covering the design of branch connections to sustain internal pressure in cases where the angle between the axes of the branch and of the run ranges from 45 deg to 90 deg NC-3643.5 gives rules governing the design of connections to sustain external pressure.

(1) Nomenclature. Figures NC-3643.3(c)(1)-1 and NC-3643.3(c)(1)-2 illustrate the notations used in the pressure–temperature design conditions of branch connections, which are as follows:

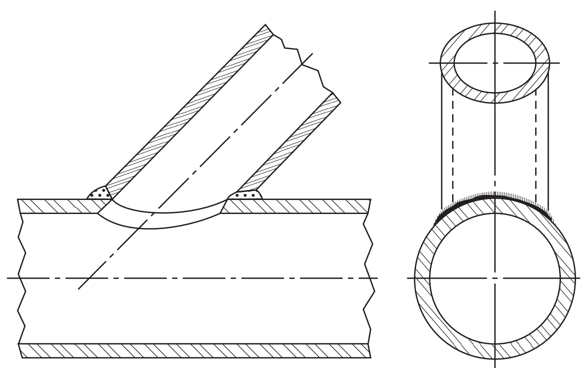
b = subscript referring to branch
D_o = outside diameter of pipe
d_1 = inside diameter of branch for right angle connections; for connections at angles between 45 deg and 90 deg, $d_1 = (D_{ob} - 2T_b) / \sin\alpha$
d_2 = half width of reinforcing zone
= the greater of d_1 or $T_b + T_h + (d_1/2)$ but in no case more than D_{ob}
h = subscript referring to run or header
L = height of reinforcement zone outside of run
= $2.5T_b + t_e$
T = nominal, actual by measurement, or minimum wall thickness of pipe permissible under purchase specification
t_e = thickness of attached reinforcing pad or height of the largest 60 deg right triangle supported by the run and branch outside diameter projected surfaces and lying completely within the area of integral reinforcement [Figure NC-3643.3(c)(1)-2]
t_m = required minimum wall thickness, in. (mm), of pipe for pressure and temperature design conditions as determined by use of eq. NC-3641.1(3) or eq. NC-3641.1(4)
α = angle between axes of branch and run, deg

(2) Requirements. A pipe having a branch connection is weakened by the opening that must be made in it, and unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide additional reinforcement. The amount of reinforcement required shall be determined in accordance with (3) through (7), NC-3643.4, or NC-3643.5.

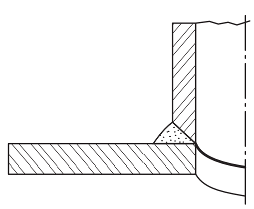
Figure NC-3643.2(b)-1
Typical Welded Branch Connections



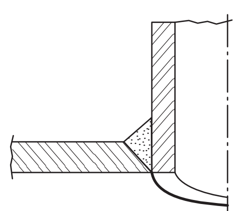
(a) Typical Welded Branch Connection Without Additional Reinforcement



(b) Typical Welded Angular Branch Connection Without Additional Reinforcement

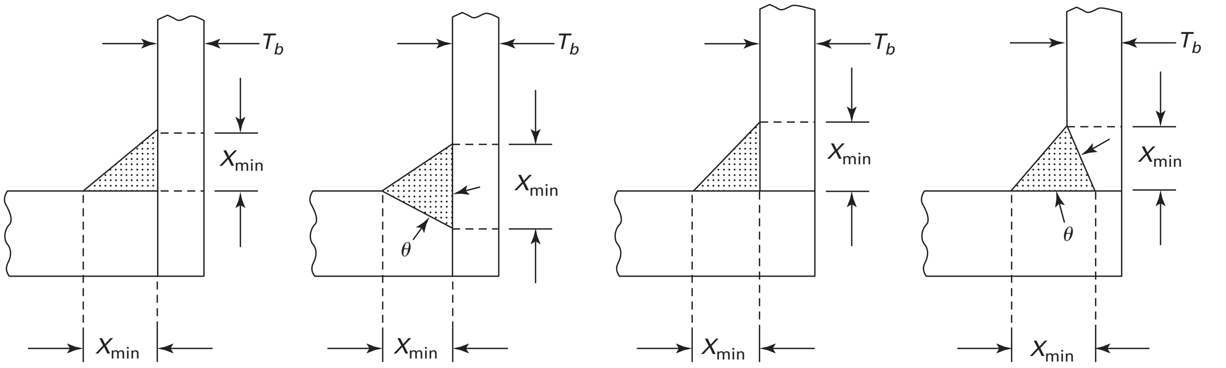


(c-1)



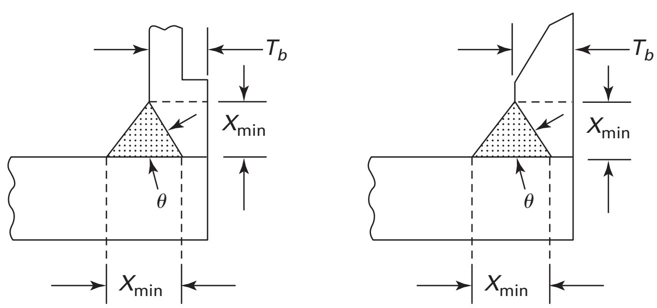
(c-2)

Figure NC-3643.2(b)-2
Typical Right Angle Branch Connections Made Using a Fillet Weld or a Partial Penetration Weld



(a) (b) (c) (d)

T_b = nominal branch pipe wall thickness
X_{min} = $1^1/_4 T_b$
θ = partial penetration weld groove angle ≥ 45 deg



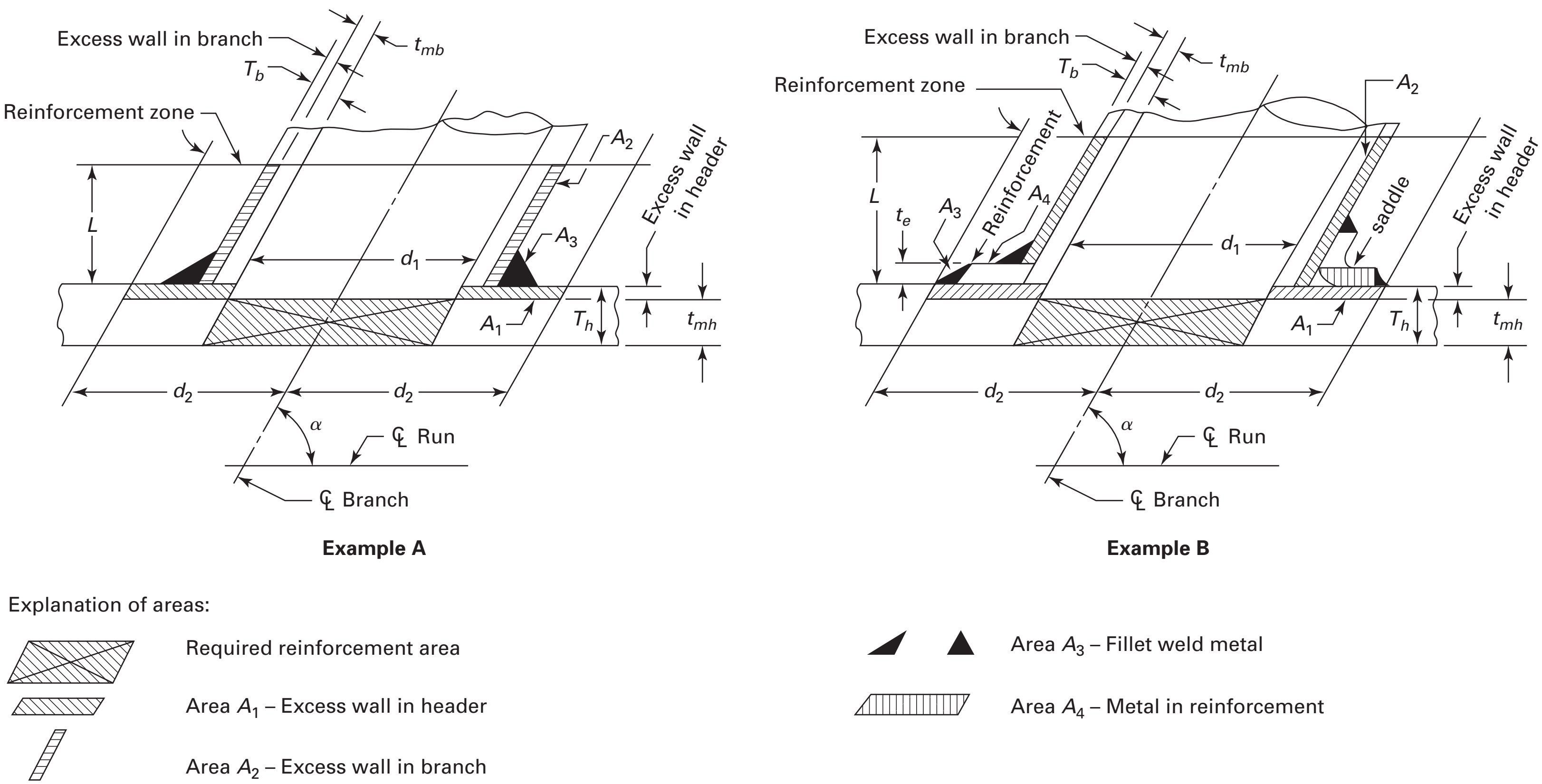
(e) ASME B16.11 Coupling **(f) Welded Outlet Fitting**

T_b = fitting wall thickness in the reinforcement zone (when the fitting is tapered in the reinforcement zone, use average wall thickness)
X_{min} = $1^1/_4 T_b$
θ = partial penetration weld groove angle ≥ 45 deg

Figure NC-3643.3(c)(1)-1
Reinforcement of Branch Connections

Required reinforcement = $(t_{mh})\ (d_1)\ (2 - \sin\alpha)$

Reinforcement areas = A_1, A_2, A_3, A_4



GENERAL NOTES:

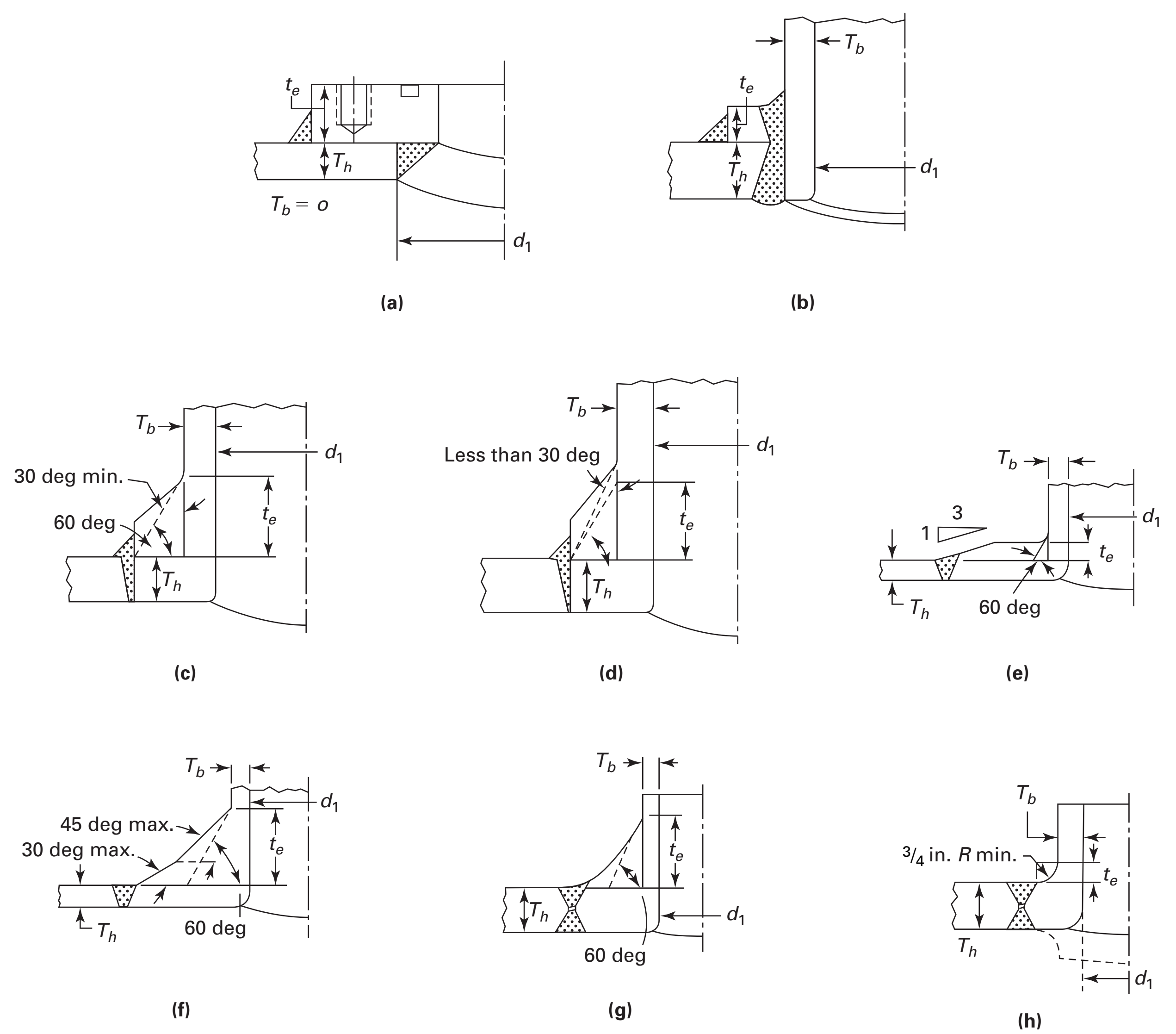
(a) When metal is added as reinforcement (Example B), the value of reinforcing area may be taken in the same manner in which excess header metal is considered. Typical acceptable methods of meeting the above requirement are shown in Figure NC-3643.3(c)(1)-2.

(b) Width to height of reinforcement shall be reasonably proportioned, preferably on a ratio as close as 4 to 1 as the available horizontal space within the limits of the reinforcing zone along the run and the O.D. of the branch will permit, but in no case may the ratio be less than 1.

(c) This Figure is to be used only for definitions of terms, not for fabrication details.

(d) Use of reinforcing saddles and pads is limited as stated in NC-3643.3(c)(7).

Figure NC-3643.3(c)(1)-2
Some Representative Configurations Describing the t_e Reinforcement Dimensions



(3) Reinforcement Area. The required reinforcement area in in.^{2} (mm^2) for branch connections shall be the quantity (t_{mh}) (d_1) $(2 - \sin \alpha)$.

(-a) For right angle connections, the required reinforcement becomes (t_{mh}) (d_1).

(-b) The required reinforcement must be within the limits of the reinforcement zone as defined in (5).

(4) Area Contributing to Reinforcement. Metal needed to meet reinforcement required by (c) must be within the limits of the reinforcement zone determined in (5) and may include the following:

A_1 = area provided by excess pipe wall in the run, in.^{2} (mm^2)
= $(2d_2 - d_1)$ $[(T_h$ − mill tolerance on $T_h) - t_{mh}]$

A_2 = area provided by excess pipe wall in the branch for a distance L above the run, in.^{2} (mm^2)
= $2L/\sin \alpha$ $[(T_b$ −mill tolerance on $T_b) - t_{mb}]$. In areas A_1 and A_2, mill tolerance becomes zero when the minimum wall is specified instead of nominal wall.

A_3 = area provided by deposited weld metal beyond the outside diameter of the run and branch, in.^{2} (mm^2)

A_4 = area provided by reinforcement, in.^{2} (mm^2)

When reinforcement area is composed of material with lower allowable stress than that of the run pipe, such reinforcement areas shall be increased by the inverse ratio of allowable stresses. No adjustment shall be made in reinforcement area for use of materials that have higher allowable stresses than the materials of the run pipe. Such reinforcement areas shall be decreased by the ratio of allowable stresses prior to any combination of areas to meet the reinforcement requirements of (c).

(5) Reinforcement Zone. The reinforcement zone is a parallelogram, the length of which shall extend a distance d_2 on each side of the center line of the branch pipe and the width of which shall start at the inside surface of the run pipe and extend to a distance of L from the outside surface of the run pipe, when measured in the plane of the branch connection.

(6) Reinforcement of Multiple Openings

(-a) When any two or more adjacent openings are so closely spaced that their reinforcement zones overlap, the two or more openings shall be reinforced in accordance with (3) with a combined reinforcement that has a strength equal to the combined strength of the reinforcement which would be required for the separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(-b) When more than two adjacent openings are to be provided with a combined reinforcement, the minimum distance between centers of any two of these openings should preferably be at least $1^1/_2$ times their average diameter and the area of reinforcement between them shall be at least equal to 50% of the total required for these two openings.

(7) Rings, Pads, and Saddles

(-a) Reinforcement provided in the form of rings, pads, or saddles shall not be appreciably narrower at the side than at the crotch.

(-b) A vent hole shall be provided at the ring, pad, or saddle to provide venting during welding and heat treatment.

(-c) Rings, pads, or saddles may be made in more than one piece, provided the joints between pieces have full thickness welds and each piece is provided with a vent hole.

(-d) Where saddles or pads are being employed for reinforcement, the potential for increased strain at the attachment welds which may occur as a result of rapid changes in differential metal temperatures between the saddle or pad, and the run should be considered in the design evaluation.

NC-3643.4 Special Requirements for Extruded Outlets. The definitions, limitations, nomenclature, and requirements of (a) through (h) below are specifically applicable to extruded outlets.

(a) Definition. An extruded outlet header is a header in which the extruded lip at the outlet has a height above the surface of the run which is equal to or greater than the radius of the curvature of the external contoured portion of the outlet, $h_o \geq r_o$ [Figure NC-3643.4(a)-1].

(b) Cases to Which Rules Are Applicable. These rules apply only to cases where the axis of the outlet intersects and is perpendicular to the axis of the run.

(c) Nomenclature. The notation used herein is illustrated in Figure NC-3643.4(a)-1. All dimensions are in inches.

D = outside diameter of run
d = outside diameter of branch pipe
D_c = corroded internal diameter of run
d_c = corroded internal diameter of branch pipe
D_o = corroded internal diameter of extruded outlet measured at the level of the outside surface of the run
h_o = height of the extruded lip, in. (mm); this must be equal to or greater than r_o except as permitted in (d)(4)
L = height of reinforcement zone
= $0.7\sqrt{dT_o}$
r_1 = half width of reinforcement zone = D_o
r_o = radius of curvature of external contoured portion of outlet measured in the place containing the axes of the run and branch; this is subject to the limitations given in (d) below
T_b = actual thickness of branch wall not including corrosion allowance
t_b = required thickness of branch pipe according to wall thickness eq. NC-3641.1(3) or eq. NC-3641.1(5), but not including any thickness for corrosion
T_o = corroded finished thickness of extruded outlet measured at a height equal to r_o above the outside surface of the run
T_r = actual thickness of run wall, not including the corrosion allowance
t_r = required thickness of the run according to eq. NC-3641.1(3) or eq. NC-3641.1(4), but not including any allowance for corrosion

(d) Radii

(1) The minimum radius shall not be less than $0.05d$, except that on branch diameters larger than 30 in. (750 mm) it need not exceed $1^1/_2$ in. (38 mm).

(2) The maximum radius for outlet pipe sizes NPS 6 (DN 150) and larger shall not exceed $0.10d$ + 0.50 in. ($0.10d$ + 13 mm). For outlet pipe sizes less than NPS 6 (DN 150), this dimension shall be not greater than $1^1/_4$ in. (32 mm).

(3) When the external contour contains more than one radius, the radius of any arc sector of approximately 45 deg shall meet the requirements of (1) and (2) above.

(4) Machining shall not be employed in order to meet the above requirements.

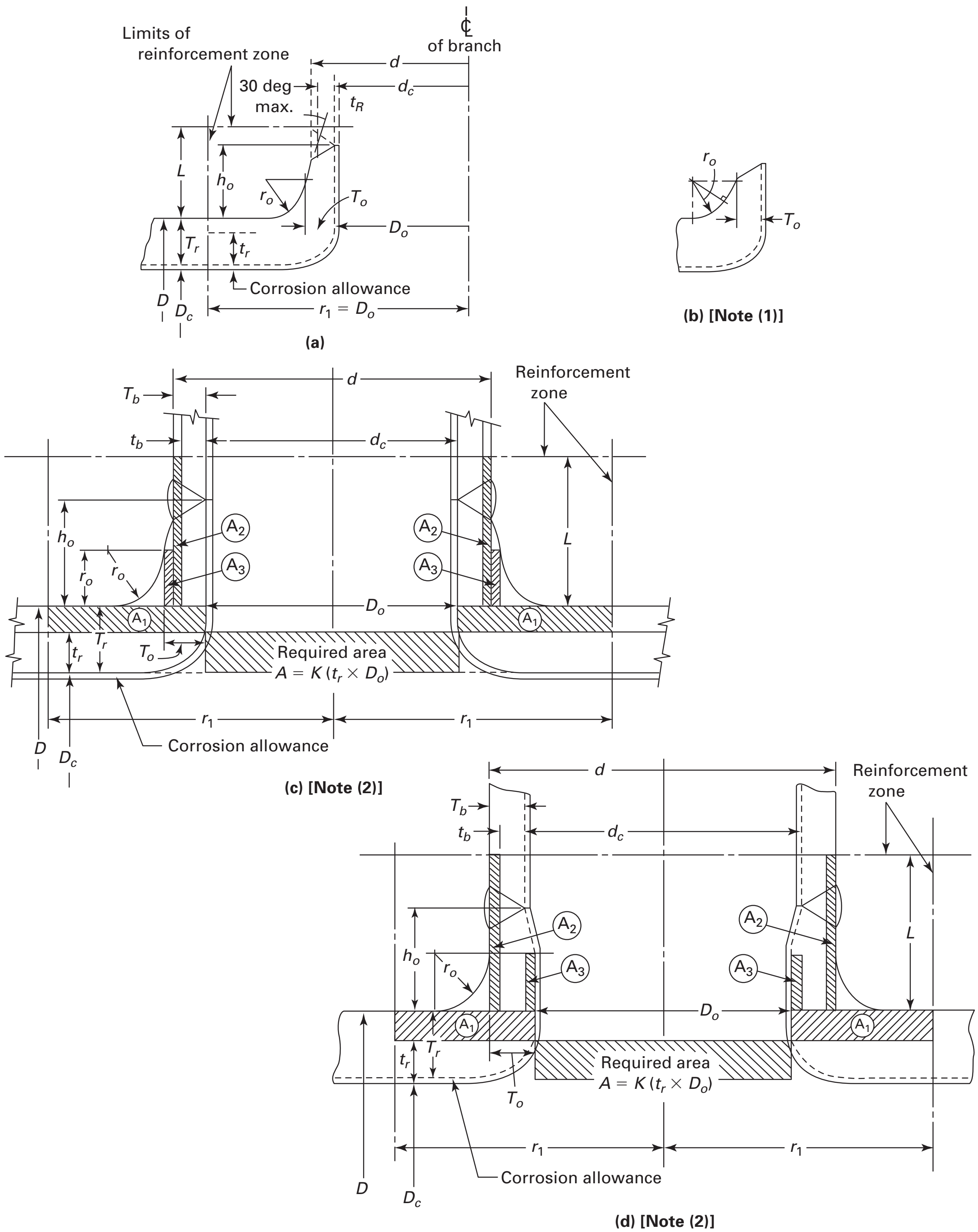
(e) Required Area. The required area is defined as

$$A = K(t_r \times D_o)$$

where K shall be taken as follows:

(1) for d/D greater than 0.60, K = 1.00

Figure NC-3643.4(a)-1
Reinforced Extruded Outlets



NOTES:
(1) Sketch to show method of establishing T_o when the taper encroaches on the crotch radius.
(2) Sketch is drawn for condition where K = 1.00.

(2) for d/D greater than 0.15 and not exceeding 0.60, $K = 0.6 + 2d/3D$

(3) for d/D equal to or less than 0.15, $K = 0.70$

(f) Reinforcement Area. The reinforcement area shall be the sum of areas $A_1 + A_2 + A_3$ as defined in (1), (2), and (3) below.

(1) Area A_1 is the area lying within the reinforcement zone resulting from any excess thickness available in the run wall:

$$A_1 = D_o(T_r - t_r)$$

(2) Area A_2 is the area lying within the reinforcement zone resulting from any excess thickness available in the branch pipe wall:

$$A_2 = 2L(T_b - t_b)$$

(3) Area A_3 is the area lying within the reinforcement zone resulting from excess thickness available in the extruded outlet lip:

$$A_3 = 2r_o(T_o - T_b)$$

(g) Reinforcement of Multiple Openings. When any two or more adjacent openings are so closely spaced that the reinforcement zones overlap, the two or more openings shall be reinforced in accordance with NC-3643.4, with a combined reinforcement that has a strength equal to the combined strength of the reinforcement that would be required for separate openings. No portion of the cross section shall be considered as applying to more than one opening or be evaluated more than once in a combined area.

(h) Marking. In addition to the above, the Certificate Holder shall be responsible for establishing and marking on the section containing extruded outlets, the Design Pressure and Temperature, and the Certificate Holder's name or trademark.

NC-3643.5 Branch Connections Subject to External Pressure.

(a) The reinforcement area required for branch connections subject to external pressure shall be 0.54 (t_{mh}) (d_1) $(2 - \sin\alpha)$. All terms as defined in NC-3643.3(c)(1), except t_{mh} is the minimum required wall thickness as determined by NC-3641.2.

(b) Procedures established for connections subject to internal pressure shall apply for connections subject to external pressure.

NC-3643.6 Reinforcement of Other Designs. The adequacy of designs to which the reinforcement requirements of NC-3643 cannot be applied shall be proved by burst or proof tests (NC-3649) on scale models or on full size structures, or by calculations previously substantiated by successful service of similar design.

NC-3644 Miters

Mitered joints may be used in piping systems under the conditions stipulated in (a) through (e) below.

(a) The thickness of a segment of a miter shall be determined in accordance with NC-3641.1. The required thickness thus determined does not allow for the discontinuity stresses which exist at the junction between segments. The discontinuity stresses are reduced for a given miter as the number of segments is increased. These discontinuity stresses may be neglected for miters in noncyclic services with incompressible fluids at pressures of 100 psi (700 kPa) and under, and for gaseous vents to atmosphere. Miters to be used in other services or at higher pressures shall meet the requirements of NC-3649.

(b) The number of full pressure or thermal cycles shall not exceed 7,000 during the expected lifetime of the piping system.

(c) The angle θ in Table NC-3673.2(b)-1 shall not be more than $22\frac{1}{2}$ deg.

(d) The center line distance between adjacent miters shall be in accordance with Table NC-3673.2(b)-1.

(e) Full penetration welds shall be used in joining miter segments.

NC-3645 Attachments

(a) External and internal attachments to piping shall be designed so as not to cause flattening of the pipe, excessive localized bending stresses, or harmful thermal gradients in the pipe wall. It is important that such attachments be designed to minimize stress concentrations in applications where the number of stress cycles, due either to pressure or thermal effect, is relatively large for the expected life of the equipment.

(b) Attachments shall meet the requirements of NC-3135.

(c) The effect of rectangular and circular cross section welded attachments on straight pipes may be evaluated using the procedures in Section III Appendices, Nonmandatory Appendix Y.

NC-3646 Closures

(a) Closures in piping systems shall be made by use of closure fittings, such as blind flanges or threaded or welded plugs or caps, either manufactured in accordance with standards listed in Table NCA-7100-1 and used within the specified pressure–temperature ratings, or made in accordance with (b) below.

(b) Closures not manufactured in accordance with the standards listed in Table NCA-7100-1 may be made in accordance with the rules contained in NC-3300 of this Subsection using the equation $t_m = t + A$, where

A = sum of mechanical allowances (NC-3613), in. (mm)
t = pressure design thickness, calculated for the given closure shape and direction of loading using appropriate equations and procedures in Article NC-3000, in. (mm)

t_m = minimum required thickness, in. (mm)

(c) Connections to closures may be made by welding, extruding, or threading. Connections to the closure shall be in accordance with the limitations provided in NC-3643 for branch connections. If the size of the opening is greater than one-half the inside diameter of the closure, the opening shall be designed as a reducer in accordance with NC-3648.

(d) Other openings in closures shall be reinforced in accordance with the requirements of reinforcement for a branch connection. The total cross-sectional area required for reinforcement in any plane passing through the center of the opening and normal to the surface of the closure shall not be less than the quantity of $d_5 t$, where

d_5 = diameter of the finished opening, in. (mm)
t = pressure design thickness for the closure, in. (mm).

NC-3647 Pressure Design of Flanged Joints and Blanks

NC-3647.1 Flanged Joints.

(a) Flanged joints manufactured in accordance with the standards listed in Table NCA-7100-1, as limited by NC-3612.1, shall be considered as meeting the requirements of NC-3640.

(b) Flanged joints not included in Table NCA-7100-1 shall be designed in accordance with Section III Appendices, Mandatory Appendix XI, Article XI-3000.

(15) **NC-3647.2 Permanent Blanks.** The minimum required thickness of permanent blanks (Figure NC-3647.2-1) shall be calculated from the following equations:

$$t_m = t + A$$

where

A = the sum of the mechanical allowances, in. (mm) (NC-3613)
t = the pressure design thickness calculated from the equation below, in. (mm)

$$t = d_6 \left(\frac{3P}{16S} \right)^{1/2}$$

where

d_6 = the inside diameter of the gasket for raised or flat face flanges or the pitch diameter of the gasket for retained gasketed flanges, in. (mm)
P = Design Pressure, psi (MPa)
S = the allowable stress in accordance with Section II, Part D, Subpart 1, Tables 1A and 1B, psi (MPa)

t_m = the minimum required thickness, in. (mm)

NC-3647.3 Temporary Blanks. Blanks to be used for test purposes only shall have a minimum thickness not less than the pressure design thickness t calculated as in NC-3647.2 above, except that P shall not be less than the test pressure and the allowable stress S may be taken as 95% of the specified minimum yield strength of the blank material (Section II, Part D, Subpart 1, Table Y-1).

NC-3647.4 Flanges. Flanges shall be integral or be attached to pipe by welding, brazing, threading, or other means within the applicable standards specified in Table NCA-7100-1.

NC-3647.5 Gaskets.

(a) Gaskets shall be made of materials which are not injuriously affected by the fluid or by temperatures within the design temperature range.

(b) Only metallic or asbestos metallic gaskets may be used on flat or raised face flanges if the expected normal service pressure exceeds 720 psi (5 MPa) or the temperature exceeds 750°F (400°C). However, compressed sheet asbestos confined gaskets are not limited as to pressures, provided the gasket material is suitable for the temperatures.

(c) The use of metal or metal asbestos gaskets is not limited as to pressure, provided the gasket materials are suitable for the fluid Design Temperature.

NC-3647.6 Bolting.

(a) Bolts, stud bolts, nuts, and washers shall comply with applicable standards and specifications listed in Table NCA-7100-1. Unless otherwise specified, bolting shall be in accordance with the latest edition of ASME B16.5. Bolts and stud bolts shall extend completely through the nuts.

(b) Studs shall be threaded full length or shall be machined down to the root diameter of the thread in the unthreaded portion, provided that the threaded portions are at least $1^1/_2$ diameters in length. Studs greater than 8 diameters in length may have an unthreaded portion which has the nominal diameter of the thread, provided the following requirements are met:

(1) the threaded portions shall be at least $1^1/_2$ diameters in length;

(2) the stud shall be machined down to the root diameter of the thread for a minimum distance of 0.5 diameters adjacent to the threaded portion; and

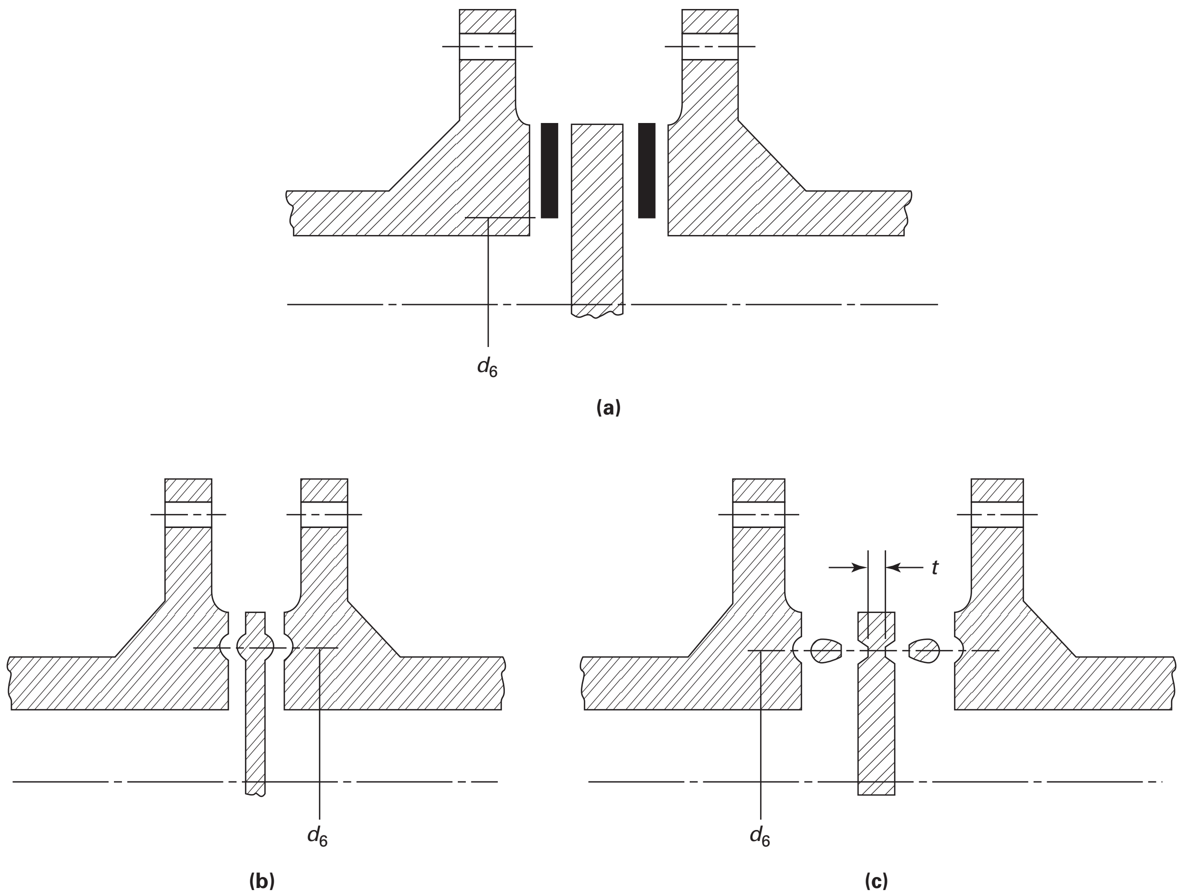
(3) a suitable transition shall be provided between the root diameter and unthreaded portions.

(c) Carbon steel bolts shall be square or heavy hexagon head bolts and shall have heavy semifinished hexagon nuts.

(d) Alloy steel stud bolts shall have heavy hexagon nuts. Headed alloy bolts are not recommended.

(e) It is recommended that all alloy bolts or stud bolts and accompanying nuts be threaded in accordance with ASME B1.1 Class 2A external threads and Class 2B internal threads.

Figure NC-3647.2-1
Types of Permanent Blanks



NC-3648 Reducers

Reducer fittings manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use. Where butt welding reducers are made to a nominal pipe thickness, the reducers shall be considered suitable for use with pipe of the same nominal thickness.

NC-3649 Pressure Design of Other Pressure-Retaining Piping Products

Other pressure-retaining piping products manufactured in accordance with the standards listed in Table NCA-7100-1 shall be considered suitable for use in piping systems at the specified pressure–temperature ratings. Pressure-retaining piping products not covered by the standards listed in Table NCA-7100-1 and for which design equations or procedures are not given in this Subsection may be used where the design of similarly shaped, proportioned, and sized components has been proved satisfactory by successful performance under comparable service conditions. Where such satisfactory service experience exists, interpolation may be made to other sized piping products with a geometrically similar shape. In the absence of such service experience, the pressure design shall be based on an analysis consistent with the general design philosophy of this Subsection and substantiated by at least one of the following:

(a) proof tests as described in ASME B16.9;

(b) experimental stress analysis (Section III Appendices, Mandatory Appendix II).

NC-3649.1 Expansion Joints — General Requirements. Expansion joints of the bellows, sliding, ball, or swivel types may be used to provide flexibility for piping systems. The design of the piping systems and the design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and shall comply with the requirements of (a) through (e) below.

(a) Piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the expansion joints other than those for the absorption of which they are both suitable and intended. Bellows expansion joints are normally not

designed for absorbing torsion. Sliding expansion joints are normally not designed for absorbing bending. In sliding and bellows expansion joints used for absorbing axial motion, the hydrostatic end force caused by fluid pressure and the forces caused by either friction resistance or spring force, or both, should be resisted by rigid end anchors, cross connections of the section ends, or other means. Where reaction to hydrostatic end forces acts on pipe, guides shall be provided to prevent buckling in any direction. For bellows expansion joints, the pipe guiding and anchorage shall conform to EJMA Standards.[28]

(b) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection and maintenance and for removal and replacement either directly or by other suitable means.

(c) Expansion joints employing mechanical seals shall be sufficiently leak-tight to satisfy safety requirements. The system designer shall specify the leak-tightness criteria for this purpose.

(d) Materials shall conform to the requirements of Article NC-2000, except that no sheet material in the quenched, aged, or air-hardened condition shall be used for the flexible element of a bellows joint. If heat treatment is required, it shall be performed either after welding the elements into a complete cylinder or after all forming of the bellows is completed, the only welding permissible after such treatment being that required to connect the element to pipe or end flanges.

(e) All welded joints shall comply with the requirements of NC-4800.

NC-3649.2 Bellows Expansion Joints. Expansion joints of the bellows type may be used to provide flexibility for piping systems. The design, material, fabrication, examination, and testing of the expansion joints shall conform to this Subsection and the requirements of (a) through (f) below.

(a) The piping system layout, anchorage, guiding, and support shall be such as to avoid the imposition of motions or forces on the bellows other than those for which they have been designed.

(b) In all systems containing bellows, the hydrostatic end force caused by pressure and the bellows spring force shall be accommodated by or resisted by rigid anchors, cross connections of the expansion joint ends, or other means. Where bellows are used in straight pipe sections to absorb axial motion and where the hydrostatic end force of the bellows acts on the pipe as a column, guides must be provided to prevent buckling of the pipe in any direction. The pipe guiding and anchorage shall conform to the requirements of the Design Specifications for the attached piping.

(c) The expansion joints shall be installed in such locations as to be accessible for scheduled inspection, where applicable.

(d) The joints shall be provided with bars or other suitable members for maintaining the proper face-to-face dimension during shipment and installation. Bellows shall not be extended or compressed to make up deficiencies in length of offset to accommodate connected piping which is not properly aligned, unless such misalignments have been specified by the system designer.

(e) The expansion joints shall be marked to show the direction of flow, if applicable, and shall be installed in accordance with this marking.

(f) Unless otherwise stated in the Design Specifications, internal sleeves shall be provided when flow velocities exceed the following values:

(1) Air, Steam, and Other Gases

(-a) ≤ NPS 6 (DN 150) — 4 ft/sec/in. (0.05 m/sec/mm) of diameter

(-b) > NPS 6 (DN 150) — 25 ft/sec (7.5 m/sec)

(2) Water and Other Liquids

(-a) ≤ NPS 6 (DN 150) — 2 ft/sec/in. (0.024 m/sec/mm) of diameter

(-b) > NPS 6 (DN 150) — 10 ft/sec (3.0 m/sec)

NC-3649.3 Bellows Expansion Joint Materials. Pressure-retaining materials in the expansion joint shall conform to the requirements of Article NC-2000.

NC-3649.4 Bellows Expansion Joint Design. Bellows may be of the unreinforced or reinforced convoluted type or of the toroidal type. The design shall conform to the requirements of Article NC-3000 and to those of (a) through (j) below.

(a) The circumferential membrane stresses in both the bellows and reinforcing member, due to pressure, shall not exceed the allowable stresses given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

(b) The sum of the bellows meridional membrane and bending stresses due to internal pressure shall not exceed a value which results in a permanent decrease in the spaces between adjacent convolutions of 7% after a pressure test of $1\frac{1}{2}$ times the Design Pressure, adjusted for temperature.

(c) The ratio of the internal pressure, at which the bellows will become unstable (squirm), to the equivalent cold service pressure shall exceed 2.25. By definition, squirm shall be considered to have occurred if under internal pressure an initially symmetrical bellows deforms, resulting in a lack of parallelism or uneven spacing of adjacent convolutions at any point on the circumference. Unless otherwise specified, this deformation shall be construed as unacceptable squirm when the ratio of the maximum convolution pitch under internal pressure to the convolution pitch before application of pressure exceeds 1.15 for unreinforced and 1.20 for reinforced bellows. In the case of universal expansion joints, which consist of two bellows joined by a cylindrical section, compliance with these criteria shall be satisfied by the entire

assembly. No external restraints on the bellows shall be employed during squirm testing other than those which will exist after installation.

(1) For single joints used in axial or lateral motion, the squirm test may be performed with the bellows fixed in the straight position at the maximum length expected in service; for rotation and universal joints, the bellows shall be held at the maximum design rotation angle or offset movement. In the case of single joints subjected to rotation movement or universal joints subjected to lateral offset movement, an instability condition as previously defined may or may not appear. Instead, movement of the convolutions may occur due to the superposition of the lateral internal pressure component on the applied rotation. In such cases, that portion of the bellows deformation due to the design rotation angle or offset movement should not be included in the deformation used to define squirm.

(2) In the case of squirm tests, the equivalent cold service pressure is defined as the Design Pressure multiplied by the ratio E_c/E_h, where E_c and E_h are defined as the modulus of elasticity of the bellows material at room temperature and normal service temperature, respectively.

(d) The combination of meridional membrane and bending stresses S in the bellows due to internal pressure and deflection, multiplied by a stress factor K_s,[29] shall not exceed the value defined by the following equation:

$$K_s \times S = S_f$$

where

K_s = $K_{sc} \times K_{ss}$, but not less than 1.25

K_{sc} = factor for differences in design fatigue curves at temperatures greater than 100°F (38°C)
= $2S_c/(S_c + S_h)$

K_{ss} = factor for the statistical variation in test results
= 1.470 − 0.044 × number of replicate tests

S = total combined meridional membrane and bending stress due to pressure and deflection, psi (MPa). The calculation of the individual stress components and their combination must be determined by the same method as used for determining S_f. In the case of single joints subjected to rotation movement and universal joints subjected to lateral offset movement, the increase in deflection stress caused by the lateral internal pressure component shall be included in determining the combined stress.

S_c = basic material allowable stress value at room temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi (MPa)

S_f = total combined stress to failure at design cyclic life (number of cycles to failure) obtained from plots of stress versus cyclic life based on data from fatigue tests of a series of bellows at a given temperature (usually room temperature) evaluated by a best fit continuous curve or series of curves, psi (MPa). The S_f plot shall be parallel to the best fit curve and shall lie below all of the data points.

S_h = basic material allowable stress value at normal service temperature from Section II, Part D, Subpart 1, Tables 1A and 1B, psi (MPa)

(e) Compliance with (a), (b), (c), and (d) above shall be demonstrated by any one of the procedures of (1), (2), or (3) below.

(1) Calculation of the individual stresses, their combination and relation to fatigue life may be performed by any analytical method based on elastic shell theory. The resulting equations must be substantiated by correlation with actual tests of a consistent series of bellows of the same basic design (unreinforced, reinforced, and toroidal bellows are considered as separate designs) by each manufacturer in order to demonstrate predictability of rupture pressure, meridional yielding, squirm, and cyclic life. A minimum of five burst tests on bellows of varying sizes, with not less than three convolutions, shall be conducted to verify that the analytical method will adequately satisfy criteria (a) and (b) above. No specimen shall rupture at less than four times its equivalent cold pressure rating. A minimum of ten squirm tests on bellows of varying diameters and number of convolutions shall be conducted to verify that the analytical method will adequately satisfy (c) above. Since column instability is most likely to occur in bellows less than 20 in. (500 mm) diameter, where the convoluted bellows length is greater than its diameter, the test specimens shall reflect these considerations. In the case of universal expansion joints, two additional tests shall be conducted to verify that the analytical method will adequately satisfy (c) above. The cyclic life versus combined stress plot used in evaluating (d) shall be obtained from the results of at least 25 fatigue tests on bellows of varying diameters, thicknesses, and convolution profiles. These curves may be used for diameter and convolution profiles other than those tested, provided that a variation in these dimensions has been included in the correlation with test data. Each group of five such tests on varying bellows may be considered the equivalent of one replicate test in determining K_s.

(2) Individual expansion joint designs may be shown to comply by the testing of duplicate bellows. At least two test specimens are required, one to demonstrate pressure capacity in accordance with (a), (b), and (c) above and the second to demonstrate fatigue life in accordance with (d) above. In the case of rupture and fatigue tests, the specimens need not possess a duplicate number of convolutions, provided the number of convolutions is not less than three and the diameter, thickness, depth, and pitch of the specimen are identical to the part to be furnished; squirm test specimens shall possess the total number of convolutions.

(-a) Any or all of the above tests of (1) or (2) may be conducted at room temperature, provided that cold service pressure is defined as the Design Pressure multiplied by the ratio of S_c/S_h for rupture specimens and E_c/E_h for squirm specimens.

(-b) The fatigue life of the test specimen shall exceed ${K_s}^{4.3}$ times the number of design cycles specified for the most significant cyclic movements. This test shall include the effect of internal pressure. If lateral and rotation movements are specified, these may be converted to equivalent axial motion for cyclic testing; the convolution deflection produced by the lateral component of the internal pressure force during the squirm test for single rotation joints and universal joints shall be added to the mechanical deflections in determining fatigue life. Where accelerated fatigue testing is employed, the deflection and number of cycles required shall be in accordance with Section III Appendices, Mandatory Appendix II. Cumulative fatigue requirements can be satisfied in accordance with (g) without additional testing by assuming that the slope of the fatigue curve is 4.3 and that the curve passes through the test point.

(3) An individual design may be shown to comply by a design analysis in accordance with NC-3200. The stresses at every point in the bellows shall be determined by either elastic shell theory or by a plastic analysis, where applicable. Where an elastic analysis is employed, the stress intensity values of Section II, Part D, Subpart 1, Tables 2A, 2B, and 4 and fatigue curves of Section III Appendices, Mandatory Appendix I may be used to evaluate the design.

(-a) The stability requirements of (c) may be demonstrated by either:

(-1) elastic stability calculations, provided that the ratio of the internal pressure at which the bellows is predicted to become unstable to the equivalent cold service pressure exceeds 10; or

(-2) the pressure test of NC-6230, provided that the test is conducted at $2^1/_4$ times the equivalent cold design pressure, and single rotation and universal joints are held at their design rotation angle or offset movement during the test and the requirements of (b) are not exceeded by such a test.

(f) The Certificate Holder's Data Report shall state which of the above procedures was utilized to verify the design.

(g) If there are two or more types of stress cycles which produce significant stresses, their cumulative effect shall be evaluated as stipulated in Steps 1 through 5 below.

Step 1. Designate the specified number of times each stress cycle of types 1, 2, ..., n, will be repeated during the life of the component as n_1, n_2, ..., n_n, respectively.

NOTE: In determining n_1, n_2, ..., n_n, consideration shall be given to the superposition of cycles of various origins which produce a total stress difference S_1, S_2, ..., S_n greater than the stress difference of the individual cycles. For example, if one type of stress cycle produces 1,000 cycles of stress difference variation from zero to +60,000 psi and another type of stress cycle produces 10,000 cycles of a stress difference variation from zero to −50,000 psi, the two types of cycles to be considered are defined by the following parameters:

$$\text{Type 1 cycle } n_1 = 1{,}000,\quad S_1 = (60{,}000 + 50{,}000) = 110{,}000\text{ psi}$$

$$\text{Type 2 cycle } n_2 = 9{,}000,\quad S_2 = (50{,}000 + 0) = 50{,}000\text{ psi}$$

Step 2. For each value S_1, S_2, ..., S_n, use the applicable design fatigue curve and corresponding method of analysis to determine the maximum number of stress cycles which would be allowable if this type of cycle were the only one acting. Call these values N_1, N_2, ..., N_n. The fatigue curve used may be either the S_f plot defined in (d) or the curve consistent with (e)(2) or (e)(3). If the fatigue curve has been developed based on a total stress difference, then the full value of S_1, S_2, ..., S_n, of Step 1 must be used to determine N; however, if the curve is based on an alternating stress, then the values S_1, S_2, ..., S_n become the alternating stresses.

Step 3. For each type of stress cycle, calculate the usage factors, U_1, U_2, ..., U_n, from $U_1 = n_1/N_1$, $U_2 = n_2/N_2$, ..., $U_n = N_n/N_n$.

Step 4. Calculate the cumulative usage factor U from $U = U_1 + U_2 + ... + U_n$.

Step 5. The cumulative usage factor U shall not exceed 1.0.

(h) The Certificate Holder shall submit a report which demonstrates compliance with NC-3649.

(i) Where necessary to carry the pressure, the cylindrical ends of the bellows may be reinforced by suitable collars. The design method used to assure that the stresses generated will not cause premature failure of the bellows material or weldment shall include the attachment weld between the bellows and end connections.

(j) The spring rates of the expansion joint assembly shall be provided by the Certificate Holder. The spring rates of a bellows can be defined by several methods due to the hysteresis loop which can occur during deflection; a restoring force may be required to return the bellows to the original neutral position after deflection. When applicable, the Design Specifications shall state the maximum allowable force that can be imposed on the connecting parts or shall require the Certificate Holder to determine the maximum force necessary to deflect the bellows a given distance, such as the maximum movement to be absorbed.

NC-3649.5 Metallic Braided Flexible Hoses. Metallic braided flexible hoses may be constructed in accordance with Section III Appendices, Nonmandatory Appendix BB.

NC-3650 ANALYSIS OF PIPING DESIGNS

NC-3651 General Requirements[30]

(a) The design of the complete piping system shall be analyzed between anchors for the effects of thermal expansion, weight, and other sustained and occasional loads. The system design shall meet the limits of NC-3650. The pressure portion of eqs. NC-3652(8), NC-3653.1(a)(9a), and NC-3653.1(b)(9b) may be replaced with the expression

$$S_{LP} = B_1 \frac{2Pd^2}{D_o{}^2 - d^2}$$

The pressure portion of eq. NC-3653.2(c)(11) may be replaced by the expression

$$S_{LP} = \frac{Pd^2}{D_o{}^2 - d^2}$$

where the terms are the same as in NC-3652, except

d = nominal inside diameter of pipe, in. (mm)
P = P or P_{max}, psi (MPa)

(b) When evaluating stresses in the vicinity of expansion joints, consideration must be given to actual cross-sectional areas that exist at the expansion joint.

(c) For analysis of flanged joints, see NC-3658.

NC-3652 Consideration of Design Conditions

The effects of pressure, weight, and other sustained mechanical loads must meet the requirements of eq. (8):

$$S_{SL} = B_1 \frac{PD_o}{2t_n} + B_2 \frac{M_A}{Z} \leq 1.5S_h \qquad (8)$$

where

B_1, B_2 = primary stress indices for the specific product under investigation [Table NC-3673.2(b)-1]
D_o = outside diameter of pipe, in. (mm)
M_A = resultant moment loading on cross section due to weight and other sustained loads, in.-lb (N·mm) (NC-3653.3)
P = internal Design Pressure, psi (MPa)
S_h = basic material allowable stress at Design Temperature, psi (MPa)
t_n = nominal wall thickness, in. (mm)
Z = section modulus of pipe, in.^{3} (mm^3) (NC-3653.3)

NC-3653 Consideration of Level A and B Service Limits

NC-3653.1 Occasional Loads.[31] The effect of pressure, weight, other sustained loads, and occasional loads, including reversing and nonreversing dynamic loads, for which Level B Service Limits are designated, must meet requirements of either (a) or (b).

(a) The following requirements shall be met:

$$S_{OL} = B_1 \frac{P_{\max} D_o}{2t_n} + B_2 \left(\frac{M_A + M_B}{Z} \right) \leq 1.8S_h \qquad (9a)$$

but not greater than $1.5S_y$. Terms are the same as in NC-3652, except:

M_B = resultant moment loading on cross section due to occasional loads, such as thrusts from relief and safety valve loads from pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and nonreversing dynamic loads, in.-lb (N·mm). For reversing and nonreversing dynamic loads, use only one-half the range. Effects of anchor displacement due to reversing and nonreversing dynamic loads may be excluded from eq. (9a) if they are included in either eq. NC-3653.2(a)(10a) or eq. NC-3653.2(c)(11).
P_{max} = peak pressure, psi (MPa)
S_h = material allowable stress at a temperature consistent with the loading under consideration, psi (MPa).
S_y = material yield strength at a temperature consistent with the loading under consideration, psi (MPa).

(b) As an alternative to (a), for piping fabricated from material designated as P-No. 1 through P-No. 9 in Section II, Part D, Subpart 1, Table 2A, and limited to $D_o/t_n \leq 40$, if Level B Service Limits, which include reversing dynamic loads (NC-3622.4) that are not required to be combined with nonreversing dynamic loads are specified, the requirements below shall apply.

$$S_{OL} = B_1 \frac{P_{\max} D_o}{2t_n} + B_2{}' \left(\frac{M_A + M_B{}'}{Z} \right) \leq 1.8S_h \qquad (9b)$$

but not greater than $1.5S_y$. Terms are the same as in NC-3652, except:

B'_2 = as defined in NC-3655(b)(3)
M'_B = resultant moment loading on cross-section due to reversing dynamic loads, in.-lb (N·mm). Effects of anchor displacement due to reversing dynamic loads may be excluded from eq. (9b) if they are included in either eq. NC-3653.2(a)(10a) or eq. NC-3653.2(c)(11).
P_{max} = peak pressure, psi (MPa)
S_h = material allowable stress at a temperature consistent with the loading under consideration, psi (MPa)
S_y = material yield strength at a temperature consistent with the loading under consideration, psi (MPa)

NC-3653.2 Thermal Expansion. For Service Loadings for which Level A and B Service Limits are designated, the requirements of either eq. (a)(10a) or eq. (c)(11), and eq. (b)(10b) must be met.

(a) The effects of thermal expansion must meet the requirements of eq. (10a):

$$S_E = \frac{iM_c}{Z} \le S_A \tag{10a}$$

Terms same as above except:

i = stress intensification factor (NC-3673.2)

M_c = range of resultant moments due to thermal expansion, in.-lb (N·mm); also include moment effects of anchor displacements due to reversing and nonreversing dynamic loads if anchor displacement effects were omitted from eq. NC-3653.1(a)(9a) or eq. NC-3653.1(b)(9b)

S_A = allowable stress range for expansion stresses (NC-3611.2), psi (MPa)

(b) The effects of any single nonrepeated anchor movement shall meet the requirements of eq. (10b):

$$\frac{iM_D}{Z} \le 3S_c \tag{10b}$$

Terms same as in NC-3653.1(a), except:

M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement), in.-lb (N·mm)

(c) The effects of pressure, weight, other sustained loads, and thermal expansion shall meet the requirements of eq. (11):

$$S_{TE} = \frac{PD_o}{4t_n} + 0.75i\left(\frac{M_A}{Z}\right) + i\left(\frac{M_C}{Z}\right) \le \left(S_h + S_A\right) \tag{11}$$

$0.75i$ shall not be less than 1.0.

NC-3653.3 Determination of Moments and Section Modulus.

(a) For purposes of eqs. NC-3652(8), NC-3653.1(a)(9a), NC-3653.1(b)(9b), NC-3653.2(a)(10a), NC-3653.2(b)(10b), and NC-3653.2(c)(11), the resultant moment for straight through components, curved pipe, or welding elbows may be calculated as follows. Determine resultant moment:

$$M_j = \left[M_{xj}^2 + M_{yj}^2 + M_{zj}^2\right]^{1/2}$$

where

j = A, B, B', C, or D, which are the subscripts of M_A, M_B, $M_B{}'$, M_C, and M_D defined in NC-3652, NC-3653.1, and NC-3653.2

(b) For intersections (branch connections or tees), calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Figure NC-3653.3-1) for full outlet intersections.

(c) For reduced outlets, calculate the resultant moment of each leg separately in accordance with (a) above. Moments are to be taken at the junction point of the legs (Figure NC-3653.3-1), except that for $r'_m/R_m < 0.5$ the branch moments at the outside surface of the run pipe may be used for the branch leg.

(d) For intersections, the section modulus used to determine stresses shall be the effective section modulus:

$$Z = \pi\left(r'_m\right)^2 T_b{}' \text{ for the branch leg}$$

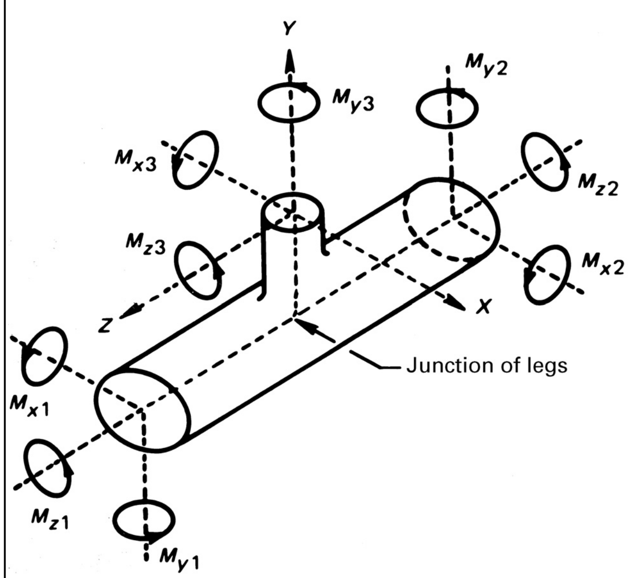
and

$$Z = \pi\left(R_m\right)^2 T_r \text{ for the run legs}$$

where

R_m = run pipe mean cross-sectional radius, in. (mm)
r'_m = branch pipe mean cross-sectional radius, in. (mm)
$T_b{}'$ = nominal branch pipe wall thickness, in. (mm)
T_r = nominal wall thickness of run pipe, in. (mm)

Figure NC-3653.3-1
Reducing or Full Outlet Branch Connections or Tees



(e) For components and joints other than intersections, the section modulus used to determine stresses shall be the classic section modulus:

$$Z = \frac{2I}{D_o}$$

where

I = moment of inertia, in.^{4} (mm^4)
= $0.0491\left(D_o^4 - D_i^4\right)$
D_i = inside diameter, in. (mm)

NC-3654 Consideration of Level C Service Limits

NC-3654.1 Permissible Pressure. When Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are specified, the permissible pressure shall not exceed the pressure P_a, calculated in accordance with eq. NC-3641.1(5), by more than 50%. The calculation of P_a shall be based on the maximum allowable stress for the material at the coincident temperature.

(15) **NC-3654.2 Analysis of Piping Components.** For Service Loadings for which Level C Service Limits [NCA-2142.4(b)(3) and NB-3113(b)] are designated, the following requirements shall apply.

(a) For Service Loadings for which Level C Service Limits are designated, except as permitted by (b) below, the conditions of eq. NC-3653.1(a)(9a) shall be met using Service Level C coincident pressure P and moments ($M_A + M_B$), which result in the maximum calculated stress. The allowable stress to be used for this condition is $2.25S_h$ but not greater than $1.8S_y$. S_h and S_y are as defined in NC-3653.1.

In addition, if the effects of anchor motion, M_{AM} from reversing dynamic loads are not considered in NC-3653, then the requirements of NC-3655(b)(4) shall be satisfied using 70% of the allowable stress given in NC-3655(b)(4).

(b) As an alternative to (a), for Service Loadings for which Level C Service Limits are designated, which include reversing dynamic loads (NC-3622.4) that are not required to be combined with nonreversing dynamic loads (NC-3622.5), the requirements of NC-3655(b) shall be satisfied using the allowable stress in NC-3655(b)(2), 70% of the allowable stress in NC-3655(b)(3), and 70% of the allowable loads in NC-3655(b)(4).

NC-3654.3 Deformation Limits. Any deformation or deflection limits prescribed by the Design Specifications shall be considered with respect to Level C Service Limits.

(15) ### NC-3655 Consideration of Level D Service Limits

If the Design Specifications specify any Service Loading for which Level D Limits are designated [NCA-2142.2(b)(4)], the following requirements shall apply.

(a) For Service Loadings for which Level D Service Limits are designated, except as permitted by (b) below, the requirements of (1), (2), and (3) below shall apply.

(1) The permissible pressure shall not exceed 2.0 times the pressure P_a calculated in accordance with eq. NC-3641.1(5). The calculation of P_a shall be based on the maximum allowable stress for the material at the coincident temperature.

(2) The conditions of eq. NC-3653.1(a)(9a) shall be met using Service Level D coincident pressure P and moment ($M_A + M_B$), which result in the maximum calculated stress. The allowable stress to be used for this condition is $3.0S_h$, but not greater than $2.0S_y$. S_h and S_y are as defined in NC-3653.1.

(3) If the effects of anchor motion M_{AM}, from reversing dynamic loads are not considered in NC-3653, then the requirements of (b)(4) shall be satisfied.

(b) As an alternative to (a), for piping fabricated from material designated P-No. 1 through P-No. 9 in Section II, Part D, Subpart 1, Table 2A, and limited to $D_o/t_n \leq 40$, if Level D Service Limits are designated, which include reversing dynamic loads (NC-3622.4) that are not required to be combined with nonreversing dynamic loads (NC-3622.5), the requirements of (1) through (5) below shall apply.

(1) The pressure occurring coincident with the earthquake or other reversing type loading, P_E, shall not exceed the Design Pressure.

(2) The sustained stress due to weight loading shall not exceed the following:

$$B_2 \frac{D_o}{2I} M_W \leq 0.5S_h$$

where

M_W = resultant moment due to weight effects, in.-lb (N·mm)
S_h = as defined in NC-3653.1

(3) The stress due to weight and inertial loading due to reversing dynamic loads in combination with the Level D coincident pressure shall not exceed the following:

$$B_1 \frac{P_E D_o}{2t} + B_2' \frac{D_o}{2I} M_E \leq 3S_h$$

where

B_2' = B_2 from Table NC-3673.2(b)-1, except as follows:
B_2' = $0.87/h^{2/3}$ for curved pipe or butt welding elbows [h as defined in Table NC-3673.2(b)-1] but not less than 1.0
= 1.33 for girth butt welds between items which do *not* have nominally identical wall thicknesses [NB-3683.4(b)]
B_{2b}' = $0.27\ (R_m/T_r)^{2/3}$ and

$B_{2r}{}' = 0.33\ (R_m/T_r)^{2/3}$ for ASME B16.9 or MSS SP-87 butt welding tees [terms as defined in Table NC-3673.2(b)-1], but neither less than 1.0

M_E = the amplitude of the resultant moment due to weight and the inertial loading resulting from reversing dynamic loads, in.-lb (N·mm). In the combination of loads, all directional moment components in the same direction shall be combined before determining the resultant moment. If the method of analysis is such that only magnitude without algebraic signs is obtained, the most conservative combination shall be assumed.

P_E = the pressure occurring coincident with the reversing dynamic load, psi (MPa)

S_h = as defined in NC-3653.1

(4) The range of the resultant moment M_{AM} and the amplitude of the longitudinal force F_{AM} resulting from the anchor motions due to earthquake and other reversing type dynamic loading shall not exceed the following:

$$C_2 \frac{M_{AM} D_o}{2I} < 6S_h$$

$$\frac{F_{AM}}{A_M} < S_h$$

where

A_M = cross-sectional area of metal in the piping component wall, in.^{2} (mm^2)

C_2 = secondary stress index from Table NB-3681(a)-1

S_h = as defined in NC-3653.1

(5) The use of the $6S_h$ limit in (4) assumes essentially linear behavior of the entire piping system. This assumption is sufficiently accurate for systems where plastic straining occurs at many points or over relatively wide regions, but fails to reflect the actual strain distribution in unbalanced systems where only a small portion of the piping undergoes plastic strain. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced

(-a) by the use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed.

(-b) by local reduction in size or cross section, or local use of a weaker material.

In the case of unbalanced systems, the design shall be modified to eliminate the unbalance or the piping shall be qualified to the equations given in (4) with $6S_h$ as $3S_h$.

(6) Piping displacements shall satisfy Design Specification limitations.

(c) As an alternative to (a) and (b), the rules contained in Section III Appendices, Nonmandatory Appendix F may be used in evaluating these service loadings independently of all other Design and Service Loadings.

NC-3658 Analysis of Flanged Joints

The pressure design of flanged joints is covered by NC-3647.1. Flanged joints subjected to combinations of moment and pressure shall meet the requirements of either NC-3658.1, NC-3658.2, or NC-3658.3. In addition, the pipe-to-flange welds shall meet the requirements of NC-3651 through NC-3655 using appropriate stress intensification factors from Table NC-3673.2(b)-1. The following nomenclature applies for NC-3658:

A_b = total cross-sectional area of bolts at root of thread or section of least diameter under stress, in.^{2} (mm^2)

C = bolt circle diameter, in. (mm)

D_f = outside diameter of raised face, in. (mm)

G = diameter at location of gasket load reaction as defined in Section III Appendices, Mandatory Appendix XI, XI-3130, in. (mm)

M_{fd} = bending or torsional moment (considered separately) as defined for M_{fs} but including dynamic loadings applied to the flanged joint during the design or service condition, in.-lb (N·mm)

M_{fs} = bending or torsional moment (considered separately) applied to the joint due to weight, thermal expansion of the piping, sustained anchor move ments, relief valve steady-state thrust, and other sustained mechanical loads applied to the flanged joint during the design or service condition, in.-lb. (N·mm). If cold springing is used, the moment may be reduced to the extent permitted by NC-3673.5.

P = Design or Service Condition Pressure as defined in NCA-2140, psi (MPa)

P_{eq} = equivalent pressure to account for the moments applied to the flange joint during the Condition, psi (MPa)

P_{fd} = pressure concurrent with M_{fd}, psi (MPa)

S = allowable bolt stress for the bolt material, psi (MPa)

S_y = yield strength, psi (MPa), of flange material at Design Temperature (Section II, Part D, Subpart 1, Tables Y-1 and Y-2)

NC-3658.1 Any Flanged Joint. Flanged joints may be analyzed and the stresses evaluated by using the methods given in Section III Appendices, Mandatory Appendix XI as modified by (a) or by (b). Alternatively, they may be analyzed in accordance with Section III Appendices, Mandatory Appendix XIII.

(a) If the flanged joint conforms to one of the standards listed in Table NCA-7100-1, and if each P' as calculated by (b) is less than the rated pressure at the Design or Service Temperature utilized, the requirements of NC-3658 are satisfied.

(b) The Design Pressure used for the calculation of H in Section III Appendices, Mandatory Appendix XI shall be replaced by a flange design pressure

$$P' = P + P_{eq}$$

The equivalent pressure P_{eq} shall be determined by the greater of:

$$P_{eq} = 16M_{fs} / \pi G^3$$

or

$$P_{eq} = 8M_{fd} / \pi G^3$$

NC-3658.2 Standard Flanged Joints at Moderate Pressures and Temperatures. Flanged joints conforming to ASME B16.5, ASME B16.47, or ANSI/AWWA C207 Class E [275 psi (1.9 MPa)], and used where neither the Design nor Service Pressure exceeds 100 psi (0.7 MPa) and neither the Design nor Service Temperature exceeds 200°F (95°C), meet the requirements of NC-3658, provided the following equations are satisfied:

$$M_{fs} \le A_b CS / 4$$

and

$$M_{fd} \le A_b CS / 2$$

NC-3658.3 ASME B16.5 Flanged Joints With High Strength Bolting. Flanged joints using flanges, bolting, and gaskets as specified in ASME B16.5 and using bolting material having an S value at 100°F (38°C) not less than 20,000 psi (138 MPa) may be analyzed in accordance with the following rules.

(a) Design Limits and Level A and B Service Limits

(1) The pressure shall not exceed the rated pressure for Level A Service Limits or 1.1 times the rated pressure for Level B Service Limits.

(2) The limitations given by eqs. (12) and (13) shall be met:

(U.S. Customary Units)

$$M_{fs} \le 3,125\left(S_y / 36,000\right) C A_b \tag{12}$$

(SI Units)

$$M_{fs} \le 21.7\left(S_y / 250\right) C A_b$$

(U.S. Customary Units)

$$M_{fd} \le 6,250\left(S_y / 36,000\right) C A_b \tag{13}$$

(SI Units)

$$M_{fd} \le 43.4\left(S_y / 250\right) C A_b$$

where the values of S_y/36,000 and S_y/250 shall not be taken as greater than unity.

(b) Level C Service Limits

(1) The pressure shall not exceed 1.5 times the rated pressure.

(2) The limitation given by eq. (17) shall be met:

(U.S. Customary Units)

$$M_{fd} \le \left[11,250A_b - (\pi / 16)D_f{}^2 P_{fd}\right] \times C\left(S_y / 36,000\right) \tag{17}$$

(SI Units)

$$M_{fd} \le \left[78.1A_b - (\pi / 16)D_f{}^2 P_{fd}\right] C\left(S_y / 250\right)$$

where the values of S_y/36,000 and S_y/250 shall not be taken as greater than unity.

(c) Level D Service Limits

(1) The pressure shall not exceed 2.0 times the rated pressure.

(2) The limitation given by eq. (b)(2)(17) shall be met, where P_{fd} and M_{fd} are pressures, psi (MPa), and moments, in.-lb (N·mm), occurring concurrently.

(d) Test Loadings. Analysis for test loadings is not required.

NC-3660 DESIGN OF WELDS

NC-3661 Welded Joints

NC-3661.1 General Requirements. Welded joints shall be made in accordance with NC-4200.

NC-3661.2 Socket Welds.[32]

(a) Socket welded piping joints shall be limited to pipe sizes of NPS 2 (DN 50) and less.

(b) Socket welds shall comply with the requirements of NC-4427.

(c) Drains and bypasses may be attached to a valve or a fitting using socket welded joints up to a maximum of NPS 4 (DN 100).

NC-3661.3 Fillet Welds and Partial Penetration Welds for Branch Connections.[33]

(a) Fillet welds and partial penetration welds may be used within the limitations of NC-3643.1(c).

(b) For fillet welds, the size of the weld shall be specified on the design drawings.

(c) For partial penetration welds, the size of the weld, the depth of the weld groove, and the groove angle shall be specified on the design drawings.

NC-3670 SPECIAL PIPING REQUIREMENTS

NC-3671 Selection and Limitations of Nonwelded Piping Joints

The type of piping joint used shall be suitable for the Design Loadings and shall be selected with consideration of joint tightness, mechanical strength, and the nature of the fluid handled.

NC-3671.1 Flanged Joints. Flanged joints shall conform to NC-3647 and NC-3658.

NC-3671.2 Expanded or Rolled Joints. Expanded or rolled joints may be used when experience or test (NC-3649) has demonstrated that the joint is suitable for the Design Loadings and when adequate provisions are made to prevent separation of the joint.

NC-3671.3 Threaded Joints. Threaded joints may be used within the limitations specified in (a), (b), and (c) below.

(a) All threads on piping products shall be taper pipe threads in accordance with the applicable standard listed in Table NCA-7100-1. Threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seal weld or a seating surface other than the threads and when experience or test (NC-3649) has demonstrated that such threads are suitable.

(b) Threaded joints shall not be used when severe erosion, crevice corrosion, shock, or vibration is expected to occur. Size limits for steam and hot water service above 220°F (104°C) shall be as follows:

Maximum Nominal Size, in. (DN)	Maximum Pressure, psi (MPa)
3 (80)	400 (2.8)
2 (50)	600 (4.1)
1 (25)	1,200 (8.3)
$^3/_4$ (20) and less	1,500 (10.3)

(c) Pipe with a wall thickness less than that of standard weight of ASME B36.10M steel pipe shall not be threaded, regardless of service. When steel pipe is threaded and used in steam service above 250 psi (1.7 MPa) or water service above 100 psi (700 kPa) and 220°F (104°C), the pipe shall be seamless and at least Schedule 80.

NC-3671.4 Flared, Flareless, and Compression Joints. Flared, flareless, and compression type tubing fittings may be used for tube sizes not exceeding 2 in. (50 mm) O.D. within the limitations of applicable standards and specifications in Table NCA-7100-1 and as specified in (a) through (e) below.

(a) Fittings and their joints shall be compatible with the tubing with which they are to be used and shall conform to the range of wall thicknesses and method of assembly recommended by the manufacturer.

(b) Fittings shall be used at pressure–temperature ratings not exceeding the recommendations of the manufacturer. Service conditions, such as vibration and thermal cycling, shall be considered in the application.

(c) All threads on piping products shall be taper pipe threads in accordance with applicable standard listed in Table NCA-7100-1. Exceptions are that threads other than taper pipe threads may be used for piping components where tightness of the joint depends on a seating surface other than the threads and when experience or tests (NC-3649) have demonstrated that such threads are suitable.

(d) In the absence of standards or specifications, the designer shall determine that the type of fitting selected is adequate and safe for the Design Loadings in accordance with the following requirements.

(1) The pressure design shall meet the requirements of NC-3649.

(2) Prototypes of the fittings to be used shall successfully meet performance tests (NC-3649) to determine the safety of the joint under simulated Service Loadings. When vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock are expected, the applicable conditions shall be incorporated in the test.

(e) Flareless fittings shall be of a design in which the gripping member or sleeve shall grip or bite into the outer surface of the tube with sufficient strength to hold the tube against pressure but without appreciably distorting the inside tube diameter. The gripping member shall also form a pressure seal against the fitting body.

(1) When using bite-type fittings, a spot check shall be made for adequate depth of bite and condition of tubing by disassembling and reassembling selected joints.

(2) Grip-type fittings that are tightened in accordance with manufacturer's instructions need not be disassembled for checking.

NC-3671.5 Caulked Joints. Caulked or leaded joints shall not be used.

NC-3671.6 Brazed and Soldered Joints.

(a) Brazed Joints. Brazed joints shall be socket type, and minimum socket depth shall be sufficient for the intended service (Figure NC-4511-1).

(b) Soldered Joints. Soldered joints shall be socket type and shall be made in accordance with applicable standards listed in Table NCA-7100-1.

(c) Limitations of Brazed and Soldered Joints

(1) Brazed socket-type joints shall not be used in systems containing flammable or toxic fluids or in areas where fire hazards are involved.

(2) Soldered socket-type joints shall be limited to systems containing nonflammable and nontoxic fluids.

(3) Soldered socket-type joints shall not be used in piping subject to mechanical or thermal shock or vibration.

(4) Brazed or soldered joints depending solely upon a fillet, rather than primarily upon brazing or soldering material between the pipe and socket, are not acceptable.

(5) Soldered joints shall be pressure and temperature rated in accordance with the applicable standards in Table NCA-7100-1, except that they shall not be used at pressures in excess of 175 psi (1.2 MPa) or at temperatures in excess of 250°F (120°C).

NC-3671.7 Sleeve Coupled and Other Patented Joints. Coupling-type, mechanical gland-type, and other patented joints may be used where experience or tests have demonstrated to the satisfaction of the designer that the joint is safe for the Design Loadings and when adequate provision is made to prevent separation of the joint.

NC-3672 Expansion and Flexibility

NC-3672.1 General Requirements.

(a) In addition to the design requirements for pressure, weight, and other loadings,piping systems subject to thermal expansion or contraction or to similar movements imposed by other sources shall be designed in accordance with the requirements for the evaluation and analysis of flexibility and stresses specified in this paragraph.

(b) Piping shall meet the expansion and flexibility requirements of this subarticle except that, where Class 2 piping is connected to Class 1 piping, the requirements for expansion and flexibility for Class 1 piping shall apply to the Class 2 piping out to the first anchor on the Class 2 piping. However, the effect of expansion stresses in combination with stresses from other causes shall be evaluated in accordance with NC-3650. Other exceptions as given in the following subparagraphs shall apply.

NC-3672.2 Properties. Thermal expansion data and moduli of elasticity shall be determined from Section II, Part D, Subpart 2, Tables TE and TM, which cover more commonly used piping materials. For materials not included in these Tables, reference shall be to authoritative source data such as publications of the National Institute of Standards and Technology.

NC-3672.3 Thermal Expansion Range. The thermal expansion range shall be determined from Section II, Part D, Subpart 2, Table TE as the difference between the unit expansion shown for the highest metal temperature and that for the lowest metal temperature resulting from service and shutdown conditions.

NC-3672.4 Moduli of Elasticity. The cold and hot moduli of elasticity E_c and E_h shall be as shown in Section II, Part D, Subpart 2, Table TM based on the temperatures established in NC-3672.3.

NC-3672.5 Poisson's Ratio. Poisson's ratio, when required for flexibility calculations, shall be taken as 0.3 at all temperatures for all materials.

NC-3672.6 Stresses. Calculations for the stresses shall be based on the least cross-sectional area of the pipe or fitting, using nominal dimensions at the location of local strain. Calculations for the expansion stress S_E shall be based on the modulus of elasticity at room temperature E_c.

(a) Stress Range. Stresses caused by thermal expansion, when of sufficient initial magnitude, relax in the hot condition as a result of local yielding or creep. A stress reduction takes place and usually appears as a stress of reversed sign when the component returns to the cold condition. This phenomenon is designated as self-springing of the line and is similar in effect to cold springing. The extent of self-springing depends on the material, the magnitude of the initial expansion and fabrication stress, the hot service temperature, and the elapsed time. When the expansion stress in the hot condition tends to diminish with time, the sum of the expansion strains for the hot and cold conditions during any one cycle remains substantially constant. This sum is referred to as the strain range; however, to permit convenient association with allowable stress, stress range is selected as the criterion for the thermal design of piping.

(b) Local Overstrain. All the commonly used methods of piping flexibility analysis assume elastic behavior of the entire piping system. This assumption is sufficiently accurate for systems in which plastic straining occurs at many points or over relatively wide regions but fails to reflect the actual strain distribution in unbalanced systems in which only a small portion of the piping undergoes plastic strain or in which, for piping operating in the creep range, the strain distribution is very uneven. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced

(1) by use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed;

(2) by local reduction in size or cross section, or local use of a weaker material;

(3) in a system of uniform size, by use of a line configuration for which the neutral axis or thrust line is situated close to the major portion of the line itself, with only a very small offset portion of the line absorbing most of the expansion strain.

(c) Conditions of this type shall be avoided where materials of relatively low ductility are used; if unavoidable, they shall be mitigated by the judicious application of cold spring.

(d) It is recommended that the design of piping systems of austenitic materials be approached with greater overall care as to general elimination of local stress raisers, examination, material selection, fabrication quality, and erection.

NC-3672.7 Flexibility. Piping systems shall be designed to have sufficient flexibility to prevent pipe movements from causing failure from overstress of the pipe material or anchors, leakage at joints, or detrimental distortion of connected equipment resulting from excessive thrusts and moments. Flexibility shall be provided by changes of direction in the piping through the use of bends, loops, or offsets; or provisions shall be made to absorb thermal movements by utilizing expansion, swivel, or ball joints, or corrugated pipe.

NC-3672.8 Expansion, Swivel, or Ball Joints. Expansion, swivel, or ball joints, if used, shall conform to the requirements and limitations of NC-3649.

NC-3673 Analysis

NC-3673.1 Method of Analysis. All systems shall be analyzed for adequate flexibility by a structural analysis unless one of the following conditions is met:

(a) the system can be judged technically adequate by an engineering comparison with previously analyzed systems;

(b) the operating temperature of the piping system is at or below 150°F (65°C) and the piping is laid out with inherent flexibility, as provided in NC-3672.7;

(c) the operating temperature of the piping system is at or below 250°F (120°C) and the piping is analyzed for flexibility using simplified methods of calculation such as handbooks or charts.

NC-3673.2 Basic Assumptions and Requirements.

(a) When calculating the flexibility of a piping system between anchor points, the system between anchor points shall be treated as a whole. The significance of all parts of the line and of all restraints, such as supports or guides, including intermediate restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines, shall be considered.

(b) Comprehensive calculations shall take into account the flexibility factors found to exist in piping products or joints other than straight pipe. Credit may be taken where extra flexibility exists in such products or joints. Flexibility factors and stress intensification factors for commonly used piping products and joints are shown in Table NC-3673.2(b)-1 [see also Figure NC-3673.2(b)-2]. The stress intensification factors and flexibility factors in Table NC-3673.2(b)-1 shall be used unless specific experimental or analytical data exist that would warrant lower stress intensification factors or higher flexibility factors.

(c) Flexibility factors are identified herein by k with appropriate subscripts. The general definition of a flexibility factor is:

$$k = \theta_{ab} / \theta_{\text{nom}}$$

where

θ_{ab} = rotation of end a, with respect to end b, due to a moment load M and in the direction of the moment M

θ_{nom} = nominal rotation assuming the component acts as a beam with the properties of the nominal pipe. For an elbow, θ_{nom} is the nominal rotation assuming the elbow acts as a curved beam

The flexibility factor k is defined in detail for specific components in Table NC-3673.2(b)-1.

(d) Stress intensification factors are identified herein by i. The definition of a stress intensification factor is based on fatigue bend testing of mild carbon steel fittings and is:

(U.S. Customary Units)

$$iS = 245{,}000N^{-0.2}$$

(SI Units)

$$iS = 1700N^{-0.2}$$

where

i = stress intensification factor
= ratio of the bending moment producing fatigue in a given number of cycles in a straight pipe with a girth butt weld to that producing failure in the same number of cycles in the fitting or joint under consideration.

N = number of cycles to failure

S = amplitude of the applied bending stress at the point of failure, psi (MPa)

(e) For piping products or joints not listed in Table NC-3673.2(b)-1, flexibility or stress intensification factors shall be established by experimental or analytical means.

(f) Experimental determination of flexibility factors shall be in accordance with Section III Appendices, Mandatory Appendix II, II-1900. Experimental determination of stress intensification factors shall be in accordance with Section III Appendices, Mandatory Appendix II, Article II-2000.

(g) Analytical determination of flexibility factors shall be consistent with the definition above.

(**15**)

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors

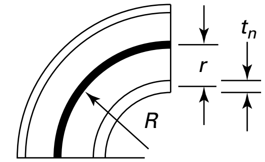
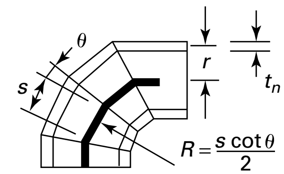
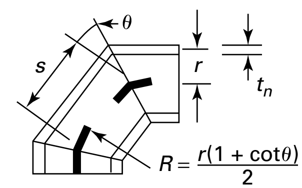
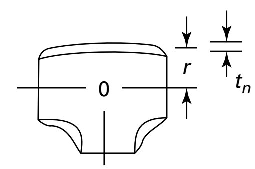
Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Note (1)], [Note (2)]	$0.4\,h - 0.1 \le 0.5$ and > 0	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \ge r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4\left(\frac{r}{t_n}\right)^{2/3}$ Run end: $B_{2r} = 0.5\left(\frac{r}{t_n}\right)^{2/3}$	$\frac{4.4\,t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$ For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right)$	

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

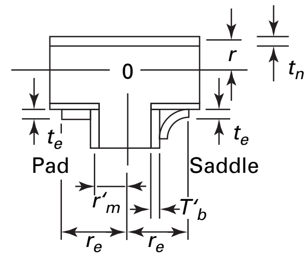
	Primary Stress Index					
Description	B_1	B_2	**Flexibility Characteristic, *h***	**Flexibility Factor, *k***	**Stress Intensification Factor, *i***	**Sketch**
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75\left(\frac{r}{t_n}\right)^{2/3}\left(\frac{r'_m}{r}\right)^{1/2}\left(\frac{T'_b}{t_n}\right)\left(\frac{r'_m}{r_{ps}}\right)$ ≥ 1.0 [Note (7)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r\left(t_n\right)^{3/2}}$	1	$\frac{0.9}{h^{2/3}} \geq 2.1$	
		Run end: $B_{2r} = \frac{0.675(r/t_n)^{2/3}}{[1 + (t'_e/2t_n)]^{5/3}} \geq 1.0$ [Note (8)]			For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right) \geq 2.1$	

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Factor, *k*	Stress Intensification Factor, *i*	Sketch
	B_1	B_2			
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $(r'_m/R_m) \le 0.9$ $B_{2b} = 0.75\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$ for $(r'_m/R_m) = 1.0$ $B_{2b} = 0.45\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right)$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation	1	Branch leg: for $(r'_m/R_m) \le 0.9$ $i_b = 1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $(r'_m/R_m) = 1.0$ $i_b = 0.9\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation	Figure NC-3673.2(b)-2
		Run legs: for $(r'_m/R_m) \le 0.5$ $B_{2r} = 0.75\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not < 1.0 for $(r'_m/R_m) > 0.5$ $B_{2r} = 0.9\left(\frac{r'_m}{t_b}\right)^{1/4}$		Run legs: for $(r'_m/R_m) \le 0.5$ $i_r = 0.8\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_b/T_r)(t_b/d_i)^{0.5}$ but not > 0.5 for $(r'_m/R_m) > 0.5$ $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

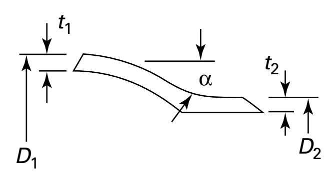
Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ Run legs: $B_{2r} = 1.3\left(\frac{r'_m}{t_b}\right)^{1/4} \ge 1.5$	1	Branch leg: $i_b = 4.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 3.0$ Run legs: $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	Figure NC-3643.2(b)-2
Girth butt weld	0.5	1.0	1	1.0	...
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75\left(\frac{t_n}{c_x}\right) \ge 0.5$	$1.5\left(\frac{t_n}{c_x}\right)$	1	For $C_x \ge 1.09t_n$, $i = 1.3$ For $C_x < 1.09t_n$, $i = 2.1\ (t_n/C_x) \ge 1.3$	Figure NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure NC-4511-1
30 deg tapered transition (ASME B16.25) $t_n < 0.237$ in. (6 mm)	0.5	1.0	1	*(U.S. Customary Units)* $1.3 + 0.0036\frac{D_o}{t_n} + 0.113/t_n \le 1.9$ *(SI Units)* $1.3 + 0.0036\frac{D_o}{t_n} + 2.87/t_n \le 1.9$	...
30 deg tapered transition (ASME B16.25) $t_n \ge 0.237$ in. (6 mm)	0.5	1.0	1	$1.3 + 0.0036\ D_o\ /\ t_n \le 1.9$	...
Concentric and eccentric reducers (ASME B16.9) [Note (12)]	0.5 for $\alpha \le 30$ deg 1.0 for 30 deg < $\alpha \le 60$ deg	1.0	1	$0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2} \le 2.0$	

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Threaded pipe joint or threaded flange	0.75	1.7	1	2.3	...

GENERAL NOTES:

(a) The following nomenclature applies:

d_i = nominal inside diameter of branch, in. (mm)
D_o = nominal outside diameter, in. (mm)
R = nominal bend radius of elbow or pipe bend, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
R_m = mean radius of run pipe, in. (mm)
r'_m = mean radius of branch pipe, in. (mm)
s = miter spacing at center line, in. (mm)
t_b = thickness in reinforcement zone of branch, in. (mm)
t_e = pad or saddle thickness, in. (mm)
t_n = nominal wall thickness of pipe, in. (mm) [matching pipe for tees and elbows, see Note (2)]
T_r = nominal wall thickness of run pipe, in. (mm)
T'_b = nominal wall thickness of branch pipe, in. (mm)
θ = one-half angle between adjacent miter axes, deg

For Figure NC-3673.2(b)-2, sketches (a) and (b):

$t_b = T_b$ if $L_1 \geq 0.5(2r'_m T_b)^{1/2}$
$= T'_b$ if $L_1 < 0.5(2r'_m T_b)^{1/2}$

For Figure NC-3673.2(b)-2, sketch (c):

$t_b = T'_b + (2/3)y$ if $\theta \leq 30$ deg
$= T'_b + 0.385L_1$ if $\theta > 30$ deg

For Figure NC-3673.2(b)-2, sketch (d):

$t_b = T'_b = T_b$

For branch connection nomenclature, refer to Figs. NC-3643.2(b)-2 and NC-3673.2(b)-2.

(b) The flexibility factors k, stress intensification factors i, and stress indices B_2 apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$. For products and joints with $50 < D_o/t_n \leq 100$, the B_1 index in Table NC-3673.2(b)-1 is valid. The B_2 index shall be multiplied by the factor $1/(XY)$, where:

$X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0
$Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°F)
$= 1.0224 - 0.000594T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°C)
$= 1.0$ for other materials

NOTES:

(1) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.
(a) One end flanged, $c = h^{1/6}$
(b) Both ends flanged, $c = h^{1/3}$
But after such multiplication, values of k and i shall not be taken as less than 1.0.

(2) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

NOTES (CONT'D):

(3) Also includes single miter joints.

(4) For checking branch leg stress:

$$Z = \pi \left(r'_m\right)^2 T'_b$$

For checking run leg stress:

$$Z = \pi \left(R_m\right)^2 T_r$$

(5) When $t_e > 1.5\ t_n$, $h = 4.05 t_n / r$.

(6) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of NC-3643 are met.

(b) The axis of the branch pipe is normal to the surface of the run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.

(d) The run pipe is a straight pipe.

(7) r'_m / r shall be taken as 0.5 for $r'_m / r > 0.5$.
r'_m / r_{ps} shall not be taken as less than 0.5.

The definition of r_{ps} is:
$r_{ps} = (r'_m + r_e) / 2$ for $t_e \geq 0.8 t_n$
$r_{ps} = r'_m + (T'_b / 2)$ for $t_e < 0.8 t_n$

(8) The definition of t'_e is:
$t'_e = t_e\ [(r_e\ /\ r'_m) - 1]$ but not greater than $1.0 t_n$

(9) If an r_2 radius is provided [Figure NC-3673.2(b)-2] that is not less than the larger of $T_b/2$, $(T'_b + y)/2$ [sketch (c)], or $T_r/2$, then the calculated values of i_b and i_r may be divided by 2, but with $i_b \geq 1.5$ and $i_r \geq 1.5$. For $r'_m / R_m \leq 0.5$, the i factors for checking run ends are independent of whether r_2 is provided or not.

(10) The equations apply only if $r'_m / R_m \leq 0.5$.

(11) In Figure NC-4427-1 sketches (c-1) and (c-2), C_x shall be taken as X_{min} and $C_x \geq 1.25\ t_n$. In Figure NC-4427-1 sketch (c-3), $C_x \geq 0.75\ t_n$. For unequal leg lengths, use the smaller leg length for C_x.

(12) The equation applies only if the following conditions are met:

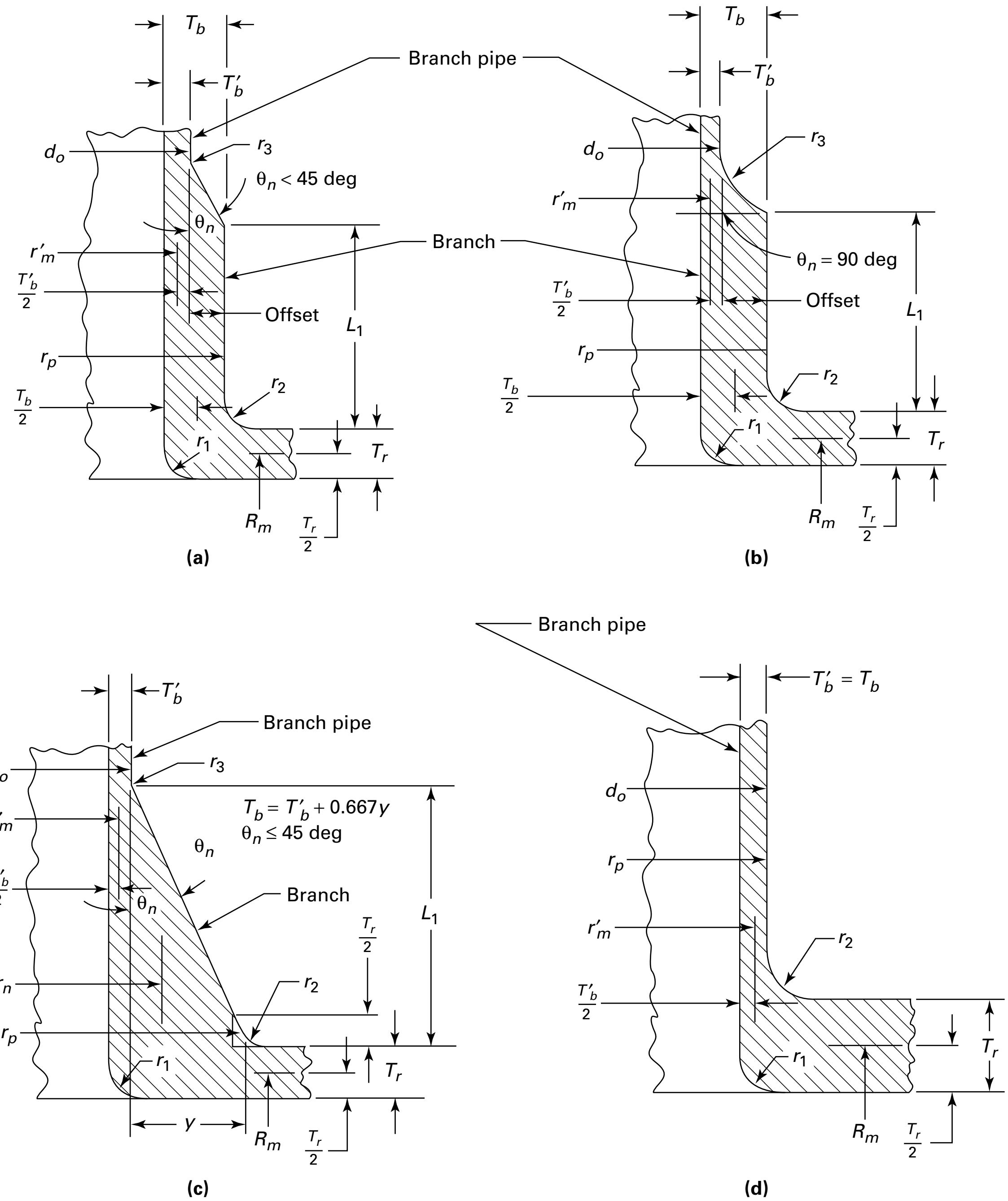
(a) Cone angle α does not exceed 60 deg.

(b) The larger of D_1 / t_1 and D_2 / t_2 does not exceed 100.

(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(d) For eccentric reducers, α is the maximum cone angle.

Figure NC-3673.2(b)-2
Branch Connection Nomenclature



Legend:

d_o = outside diameter of branch pipe, in. (mm)
R_m = mean radius of run pipe, in. (mm)
r'_m = mean radius of branch pipe, in. (mm)
T_r = nominal thickness of run pipe, in. (mm)
T'_b = nominal thickness of branch pipes, in. (mm)

GENERAL NOTE: T_b, θ, r_1, r_2, r_3, r_p, and y are defined in this figure.

(h) Analytical determination of stress intensification factors may be based on the empirical relationship

$$i = C_2K_2 / 2, \text{but not less than} 1.0$$

where C_2 and K_2 are stress indices for Class 1 piping products or joints from NB-3681(a)-1, or are determined as explained below.

Analytical determination of stress intensification factors shall be correlated with experimental fatigue results. Experimental correlation may be with new test data or with test data from similar products or joints reported in literature. Finite element analyses or other stress analysis methods may be used to determine C_2; however, tests or established stress concentration factor data should then be used to determine K_2.

(i) For certain piping products or joints the stress intensification factor may vary depending on the direction of the applied moment, such as in an elbow or branch connection. For these cases, the stress intensification factor used in eqs. NC-3653.2(a)(10a), NC-3653.2(b)(10b), and NC-3653.2(c)(11) shall be the maximum stress intensification factor for all loading directions as determined in accordance with (f) or (h) above.

(j) Stress intensification factors determined in accordance with (f) above shall be documented in accordance with Section III Appendices, Mandatory Appendix II, II-2050. The test report may be included and certified with the Design Report (NCA-3551.1 and NCA-3555) for the individual piping system or a separate report furnished (Section III Appendices, Mandatory Appendix II, II-2050).

(k) Stress intensification factors determined in accordance with (h) above shall be documented in a report with sufficient detail to permit independent review. The review shall be performed by an engineer competent in the applicable field of design in accordance with Section III Appendices, Mandatory Appendix XXIII. The report shall be included and certified as part of the design report for the piping system (NCA-3551.1 and NCA-3555).

(l) The total expansion range as determined from NC-3672.3 shall be used in all calculations, whether or not the piping is cold sprung. Expansion of the line, linear and angular movements of the equipment, supports, restraints, and anchors shall be considered in the determination of the total expansion range.

(m) Where simplifying assumptions are used in calculations or model tests, the likelihood of underestimates of forces, moments, and stresses, including the effects of stress intensification, shall be evaluated.

(n) Dimensional properties of pipe and fittings used in flexibility calculations shall be based on nominal dimensions.

(o) When determining stress intensification factors by experimental methods, NC-3653.3(d) shall not apply. The nominal stress at the point under consideration (crack site, point of maximum stress, etc.) shall be used.

NC-3673.3 Cold Springing. The beneficial effect of judicious cold springing in assisting a system to attain its most favorable position is recognized. Inasmuch as the life of a system under cyclic conditions depends on the stress range rather than the stress level at any one time, no credit for cold spring is allowed with regard to stresses. In calculating end thrusts and moments acting on equipment, the actual reactions at any one time, rather than their range, shall be used. Credit for cold springing is allowed in the calculations of thrusts and moments, provided the method of obtaining the designed cold spring is specified and used.

NC-3673.4 Movements. Movement caused by thermal expansion and loadings shall be determined for consideration of obstructions and design of proper supports.

NC-3673.5 Computing Hot and Cold Reactions.

(a) In a piping system with no cold spring or an equal percentage of cold springing in all directions, the reactions of R_h and R_c, in the hot and cold conditions, respectively, shall be obtained from the reaction R derived from the flexibility calculations based on the modulus of elasticity at room temperature E_c using eqs. (14) and (15).

$$R_h = \left(1 - \frac{2}{3}C\right)\left[\frac{E_h}{E_c}\right]R \tag{14}$$

$$R_c = CR$$
$$= \left[1 - \frac{(S_h)}{(S_E)}\cdot\frac{(E_c)}{(E_h)}\right]R \tag{15}$$

whichever is greater, and with further condition that

$$\frac{(S_h)}{(S_E)}\cdot\frac{(E_c)}{(E_h)} < 1$$

where

- C = cold spring factor varying from zero for no cold spring to 1.00 for 100% cold spring
- E_c = modulus of elasticity in the cold condition, psi (MPa)
- E_h = modulus of elasticity in the hot condition, psi (MPa)
- R = maximum reaction for full expansion range based on E_c which assumes the most severe condition (100% cold spring, whether such is used or not), lb (N)
- R_c, R_h = maximum reactions estimated to occur in the cold and hot conditions, respectively, lb (N)
- S_E = computed expansion stress, psi (MPa) [NC-3653.2(a)]

(b) If a piping system is designed with different percentages of cold spring in various directions, eqs. (a)(14) and (a)(15) are not applicable. In this case, the piping system shall be analyzed by a comprehensive method. The

calculated hot reactions shall be based on theoretical cold springs in all directions not greater than two-thirds of the cold springs as specified or measured.

NC-3673.6 Reaction Limits. The reactions computed shall not exceed limits which the attached equipment can safely sustain.

NC-3674 Design of Pipe Supports

Pipe supports shall be designed in accordance with the requirements of Subsection NF.

NC-3677 Pressure Relief Piping

NC-3677.1 General Requirements. Pressure relief piping within the scope of this subarticle shall be supported to sustain reaction forces and shall conform to the requirements of the following subparagraphs.

NC-3677.2 Piping to Pressure-Relieving Safety Devices.

(a) Piping that connects a pressure relief device to a piping system shall comply with all the requirements of the Class of piping of the system which it is designed to relieve.

(b) There shall be no intervening stop valves between systems being protected and their protective device or devices, except as provided for in NC-7142.

NC-3677.3 Discharge Piping From Pressure-Relieving Safety Devices.

(a) Discharge piping of pressure relief devices shall comply with the requirements of the Class of piping applicable to the conditions under which it operates.

(b) There shall be no intervening stop valves between the protective device or devices and the point of discharge, except as provided for in NC-7142.

(c) When discharging directly to the atmosphere, discharge shall not impinge on other piping or equipment and shall be directed away from platforms and other areas used by personnel.

(d) It is recommended that individual discharge lines be used. For requirements on discharge piping, see NC-7141(f).

(e) Discharge lines from pressure-relieving safety devices within the scope of this subarticle shall be designed to facilitate drainage.

(f) When the umbrella or drip pan type of connection is used, the discharge piping shall be so designed as to prevent binding due to expansion movements. Drainage shall be provided to remove water collected above the safety valve seat.

NC-3678 Temporary Piping Systems

Prior to service of piping systems and associated equipment, certain temporary piping may be installed to accommodate cleaning by blowing out with steam or air, by acid or caustic fluid circulation, or other flushing methods. Such temporary piping shall be designed to safeguard against rupture or other failure which could become a hazard to health or safety.

NC-3690 DIMENSIONAL REQUIREMENTS FOR PIPING PRODUCTS

NC-3691 Standard Piping Products

Dimensions of standard piping products shall comply with the standards and specifications listed in Table NCA-7100-1.

NC-3692 Nonstandard Piping Products

The dimensions of nonstandard piping products shall be such as to provide strength and performance equivalent to standard products, except as permitted in NC-3641.

NC-3700 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

NC-3720 DESIGN RULES

(a) The design of the pressure-retaining portion of electrical and mechanical penetration assemblies shall be the same as for vessels (NC-3300).

(b) For closing seams in electrical and mechanical penetration assemblies meeting the requirements of NC-4730(c), the closure head shall meet the requirements of NC-3325 using a factor $C = 0.20$. The fillet weld shall be designed using an allowable stress of $0.5S$.

NC-3800 DESIGN OF ATMOSPHERIC STORAGE TANKS

NC-3810 GENERAL REQUIREMENTS

NC-3811 Acceptability

The requirements for acceptability of atmospheric storage tanks are given in the following subparagraphs.

NC-3811.1 Scope. The design rules for atmospheric storage tanks cover vertical cylindrical flat bottom above ground[34] welded tanks at atmospheric pressure. These tanks may contain liquids such as refueling water, condensate, borated reactor coolant, or liquid radioactive waste. Such tanks may be within building structures, depending upon the liquid to be contained, or they may be above grade exposed to atmospheric conditions.

NC-3811.2 Design Requirements. The design rules for atmospheric storage tanks shall conform to the design requirements of NC-3100 and NC-3300 except as they may be modified by the requirements of this subarticle. The specific design requirements shall be stipulated in the Design Specifications.

NC-3812 Design Report

The Certificate Holder manufacturing a storage tank conforming to the design requirements of this subarticle is required to provide a Design Report as part of his responsibility for achieving structural integrity of the tank. The Design Report shall be certified when required by NCA-3550.

NC-3820 DESIGN CONSIDERATIONS

NC-3821 Design and Service Loadings

(a) Loadings shall be identified as Design or Service, and if Service, they shall have Level A, B, C, or D Service Limits designated (NCA-2142).

(b) The provisions of NC-3110 shall apply.

(c) The stress limits given in NC-3821.5 shall be met.

NC-3821.1 Design Pressure. The Design Pressure[35] shall be atmospheric.

NC-3821.2 Design Temperature. The Design Temperature shall not be greater than 200°F (95°C).

NC-3821.3 Loadings. The requirements of NC-3111 shall be met.

NC-3821.4 Welded Joint Restrictions. The restrictions given in (a) through (c) below on type and size of joints or welds shall apply.

(a) Tack welds shall not be considered as having any strength value in the finished structure.

(b) The minimum size of fillet welds shall be in accordance with NC-4246.6.

(c) All nozzle welds shall be in accordance with NC-4246.5.

NC-3821.5 Limits of Calculated Stresses for Design and Service Loadings. Stress[20] limits for Design and Service Loadings are specified in Table NC-3821.5-1. The symbols used in Table NC-3821.5-1 are defined as follows:

S = allowable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, psi (MPa). The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

σ_b = bending stress, psi (MPa). This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress, psi (MPa). This stress is the same as σ_m, except that it includes the effect of discontinuities.

σ_m = general membrane stress, psi (MPa). This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

Typical examples of locations and loadings for which σ_m, σ_L, and σ_b are applicable are shown in Section III Appendices, Mandatory Appendix XIII, Table XIII-1130-1 with σ considered as equivalent to P in Section III Appendices, Mandatory Appendix XIII, Table XIII-1130-1.

NC-3830 BOTTOM DESIGN

NC-3831 Plate Sizes

(a) All bottom plates shall have a minimum nominal thickness of $^1/_4$ in. (6 mm) exclusive of any corrosion allowance required by the Design Specifications.

(b) Bottom plates shall be ordered of sufficient size so that, when trimmed, at least a 1 in. (25 mm) width will project beyond the outside edge of the weld attaching the bottom to the shell plate.

(c) The type of foundation used for supporting the tank shall be taken into account in the design of the bottom plates and welds. For recommended practice for construction of foundations see API-650, Appendix B.

NC-3832 Methods of Construction

Bottoms shall be built to either one of the alternative methods of construction given in NC-4246.1.

NC-3833 Shell-to-Bottom Attachment

The requirements for shell-to-bottom attachments are given in NC-4246.2.

NC-3840 SHELL DESIGN

NC-3841 Loads

(a) Thicknesses shall be computed on the basis of the specific gravity of the stored material but in no case shall the specific gravity be less than 1.00. The tension in each ring shall be computed 12 in. (300 mm) above the center

Table NC-3821.5-1
Design and Service Limits

Service Limit	Stress Limits [Note (1)] and [Note (2)]
Design and Level A	$\sigma_m \le 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.5S$
Level B	$\sigma_m \le 1.10S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.65S$
Level C	$\sigma_m \le 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.8S$
Level D	$\sigma_m \le 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 2.4S$

NOTES:
(1) See NC-3921.5 for definitions of symbols.
(2) These limits do not take into account either local or general buckling that might occur in thin-wall vessels.

line of the lower horizontal joint of the course in question. In computing these stresses, the tank diameter shall be taken as the nominal diameter of the bottom course.

(b) Isolated radial loads on tank shells, such as caused by heavy loads on platforms and elevated walkways between tanks, shall be distributed by rolled structural sections, plate ribs, or built-up members, preferably in a horizontal position.

NC-3842 Diameters and Thicknesses of Shell Plates

(a) For method of determining minimum thicknesses[36] of shell plates, see NC-3324.3. For pressure-retaining material, see NC-2121.

(b) In no case shall the nominal thickness[37] of shell plates be less than the following:

Nominal Tank Diameter [Note (1)], ft (m)	Nominal Thickness, in. (mm)
Smaller than 50 (15)	$^3/_{16}$ (5)
50 to 120 (15 to 37), incl.	$^1/_4$ (6)

NOTE:
(1) Nominal tank diameter shall be the center line diameter of the shell plates unless otherwise stipulated in the Design Specifications.

(c) The maximum nominal thickness of tank shell plates shall be $1^1/_2$ in. (38 mm).

NC-3843 Arrangement of Members

(a) The tank shell shall be designed to have all courses vertical. Unless otherwise specified, abutting shell plates at horizontal joints shall have a common vertical center line of thickness. Vertical joints in adjacent shell courses shall not be in alignment but shall be offset from each other a minimum distance of 6 in. (150 mm).

(b) Except as specified for self-supporting roofs and for tanks having the flanged roof-to-shell detail described in (c) below, tank shells shall be supplied with top angles of not less than the following sizes: tanks 35 ft (11 m) and smaller in diameter — $2^1/_2$ in. × $2^1/_2$ in. × $^1/_4$ in. (64 mm × 64 mm × 6 mm); tanks of more than 35 ft to 60 ft (11 m to 18 m), inclusive, in diameter — $2^1/_2$ in. × $2^1/_2$ in. × $^5/_{16}$ in. (64 mm × 64 mm × 8 mm); tanks larger than 60 ft (18 m) in diameter — 3 in. × 3 in. × $^3/_8$ in. (75 mm × 75 mm × 10 mm). The outstanding leg of the top angle may extend inside or outside the tank shell.

(c) See (1) and (2) below

(1) For tanks not exceeding 35 ft (11 m) in diameter and having supported cone roofs, the top edge of the shell may be flanged in lieu of installing a top angle. The radius of bend and the width of the flanged edge shall conform to the details of Figure NC-4246.3-1 sketch (c).

(2) This construction may be used for any tank having a self-supporting roof if the total cross-sectional area of the junction fulfills the stated area requirements for the top angle construction. No additional member, such as an angle or bar, shall be added to the flanged roof-to-shell detail.

(d) For tanks not exceeding 35 ft (11 m) in diameter and having a supported flat roof, the roof plates may be flanged and butt welded to the shell. The flanged tank roof plates shall be butt welded. The inside radius of the knuckle shall not be less than $1.75t$ nor more than $8t$.

NC-3850 ROOF DESIGN

NC-3851 Types of Roofs

The types of roofs are defined in the following subparagraphs.

NC-3851.1 Supported Cone Roof. A supported cone roof is a roof formed to approximately the surface of a right cone, with its principal support provided by either rafters on girders and columns or rafters on trusses with or without columns.

NC-3851.2 Supported Flat Roof. A supported flat roof is a roof which is essentially flat, with its principal support provided by either rafters supported by the shell without columns or by rafters in conjunction with girders and trusses with or without columns.

NC-3851.3 Self-Supporting Cone Roof. A self-supporting cone roof is a roof formed to approximately the surface of a right cone, supported only at its periphery.

NC-3851.4 Self-Supporting Dome Roof. A self-supporting dome roof is a roof formed to approximately a spherical surface, supported only at its periphery.

NC-3851.5 Self-Supporting Umbrella Roof. A self-supporting umbrella roof is a modified dome roof so formed that any horizontal section is a regular polygon with as many sides as there are roof plates, supported only at its periphery.

NC-3852 General Roof Design Requirements

NC-3852.1 Loading Requirements. All roofs and supporting structures shall be designed to support dead load, plus a uniform live load of not less than 25 lb/ft^2 (120 kg/m^2) of projected area unless otherwise specified, except that tanks installed in an enclosed area, not exposed to the elements, shall be designed to support the dead load plus a uniform live load of not less than 10 lb/ft^2 (50 kg/m^2).

NC-3852.2 Minimum Plate Thickness. Roof plates shall have a minimum nominal thickness of $^3/_{16}$ in. (5 mm). A greater thickness may be required for self-supporting roofs. Any specified corrosion allowance for the plates of self-supporting roofs shall be added to the calculated thickness. Any specified corrosion allowance for plates of supported roofs shall be added to the minimum nominal thickness.

NC-3852.3 Minimum Thickness of Supporting Members. All internal and external structural members shall have a minimum nominal thickness, in any component, of 0.17 in. (4 mm).

NC-3852.4 Attachment of Roof Plates. Roof plates shall be attached to the top angle of the tank in accordance with NC-4246.3. Roof plates of supported roofs shall not be attached to internal supporting members.

NC-3852.5 Welding of Roof Plates.

(a) If the continuous fillet weld between the roof plates and the top angle does not exceed $^3/_{16}$ in. (5 mm) and the slope of the roof at the top angle attachment does not exceed 2 in./ft (167 mm/m) (16.7%), the joint may be considered to serve as an emergency venting device which, in case of excessive internal pressure, will fail before failure occurs in the tank shell joints or the shell-to-bottom joint. Failure of the roof-to-shell joint may be accompanied by buckling of the top angle.

(b) Where the weld size exceeds $^3/_{16}$ in. (5 mm) or where the slope of the roof at the top angle attachment is greater than 2 in./ft (167 mm/m) (16.7%), emergency venting devices conforming to the specifications noted in API Standard 2000[38] shall be provided. The Certificate Holder shall provide a suitable tank connection for the device.

(c) Roof plates shall be welded in accordance with NC-4246.4.

NC-3852.6 Allowable Stresses.[39] All parts of the structure shall be so proportioned that the sum of the static stresses shall not exceed the values given in (a) through (d) below.

(a) Tension

(1) in rolled steel, on net section, 20 ksi (135 MPa);

(2) in full penetration groove welds on the thinner plate area, 18 ksi (125 MPa).

(b) Compression

(1) in rolled steel, where lateral deflection is prevented, 20.0 ksi (135 MPa);

(2) in full penetration groove welds on the thinner plate area, 20.0 ksi (135 MPa);

(3) in columns, on cross-sectional area, ksi (MPa) for L/r not over 120,

$$\left[1 - \frac{(L/r)^2}{34,700}\right]\frac{CY}{FS}$$

where

C = 33 for U.S. Customary calculations
= 228 for SI calculations

for L/r over 120 to 131.7, inclusive

$$\frac{\left[1 - \frac{(L/r)^2}{34,700}\right]\frac{CY}{FS}}{1.6 - L/200r}$$

where

C = 33 for U.S. Customary calculations
= 228 for SI calculations

for L/r over 131.7

$$\frac{CY}{(L/r)^2(1.6 - L/200r)}$$

where

C = 149,000 for U.S. Customary calculations
= 1.03×10^6 for SI calculations

FS = design factor

$$= \frac{5}{3} + \left[\frac{(L/r)}{350}\right] - \left[\frac{(L/r)^3}{18,300,000}\right]$$

L = unbraced length of column, in. (mm)
R = outside radius of tubular section, in. (mm)
r = least radius of gyration of column, in. (mm)
t = thickness of tubular section, in. (mm); $^1/_4$ in. (6 mm) minimum for main compression members, $^3/_{16}$ in. (5 mm) minimum for bracing and other secondary members
Y = 1.0, for structural sections or tubular sections having t/R values equal to or exceeding 0.015
= $[(^{200}/_3)(t/R)]\ [2 - (^{200}/_3)(t/R)]$, for tubular sections having t/R values less than 0.015

For main compression members, the ratio L/r shall not exceed 180. For bracing and other secondary members, the ratio L/r shall not exceed 200.

(c) Bending

(1) In tension and compression on extreme fibers of rolled shapes and built-up members with an axis of symmetry in the plane of loading where the laterally unsupported length of compression flange is no greater than 13 times its width, the compression flange width– thickness ratio does not exceed 17, and the web depth– thickness ratio does not exceed 22.0 ksi (150 MPa).

(2) In tension and compression on extreme fibers of unsymmetrical members where the member is supported laterally at intervals no greater than 13 times its compression flange width, 20.0 ksi (135 MPa).

(3) In tension on extreme fibers of other rolled shapes, built-up members, and plate girders, 20 ksi (135 MPa).

(4) In compression on extreme fibers of other rolled shapes, plate girders, and built-up members having an axis of symmetry in the plane of loading, the larger value, ksi (MPa), computed by the following:

(U.S. Customary Units)

$$20 - \frac{0.571}{1,000}\left(\frac{l}{r}\right)^2$$

(SI Units)

$$138 - 0.394\left(\frac{l}{r}\right)^2$$

or

(U.S. Customary Units)

$$\frac{12,000}{\left(ld/A_f\right)} \leq 20$$

(SI Units)

$$\frac{83,000}{\left(ld/A_f\right)} \leq 138$$

where

A_f = area of compression flange, in.^{2} (mm^2)
d = depth of section, in. (mm)
l = unbraced length of compression flange, in. (mm)
r = radius of gyration of section about an axis in the plane of loading, in. (mm)

Compression, ksi (MPa), on extreme fibers of other unsymmetrical sections:

(U.S. Customary Units)

$$\frac{12,000}{\left(ld/A_f\right)} \leq 20$$

(SI Units)

$$\frac{83,000}{\left(ld/A_f\right)} \leq 138$$

(d) Shearing

(1) In fillet, plug, slot and partial penetration groove welds across throat area, 13.6 ksi (94 MPa).

(2) On the gross area of the webs of beams and girders when t is the thickness of the web, inches and h, the clear distance between web flanges, inches, is not more than $60t$, or when the web is adequately stiffened, 13.0 ksi (90 MPa).

(3) On the gross area of the webs of beams and girders, if the web is not stiffened so that h is more than $60t$, the greatest average shear V/A, ksi (MPa), shall not exceed

(U.S. Customary Units)

$$\frac{19.5}{1 + h^2/7,200t^2}$$

(SI Units)

$$\frac{134}{1 + h^2/7,200t^2}$$

where V is the total shear, kips (N), and A is the gross area of the web, in.^{2} (mm^2).

NC-3853 Supported Cone Roofs — General Requirements

NC-3853.1 Slope of Roof. The slope of the roof shall be $^3/_4$ in./ft (62 mm/m) (6.25%) or greater. If the rafters are set directly on chord girders, producing slightly varying rafter slopes, the slope of the flattest rafter shall conform to the specified roof slope.

NC-3853.2 Main Supporting Members. Main supporting members, including those supporting the rafters, may be rolled or fabricated sections or trusses. Although these members may be in contact with the roof plates, the compression flange of a member or the top chord of a truss shall be considered to receive no lateral support from the roof plates and shall be laterally braced, if necessary, by other acceptable methods. The allowable stresses in these members shall be governed by NC-3852.6.

NC-3853.3 Design of Rafters. Structural members, serving as rafters, may be rolled or fabricated sections but in all cases shall conform with the rules of NC-3852 through NC-3853. Rafters in direct contact with the roof plates applying the loading to the rafters may be considered to receive adequate lateral support from the friction between the roof plates and the compression flanges of the rafters, with the following exceptions:

(a) trusses and open web joints used as rafters;

(b) rafters having a nominal depth greater than 15 in. (375 mm);

(c) rafters having a slope greater than 2 in./ft (167 mm/m) (16.7%).

NC-3853.4 Spacing of Rafters. Rafters shall be spaced so that, in the outer ring, their centers shall not be more than 6.28 ft (1.9 m) apart, measured along the circumference of the tank. Spacing on inner rings shall not be greater than $5^1/_2$ ft (1.7 m).

NC-3853.5 Roof Columns. Roof columns shall be made from structural shapes or pipe.

NC-3853.6 Attachment of Rafter Clips and Column Base Clip Guides. Rafter clips for the outer row of rafters shall be welded to the tank shell. Column base clip guides shall be welded to the tank bottom to prevent lateral movement of column bases. All other structural attachments shall be either bolted or welded.

NC-3853.7 Welding of Roof Plates. Roof plates shall be welded in accordance with NC-4246.4. The size of the roof to top angle weld shall be $^{3}/_{16}$ in. (5 mm) or less.

NC-3854 Supported Flat Roofs

NC-3854.1 General Requirements. The use of supported flat roofs shall be limited to tanks having diameters not greater than 35 ft (11 m). The design of supported flat roofs shall be in accordance with NC-3853 except as noted NC-3854.2.

NC-3854.2 Main Supporting Members.

(a) Requirements of NC-3853.1 do not apply.

(b) Supporting structural members may be either internal or external to the roof plate.

(c) External rafters shall not be welded to the top angle or attached to the shell plate.

(d) External rafters shall be welded to the roof plate. The weld shall be sized to carry the combined dead and live loads on the roof plate.

NC-3855 Self-Supporting Cone Roofs

NC-3855.1 Nomenclature. The symbols used are defined as follows:

A_t = combined cross-sectional area of roof plate, shell plate, and top shell angle, in.^{2} (mm^2)
D = nominal diameter of tank shell, ft (m)
f = tensile working stress for the material of the roof plates, shell plates, or top shell angle, whichever is the least value, at the service temperature, psi (MPa)
P = dead load of roof, plus the live load, lb/ft^2 (kPa)
R = radius of curvature of roof, ft (m)
t_r = nominal thickness of roof plates, in. (mm)
θ = angle of cone elements with the horizontal, deg

NC-3855.2 Design Requirements. Self-supporting cone roofs shall conform to the requirements[40] of (a) through (c) below.

(a) Slope

(1) Maximum θ = 37 deg (tangent = 9:12)

(2) Minimum sin θ = 0.165 [slope 2 in./ft (167 mm/m) (16.7%)]

(b) Plate Thickness

(1) Minimum/Maximum

(U.S. Customary Units)

$$\text{Minimum } t_r = D/400 \sin\theta, \text{but not less than } \frac{3}{16} \text{ in.}$$

$$\text{Maximum } t_r = \frac{1}{2} \text{ in.}$$

(SI Units)

$$\text{Minimum } t_r = D/4.8 \sin\theta, \text{but not less than 5 mm}$$
$$\text{Maximum } t_r = 13 \text{ mm}$$

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than $^{3}/_{16}$ in. (5 mm).

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in.^{2} (mm^2), plus the cross-sectional areas of the shell and roof plates within a distance of 16 times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed:

(U.S. Customary Units)

$$\frac{D^2}{3,000 \sin\theta}$$

(SI Units)

$$\frac{D^2}{0.43 \sin\theta}$$

NC-3856 Self-Supporting Dome and Umbrella Roofs

NC-3856.1 Nomenclature. See NC-3855.1 for nomenclature.

NC-3856.2 Design Requirements. Self-supporting dome and umbrella roofs shall conform to the requirements[37] of (a) through (c) below.

(a) Radius of Curvature

$$R = D \text{ unless otherwise specified}$$

$$\text{Minimum } R = 0.80D$$

$$\text{Maximum } R = 1.2\,D$$

(b) Plate Thickness

(1) Minimum/Maximum

(U.S. Customary Units)

$$\text{Minimum } t = R/200, \text{ but not less than } \frac{3}{16} \text{ in.}$$

$$\text{Maximum } t = \frac{1}{2} \text{ in.}$$

(SI Units)

$$\text{Minimum } t = R/2.4, \text{ but not less than 5 mm}$$
$$\text{Maximum } t = 13 \text{ mm}$$

(2) Self-supporting roofs having the roof plates stiffened by sections welded to the plates need not conform to the minimum thickness requirements but shall be not less than $^{3}/_{16}$ in. (5 mm).

(c) Top Angle to Roof-to-Shell Joint. The cross-sectional area of the top angle, in.^{2} (mm^2), plus the cross-sectional areas of the shell and roof plates within a distance of 16

times their thicknesses, measured from their most remote point of attachment to the top angle, shall equal or exceed:

(U.S. Customary Units)

$$\frac{DR}{1,500}$$

(SI Units)

$$\frac{DR}{0.216}$$

NC-3856.3 Top Angle Attachment for Self-Supporting Roofs.

(a) The top angle sections for self-supporting roofs shall meet the requirements of NC-4246.4.

(b) For self-supporting roofs, the edges of the roof plates may be flanged horizontally to rest flat against the top angle to improve welding conditions.

NC-3860 TANK CONNECTIONS AND APPURTENANCES

NC-3861 Roof Manholes

Roof manholes shall conform to Figure NC-3861-1 and Table NC-3861-1, except that alternative designs which provide equivalent strength are permissible if agreed to by the Owner or his designee.

NC-3862 Roof Nozzles

(a) Flanged roof nozzles shall conform to Figure NC-3862(a)-1 and Table NC-3862(a)-1. Threaded nozzles shall conform to Figure NC-3862(a)-2 and Table NC-3862(a)-2. Alternative designs for flanged roof nozzles and threaded nozzles can be used, provided they are of equivalent strength and agreed to by the Owner or his designee.

(b) Roof nozzles are not intended to take loads from pipe reactions. Earthquake loadings need not be considered.

NC-3863 Bottom Outlet Elbows

Bottom outlet elbows shall conform to Figure NC-3863-1 and Table NC-3863-1.

NC-3864 Threaded Connections

Threaded piping connections shall be female and shall be tapered. The threads shall conform to the requirements for taper pipe threads included in ANSI/ASME B1.20.1.

NC-3865 Platforms, Walkways, and Stairways

Platforms, walkways, and stairways shall be in accordance with Tables NC-3865-1 through NC-3865-3.

NC-3866 Nozzle Piping Transitions

The stress limits of Table NC-3821.5-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NC-3334, except as provided in NC-3867. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of NC-3600.

NC-3867 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NC-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NC-3821.5-1. Under these conditions, no analysis is required to demonstrate compliance for pressure-induced stresses in the nozzle region.

(b) Where external piping loads are to be designed for, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle shell region. These stresses, in conjunction with pressure-induced stresses, shall meet the limits of Table NC-3821.5-1 for (σ_m or σ_L) + σ_b. In this case, the pressure-induced stresses in the (σ_m or σ_L) + σ_b category may be assumed to be no greater than the limit specified for σ_m in Table NC-3821.5-1 for a given loading.

NC-3900 ZERO psi TO 15 psi (0 kPa TO 100 kPa) STORAGE TANK DESIGN

NC-3910 GENERAL REQUIREMENTS

NC-3911 Acceptability

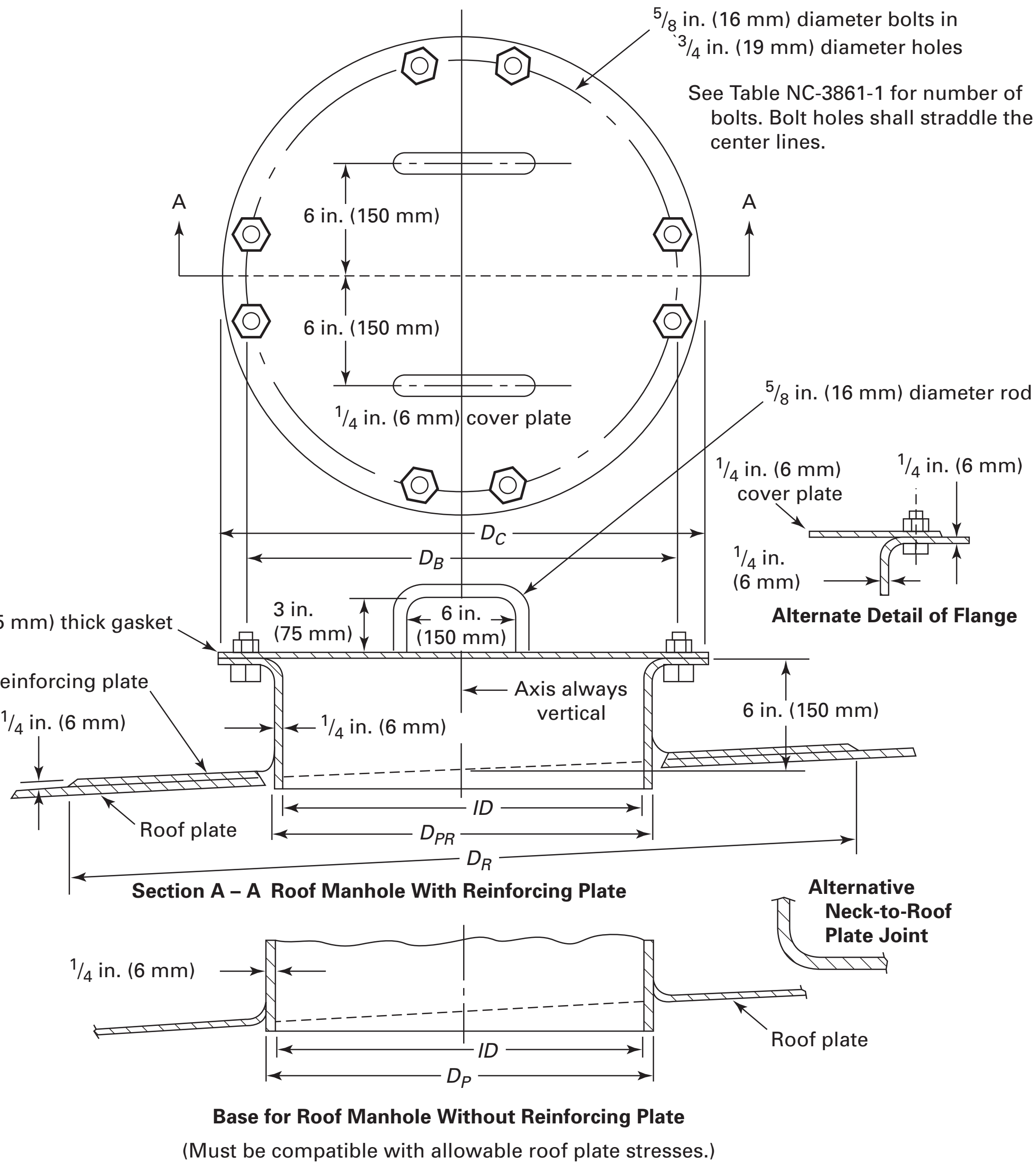
NC-3911.1 Scope. The design rules for 0 psi to 15 psi (0 kPa to 100 kPa) storage tanks shall cover above ground[34] welded storage tanks. These tanks may contain liquids or gases such as refueling water, condensate, borated reactor coolant, or radioactive waste. Such tanks are normally located within building structures. (15)

NC-3911.2 Design Requirements.

(a) The design requirements for 0 psig to 15 psig (0 kPa to 100 kPa) storage tanks shall conform to the design rules of NC-3100 and NC-3300, except where they may be modified by the requirements of this subarticle. The specific design requirements shall be stipulated in the Design Specifications.

(b) The total liquid capacity of a tank shall be defined as the total volumetric liquid capacity below the high liquid design level. The nominal liquid capacity of a tank shall be defined as the total volumetric liquid capacity between the plane of the high liquid design level and the elevation of the tank grade immediately adjacent to the wall of the tank or such other low liquid design level as the Certificate Holder shall stipulate.

Figure NC-3861-1
Roof Manholes



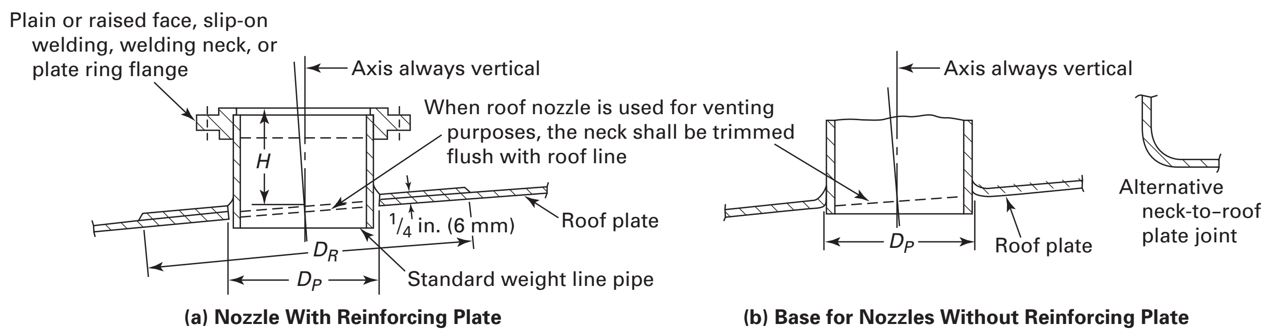
GENERAL NOTE: See Table NC-3861-1.

Table NC-3861-1
Roof Manholes

Size of Manhole, in. (mm)	Diameter of Neck, I.D., in. (mm)	Diameter of Cover Plate, D_C, in. (mm)	Diameter of Bolt Circle, D_B, in. (mm)	Number of Bolts	Diameter of Gasket		Diameter of Hole in Roof Plate or Reinforcing Plate, D_P, in. (mm)	O.D. of Reinforcing Plate, D, in. (mm)
					I.D., in. (mm)	O.D., in. (mm)		
20 (500)	20 (500)	26 (660)	23$^1/_2$ (588)	16	21$^1/_2$ (545)	26 (660)	20$^5/_8$ (525)	42 (1 070)
24 (600)	24 (600)	30 (750)	27$^1/_2$ (700)	20	25$^1/_2$ (650)	30 (750)	24$^5/_8$ (625)	46 (1 170)

GENERAL NOTE: See Figure NC-3861-1.

Figure NC-3862(a)-1 (15)
Flanged Roof Nozzles



GENERAL NOTES:
(a) See Table NC-3862(a)-1.
(b) Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ASME B16.5.
(c) Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

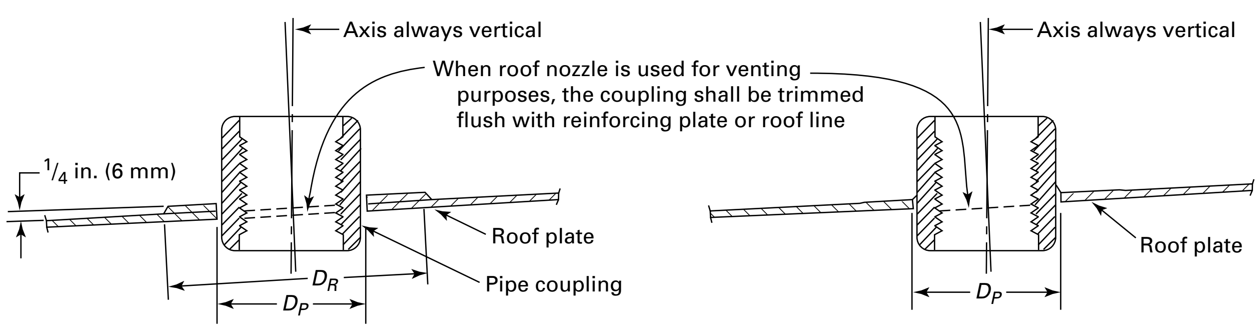
Table NC-3862(a)-1
Flanged Roof Nozzles

Nominal Size of Nozzle, in. (mm)	O.D. of Pipe Neck, in. (mm)	Diameter of Hole in Roof Plate or Reinforcing Plate, D_P, in. (mm)	Height of Nozzle, H, in. (mm)	O.D. of Reinforcing Plate, D_R, in. (mm)
$1^1/_2$ (DN 40)	1.900 (48)	2 (50)	6 (150)	5 (125) [Note (1)]
2 (DN 50)	$2^3/_8$ (60)	$2^1/_2$ (64)	6 (150)	7 (180) [Note (1)]
3 (DN 80)	$3^1/_2$ (89)	$3^5/_8$ (92)	6 (150)	9 (230) [Note (1)]
4 (DN 100)	$4^1/_2$ (114)	$4^5/_8$ (117)	6 (150)	11 (280) [Note (1)]
6 (DN 150)	$6^5/_8$ (168)	$6^3/_4$ (170)	6 (150)	15 (380) [Note (1)]
8 (DN 200)	$8^5/_8$ (219)	$8^7/_8$ (225)	6 (150)	18 (450)
10 (DN 250)	$10^3/_4$ (273)	11 (280)	8 (200)	22 (560)
12 (DN 300)	$12^3/_4$ (324)	13 (330)	8 (200)	24 (600)

GENERAL NOTE: See Figure NC-3862(a)-1.

NOTE:
(1) Reinforcing plates are not required on 6 in. (DN 150) or smaller nozzles, but may be used if desired.

Figure NC-3862(a)-2
Screwed or Socket Weld Roof Nozzles



GENERAL NOTE: See Table NC-3862(a)-2 and NC-3864.

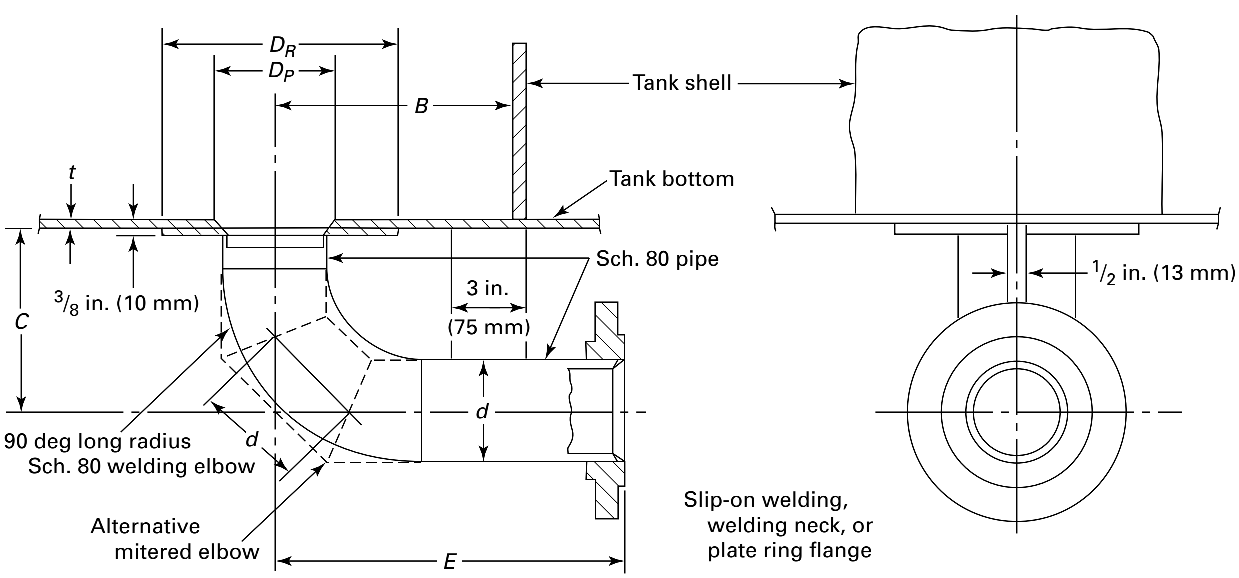
Table NC-3862(a)-2
Screwed or Socket Weld Roof Nozzles

Nominal Size of Nozzle, in. (mm)	Nominal Size of Coupling, in. (mm)	Diameter of Hole in Roof Plate or Reinforcing Plate, D_P, in. (mm)	O.D. of Reinforcing Plate, D_R, in. (mm)
$^3/_4$ (DN 20)	$^3/_4$ (DN 20)	$1^7/_{16}$ (37)	4 (100) [Note (1)]
1 (DN 25)	1 (DN 25)	$1^{23}/_{32}$ (44)	$4^1/_2$ (113) [Note (1)]
$1^1/_2$ (DN 45)	$1^1/_2$ (DN 45)	$2^{11}/_{32}$ (60)	5 (125) [Note (1)]
2 (DN 50)	2 (DN 50)	3 (76)	7 (180) [Note (1)]
3 (DN 80)	3 (DN 80)	$4^1/_8$ (105)	9 (230) [Note (1)]
4 (DN 100)	4 (DN 100)	$5^{11}/_{32}$ (136)	11 (280) [Note (1)]
6 (DN 150)	6 (DN 150)	$7^{17}/_{32}$ (191)	15 (380) [Note (1)]
8 (DN 200)	8 (DN 200)	$9^7/_8$ (251)	18 (450)
10 (DN 250)	10 (DN 250)	12 (305)	22 (560)
12 (DN 300)	12 (DN 300)	$14^1/_4$ (362)	24 (600)

GENERAL NOTE: See Figure NC-3862(a)-2.

NOTE:
(1) Reinforcing plates are not required on 6 in. (DN 150) or smaller nozzles, but may be used if desired.

Figure NC-3863-1
Typical Welded Bottom Outlet Elbow (15)



GENERAL NOTES:
(a) See Table NC-3863-1.
(b) Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ASME B16.5.
(c) Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

Table NC-3863-1
Welded Bottom Outlet Elbow

Nominal Pipe Size, in. (mm) [Note (1)]	Distance From Center of Elbow to Shell, *B*, in. (mm)	Distance From Center of Outlet to Bottom, *C*, in. (mm)	Diameter of Hole in Tank Bottom, D_P, in. (mm)	O.D. of Reinforcing Plate, D_R, in. (mm)	Distance From Center of Elbow to Face of Outlet Flange, *E*, in. (mm)
2 (DN 50)	7$^1/_2$ (191)	6 (152)	3$^1/_8$ (79)	6$^1/_4$ (159)	12 (305)
3 (DN 80)	8$^1/_2$ (216)	7 (178)	4$^1/_4$ (108)	7$^3/_4$ (197)	13 (330)
4 (DN 100)	9$^1/_2$ (241)	7$^{13}/_{16}$ (198)	5$^1/_4$ (133)	9$^3/_4$ (248)	14 (356)
6 (DN 150)	11 (279)	9$^3/_8$ (238)	7$^3/_8$ (187)	12$^3/_4$ (324)	16 (406)
8 (DN 200)	13 (330)	12$^3/_8$ (314)	9$^3/_8$ (238)	16$^1/_2$ (419)	18 (457)

GENERAL NOTE: See Figure NC-3863-1.

NOTE:
(1) Extra-strong pipe, refer to ASME B36.10M.

Table NC-3865-1
Platforms and Walkways

1. All parts to be made of metal.
2. Width of floor level (min.): 24 in. (300 mm).
3. Flooring to be made of grating or nonslip material.
4. Height of top railing above floor [Note (1)]: 42 in. (1 050 mm).
5. Height of toeboard (min.): 3 in. (75 mm).
6. Space between top of floor and bottom of toeboard (max.):$^1/_4$ in. (6 mm).
7. Height of midrail: approximately one-half the distance from top of walkway to top of railing.
8. Distance between railing posts (max.): 96 in. (2 400 mm).
9. The completed structure shall be capable of supporting a moving concentrated load of 1,000 lb (4 450 N), and the handrailing structure shall be capable of withstanding a load of 200 lb (890 N) applied in any direction at any point on the top rail.
10. Handrails to be on both sides of platform, discontinuing where necessary for access.
11. At handrail openings, any space between tank and platform wider than 6 in. (150 mm) should be floored.
12. Tank runways, which extend from one part of a tank to any part of an adjacent tank or to ground or other structure, shall be so supported as to permit free relative movement of the structures joined by the runway. This may be accomplished by firm attachment of runway to one tank, but with a slip joint at point of contact between runway and other tank. This is to permit either tank to settle or be disrupted by an explosion without endangering the other.

NOTE:
(1) Handrail height as required by ANSI specifications. This height is mandatory in some states.

Table NC-3865-2
Stairways

1. All parts to be made of metal.
2. Width of stairs (min.): 24 in. (300 mm).
3. Angle [Note (1)] of stairway with a horizontal line (max.): 50 deg.
4. Width of stair treads (min.): 8 in. (200 mm) [The run defined as the horizontal distance between the noses of successive tread pieces and the rise of stair treads shall be such that the sum of twice the rise, plus the run, shall be not less than 24 in. (600 mm) nor more than 26 in. (650 mm). Rises shall be uniform throughout the height of the stairway.]
5. Treads to be made of grating or nonslip material.
6. Top railing shall join platform handrail without offset, and the height measured vertically from tread level at nose of tread shall be 30 in. to 34 in. (750 to 850 mm).
7. Distance between railing posts (max.) measured along slope of railing: 96 in. (2 400 mm).
8. The completed structure shall be capable of supporting a moving concentrated load of 1,000 lb (4 450 N), and the handrailing structure shall be capable of withstanding a load of 200 lb (890 N) applied in any direction at any point on the top rail.
9. Handrails shall be on both sides of straight stairs; also, handrails shall be on both sides of circular stairs when the clearance between tank shell and stair stringer exceeds 8 in. (200 mm).
10. Circumferential stairways should be completely supported on the shell of the tank, and ends of the stringers should be clear of the ground.

NOTE:
(1) It is recommended that the same angle be employed for all stairways in a tank group or plant area.

Table NC-3865-3
Stairway Rise, Run, and Angle Relationships

	2R + r = 24 in. (600 mm)			2R + r = 26 in. (650 mm)		
		Angle			Angle	
Height of Rise R, in. (mm)	Width of Run, r, in. (mm)	deg	min	Width of Run, r, in. (mm)	deg	min
5¼ (133)	13½ (343)	21	15	...	...	...
5½ (140)	13 (330)	22	56	15 (381)	20	9
5¾ (146)	12½ (318)	24	43	14¼ (362)	21	38
6 (152)	12 (305)	26	34	14 (356)	23	12
6¼ (159)	11½ (292)	28	30	13½ (343)	24	53
6½ (165)	11 (279)	30	35	13 (330)	26	34
6¾ (171)	10½ (267)	32	45	12½ (318)	28	23
7 (178)	10 (254)	35	0	12 (305)	30	15
7¼ (184)	9½ (241)	38	20	11½ (292)	32	13
7½ (191)	9 (229)	39	50	11 (279)	34	18
7¾ (197)	8½ (216)	42	22	10½ (267)	36	26
8 (203)	8 (203)	45	0	10 (254)	38	40
8¼ (210)	7½ (191)	47	43	9½ (241)	41	0
8½ (216)	...	...	...	9 (229)	43	23
8¾ (222)	...	...	...	8½ (216)	45	49
9 (229)	...	...	...	8 (203)	48	22

NC-3912 Design Report

The Certificate Holder of a storage tank conforming to the design requirements of this subarticle is required to provide a Design Report as part of his responsibility for achieving structural integrity of the tank. The Design Report shall be certified when required by NCA-3550.

NC-3920 DESIGN CONSIDERATIONS

NC-3921 Design and Service Loadings

(a) Conditions shall be identified as Design or Service, and if Service, they shall have Service Limits designated Level A, B, C, or D (NCA-2142).

(b) The provisions of NC-3110 shall apply.

(c) The stress limits of NC-3921.8 shall be met.

NC-3921.1 Design Pressure.

(a) The walls of the gas or vapor space and other components of the tank above the maximum liquid level[41] at the top of the tank shall be designed for a pressure not less than that at which the pressure relief valves are to be set[42] and for the maximum partial vacuum which can be developed in such space[43] when the inflow of air, gas, or vapor through the vacuum relief valves is at its maximum specified rate. The maximum positive gage pressure for which this space is designed shall be understood to be the nominal pressure rating for the tank and shall not exceed 15 psi (100 kPa).

(b) All portions of the tank at levels below maximum liquid level shall be designed for the most severe combination of gas pressure or partial vacuum and static liquid head.

NC-3921.2 Design Temperature. The Design Temperature shall not be greater than 200°F (95°C).

NC-3921.3 Tank Shape. Tank walls shall be so shaped as to avoid any pockets on the inside where gases may become trapped when the liquid level is being raised or pockets on the outside where rainwater may collect.

NC-3921.4 Loadings. The requirements of NC-3111 shall be met.

NC-3921.5 Corrosion Allowance. When corrosion is expected on any part of the tank wall or on any external or internal supporting or bracing members upon which the safety of the completed tank depends, additional metal thickness in excess of that required by the design computations shall be provided or some satisfactory method of protecting these surfaces from corrosion shall be employed. Such added thickness need not be the same for all zones of exposure inside and outside the tank.

NC-3921.6 Linings. When corrosion resistant linings are attached to any element of the tank wall, including nozzles, their thickness shall not be included in the computation for the required wall thickness.

NC-3921.7 Welded Joint Restrictions. The restrictions on type and size of joints or welds given in (a) through (c) below apply.

(a) Tack welds shall not be considered as having any strength value in the finished structure.

(b) The minimum size of fillet welds shall be in accordance with NC-4247.6.

(c) All nozzle welds shall be in accordance with NC-4244.

NC-3921.8 Limits of Calculated Stresses for Design and Service Loadings. Stress[20] limits for Design and Service Loadings are specified in Table NC-3921.8-1. The symbols used in Table NC-3921.8-1 are defined as follows:

S = allowable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, psi (MPa). The allowable stress shall correspond to the highest metal temperature at the section under consideration during the loading under consideration.

σ_b = bending stress, psi (MPa). This stress is equal to the linear varying portion of the stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

σ_L = local membrane stress, psi (MPa). This stress is the same as σ_m except that it excludes the effect of discontinuities.

σ_m = general membrane stress, psi (MPa). This stress is equal to the average stress across the solid section under consideration. It excludes discontinuities and concentrations and is produced only by pressure and other mechanical loads.

Typical examples of locations and loadings for which σ_b, σ_L, and σ_m are applicable are shown in Section III Appendices, Mandatory Appendix XIII, Table XIII-1130-1, with σ in Table NC-3921.8-1 considered as equivalent to P in Section III Appendices, Mandatory Appendix XIII, Table XIII-1130-1.

NC-3922 Maximum Allowable Stress Values for Tanks

NC-3922.1 Nomenclature. The symbols used are defined as follows:

c = allowance for corrosion

M = ratio of the compressive stress S_c to the maximum allowable compressive stress S_{cs} (Figures NC-3922.1-1 and NC-3922.1-2)

N = ratio of the tensile stress S_t to the maximum allowable stress for simple tension S_{ts}

R = radius of the tank wall

R_1 = radius of curvature of the tank wall in a meridian plane

R_2 = length of the normal to the tank wall measured from the wall of the tank to its axis of revolution

S_c = general symbol for indicating a compressive stress, psi (MPa), which may be either an allowable or computed value, depending on the context in which the symbol is used

S_{ca} = allowable compressive stress, psi (MPa), which is lower than S_{cs} because of the presence of a coexistent tensile or compressive stress perpendicular to it

S_{cc} = computed compressive stress, psi (MPa), at the point under consideration

S_{cs} = maximum allowable longitudinal compressive stress, psi (MPa), for a cylindrical wall acted upon by an axial load with neither a tensile nor a compressive force acting concurrently in a circumferential direction and determined in accordance with NC-3922.3(a) for the thickness– radius ratio involved

S_t = general symbol for indicating a tensile stress, psi (MPa), which may be either an allowable or computed value depending on the context in which the symbol is used

S_{ta} = allowable tensile stress, psi (MPa), which is lower than S_{ts} because of the presence of a coexistent compressive stress perpendicular to it

S_{tc} = computed tensile stress, psi (MPa), at the point under consideration

S_{ts} = maximum allowable stress for simple tension, psi (MPa) (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)

t = thickness of sidewalls, roof, or bottom, including corrosion allowance.

T_1 = meridional unit force in the wall of the tank, lb/in. (N/mm) of latitudinal arc

T_2 = latitudinal unit force in the wall of the tank, lb/in. (N/mm) of meridional arc

NC-3922.2 Maximum Tensile Stresses. The maximum tensile stresses in the outside walls of a tank, as determined for any loadings or any concurrent combination of such loadings shall not exceed the applicable stress values determined in accordance with (a) or (b) below.

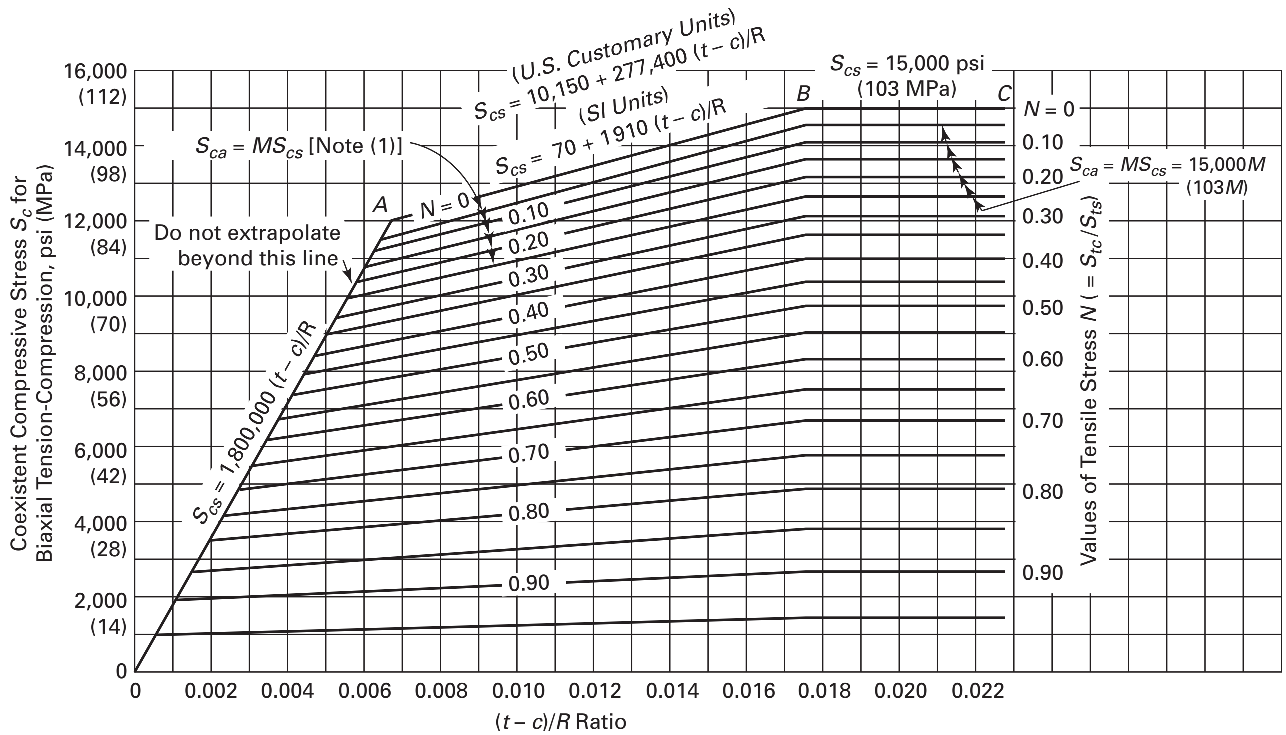
(a) If both the meridional and latitudinal unit forces T_1 and T_2 are tensile, or if one of these forces is tensile and the other is zero, the computed tensile stress S_{tc} shall not exceed the applicable value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

Table NC-3921.8-1
Design and Service Limits for Steel Tanks

Service Limit	Stress Limits [Note (1)] and [Note (2)]
Design and Level A	$\sigma_m \le 1.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.5S$
Level B	$\sigma_m \le 1.10S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.65S$
Level C	$\sigma_m \le 1.5S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 1.8S$
Level D	$\sigma_m \le 2.0S$ $(\sigma_m \text{ or } \sigma_L) + \sigma_b \le 2.4S$

NOTES:
(1) See NC-3921.8 for definitions of symbols.
(2) These limits do not take into account either local or general buckling that might occur in thin-wall vessels.

Figure NC-3922.1-1 Biaxial Stress Chart for Combined Tension and Compression, 30,000 psi to 38,000 psi (205 MPa to 260 MPa) Yield Strength Steels (15)



GENERAL NOTES:

(a) At no time can a compressive stress for a particular value of $(t - c)/R$ exceed S_{cs} represented by curve OABC. No values of compressive stress or N are permitted to fall to the left or above this curve. (See Figure NC-3922.1-2 for relationships between factors M and N.)

(b) If compressive stress is latitudinal, use $R = R_1$.

(c) If compressive stress is meridional, use $R = R_2$.

NOTE:

(1) See below.

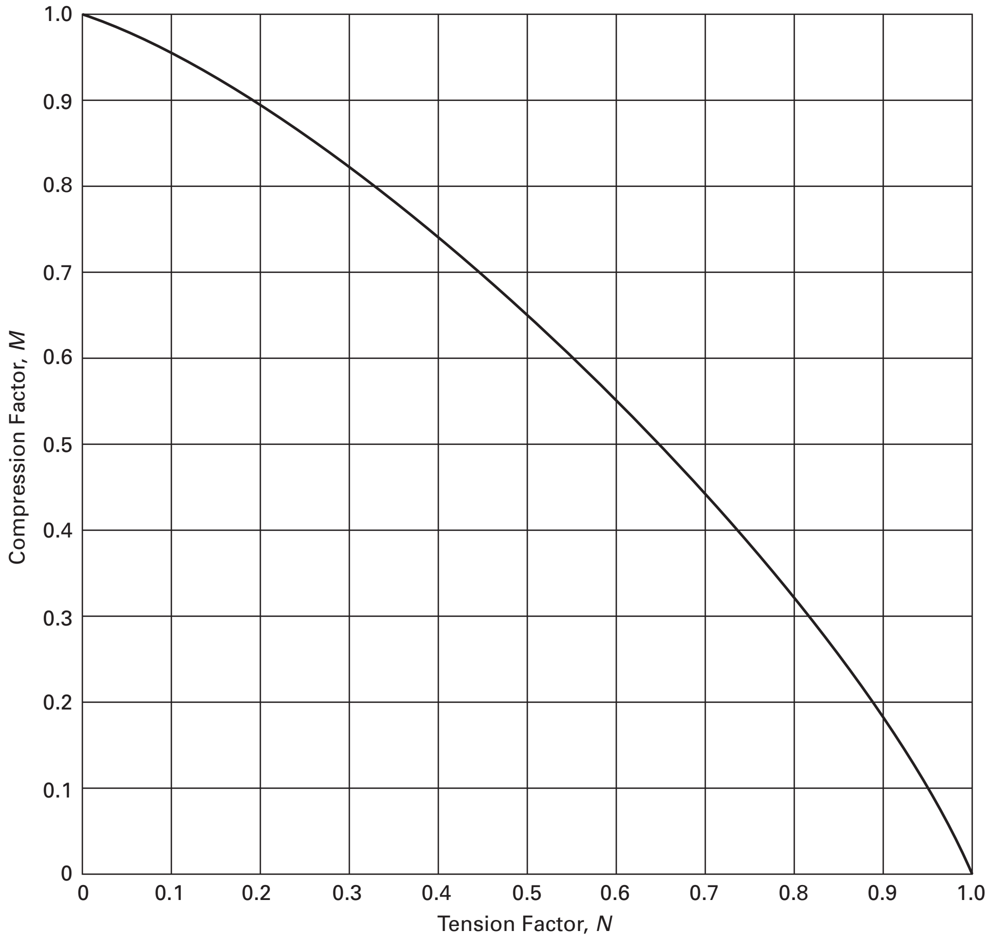
(U.S. Customary Units)

$$S_{ca} = MS_{cs} = M\left[10,150 + 277,400\left(t - c\right)/R\right]$$

(SI Units)

$$S_{ca} = MS_{cs} = M\left[70 + 1\ 910\left(t - c\right)/R\right]$$

Figure NC-3922.1-2
Reduction of Design Stresses Required to Allow for Biaxial Stresses of Opposite Sign



GENERAL NOTE:

$$N^2 + MN + M^2 = 1$$

or

$$(S_t/S_{ts})^2 + (S_t/S_{ts})(S_c/S_{cs}) + (S_c/S_{cs})^2 = 1$$

where

$M = S_c/S_{cs}$

S_c = the compressive stress, psi (MPa), at the point under consideration

S_{cs} = the maximum allowable longitudinal compressive stress, psi (MPa), for a cylindrical wall acted upon by an axial load with neither a tensile nor a compressive force acting concurrently in a circumferential direction; determined in accordance with NC-3922.3(a) for the thickness to radius ratio involved

$N = S_t/S_{ts}$

S_t = the tensile stress, psi (MPa), at the point under consideration

S_{ts} = the maximum allowable stress for simple tension, psi (MPa) *(b)* If the meridional unit force T_1 is tensile and the coexistent latitudinal unit force T_2 is compressive, or if T_2 is tensile and T_1 is compressive, the computed tensile stress S_{tc} shall not exceed a value of S_{ta} obtained by multiplying the applicable stress value given in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 by the appropriate value of N obtained from Figure NC-3922.1-1 for the value of compressive stress ($S_c = S_{cc}$) and co-related ratio of $(t - c)/R$ involved. However, in cases where the unit force acting in compression does not exceed 5% of the coexistent tensile unit force acting perpendicular to it, the designer may permit a tensile stress of the magnitude specified in (a) above. Section F.1 of Appendix F of API 620 Feb. 1970 Ed.[44] gives examples illustrating the determination of allowable tensile stress values S_{ta}. In no event shall the value of S_{ta} exceed the allowable stress for simple tension shown in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.

(15) **NC-3922.3 Maximum Compressive Stresses.** Except as provided in NC-3933.4(b), the maximum compressive stresses in the outside walls of a tank, as determined for the loadings, shall not exceed the applicable stress values determined in accordance with (a) through (d) below.

(a) If a cylindrical wall, or portion thereof, is acted upon by a longitudinal compressive force with neither a tensile nor a compressive force acting concurrently in a circumferential direction, the computed compressive stress S_{cc} shall not exceed a value S_{cs} established for the applicable thickness–radius ratio as follows:[45]

For $(t - c)/R$ values less than 0.00667

(U.S. Customary Units)

$$S_{cs} = 1,800,000\frac{t - c}{R}$$

(SI Units)

$$S_{cs} = 12\,400\frac{t - c}{R}$$

For $(t - c)/R$ values between 0.00667 and 0.0175

(U.S. Customary Units)

$$S_{cs} = 10,150 + 277,400\frac{t - c}{R}$$

(SI Units)

$$S_{cs} = 70 + 1\,910\frac{t - c}{R}$$

For $(t - c)/R$ values greater than 0.0175

$$S_{cs} = 15,000 \text{ psi } (103 \text{ MPa})$$

However, the values of S_{cs} calculated as above, but with R taken as equal to R_1 when the compressive unit force under consideration is latitudinal or with R taken as equal to R_2 when the compressive unit force is meridional, form the basis for the rules given in (b), (c), and (d) below for walls of double curvature.

(b) If both the meridional and latitudinal unit forces T_1 and T_2 are compressive and of equal magnitude, the computed compressive stress S_{cc} shall not exceed a value S_{ca} established for the applicable thickness–radius ratio as follows:

For $(t - c)/R$ values less than 0.00667

(U.S. Customary Units)

$$S_{ca} = 1,000,000(t - c)/R$$

(SI Units)

$$S_{ca} = 6\,900(t - c)/R$$

For $(t - c)/R$ values between 0.00667 and 0.0175

(U.S. Customary Units)

$$S_{ca} = 5,650 + 154,200(t - c)/R$$

(SI Units)

$$S_{ca} = 39 + 1\,060(t - c)/R$$

For $(t - c)/R$ values greater than 0.0175

$$S_{ca} = 8,340 \text{ psi } (57.5 \text{ MPa})$$

(c) If both the meridional and latitudinal unit forces T_1 and T_2 are compressive but of unequal magnitude, both the larger and the smaller computed compressive stresses shall be limited to values which satisfy the following requirements:[46]

$$\frac{(\text{larger stress}) + 0.8(\text{smaller stress})}{S_{cs} \text{ determined using } R \text{ for the larger unit force}} \leq 1.0$$

$$\frac{1.8(\text{smaller stress})}{S_{cs} \text{ determined using } R \text{ for the smaller unit force}} \leq 1.0$$

(d) If the meridional unit force T_1 is compressive and the coexistent unit force T_2 is tensile, or if T_2 is compressive and T_1 is tensile, the computed compressive stress S_{cc} shall not exceed a value of S_{ca} determined from Figure NC-3922.1-1 by entering the computed value of N and the value of $(t - c)/R$ associated with the compressive unit stress, and reading the value of S_c which corresponds to that point. Such value of S_c will be the limiting value of S_{ca} for the given conditions. Section F.1 of Appendix F of API 620 Feb. 1970 Ed. gives examples illustrating the determination of allowable compressive stress values S_{ca}.

NC-3922.4 Maximum Shearing Stresses. The maximum shearing stresses in welds used for attaching manways, nozzles, reinforcements, or other attachments to the walls of a tank, and in sections of manway or nozzle necks serving as reinforcement attachment, shall not exceed 80% of the applicable maximum allowable tensile stress value S_{ts}.

NC-3923 Maximum Allowable Stress Values for Structural Members

NC-3923.1 General Stress Limits. Subject to the provisions of NC-3923.2(c), the maximum stresses in internal or external diaphragms, webs, trusses, columns, and other framing, as determined for any loadings, shall not exceed the applicable allowable stresses given in Table NC-3923.1-1.

NC-3923.2 Slenderness Ratio Limits. The slenderness ratio (the ratio of the unbraced length l to the least radius of gyration r) for structural members in compression and for tension members other than rods shall not exceed the following values, except as provided in (a) below:

	Maximum l/r
For main compression members	120
For bracing and other secondary members in compression	200
For main tension members	240
For bracing and other secondary members in tension	300

(a) The slenderness ratio of main compression members inside of a tank may exceed 120, but not 200, provided the member is not ordinarily subject to shock or vibration loads and the unit stress under full Design Loadings does not exceed the following fraction of the stress value given in Table NC-3923.1-1 for the member's actual l/r ratio:

$$f = 1.6 - \frac{l}{200r}$$

(b) The gross and net sections of structural members shall be as determined in (1) through (5) below.

(1) The gross section of a member at any point shall be determined by summing the products of the thickness and the gross width of each element as measured normal to the axis of the member. The net section shall be determined by substituting for the gross width the net width which, in the case of a member having a chain of holes extending across it in any diagonal or zigzag line, shall be computed by deducting from the gross width the sum of the diameters of all holes in the chain and adding, for each gage space in the chain, the following quantity:

$$\frac{s^2}{4g}$$

where

g = transverse spacing (gage), in. (mm), of the same two holes
s = longitudinal spacing (pitch), in. (mm), of any two successive holes

(2) In the case of angles, the gage for holes in opposite legs shall be the sum of the gages from the back of the angle less the thickness.

(3) In determining the net section across plug or slot welds, the weld metal shall not be considered as adding to the net area.

(4) For splice members, the thickness considered shall be only that part of the thickness of the member which has been developed by the welds or other attachments beyond the section considered.

(5) In pin connected tension members other than forged eyebars, the net section across the pinhole, transverse to the axis of the member, shall not be less than 135%, and the net section beyond the pinhole, parallel to the axis of the member, shall not be less than 90% of the net section of the body of the member. The net width of a pin connected member across the pinhole, transverse to the axis of the member, shall not exceed eight times the thickness of the member at the pin, unless lateral buckling is prevented.

(c) External structural or tubular columns and framing subject to stresses produced by a combination of wind and other applicable loads specified in NC-3921.4 may be proportioned for unit stresses 25% greater than those specified in Table NC-3923.1-1, provided the section thus required is not less than that required for all other applicable loads combined on the basis of the unit stresses specified in Table NC-3923.1-1. A corresponding increase may be applied to the allowable unit stresses in the connecting bolts or welds.

NC-3930 DESIGN PROCEDURE

NC-3931 Design of Tank Walls

(a) Free body analyses shall be made at successive levels from the top to the bottom of the tank for the purpose of determining the magnitude and character of the meridional and latitudinal unit forces which will exist in the walls of the tank at critical levels under all the various combinations of gas pressure or partial vacuum and liquid head to be encountered in service which may have a controlling effect on the design. To this end it will sometimes be necessary to make several analyses at a given level of the tank to establish the governing conditions of

(15)

Table NC-3923.1-1
Maximum Allowable Stress Values for Structural Members

	Column 1 for Members Not Subject to Pressure-Imposed Loads, ksi (MPa)	Column 2 for Internal Members Resisting Pressure, ksi (MPa)
(a) Tension		
Rolled steel, on net section	18.0 (124)	[Note (1)]
Butt welds, on cross-sectional area in, or at edge of, weld [Note (2)]	18.0 (124)	[Note (1)]
Bolts and other threaded parts, on net area at root of thread	18.0 (124)	[Note (1)]
(b) Compression		
For axially loaded structural columns, structural bracing, and structural secondary members, on gross section	$\dfrac{18}{1+\dfrac{l^2}{18,000r^2}}\left(\dfrac{124}{1+\dfrac{l^2}{18\ 000r^2}}\right)$ but not to exceed 15 (103)	Same values as for column 1
For axially loaded tubular columns, tubular bracing, and tubular secondary members, on gross section [minimum permissible thickness, $^1/_4$ in. (6.4 mm)]	$\dfrac{18.0Y}{1+\dfrac{l^2}{18,000r^2}}\left(\dfrac{124Y}{1+\dfrac{l^2}{18\ 000r^2}}\right)$ but not to exceed $15Y$ $(103Y)$	Same values as for column 1
where l = unbraced length of column, in. (mm) R = outside radius of tubular column, in. (mm) r = corresponding least radius of gyration of column, in. (mm) t = thickness of tubular column, in. (mm) Y = unity (1.0) for values of t/R equal to or exceeding 0.015 = $^2/_3$ (100 t/R)[2 − $^2/_3$ (100 t/R)], for values of t/R less than 0.015		
Butt welds, on least cross-sectional area in, or at edge of, weld (crushing)	18.0 (124)	15.0 (100)
Plate girder stiffeners, on gross section	18.0 (124)	15.0 (100)
(c) Bending		
Tension on extreme fibers of rolled sections, plate girders, and built-up members	18.0 (124)	[Note (1)]
Compression on extreme fibers of rolled sections, plate girders, and built-up members:		
With ld/bt not in excess of 600	18.0 (124)	Same as tension value [Note (1)]
With ld/bt in excess of 600	$\dfrac{10,800.0}{ld\,/\,bt}\left(\dfrac{74\ 400}{ld\,/\,bt}\right)$	$\dfrac{600 \times \text{tension value}^1}{ld\,/\,bt}$
where b = width of its compression flange, in. (mm) d = depth of the member, in. (mm) l = unsupported length of the member, in. (mm), except that, for a cantilever beam not fully stayed at its outer end against translation or rotation, l shall be taken as twice the length of the compression flange t = thickness of its compression flange, in. (mm)		
Stress on extreme fibers of pins	27.0 (186)	20.0 (138)
Members subjected to both axial and bending loads shall be so proportioned that the maximum combined axial and bending stress will not exceed the permissible value for axial loading alone.		

Table NC-3923.1-1
Maximum Allowable Stress Values for Structural Members (Cont'd)

	Column 1 for Members Not Subject to Pressure-Imposed Loads, ksi (MPa)	Column 2 for Internal Members Resisting Pressure, ksi (MPa)
(c) Bending (Cont'd)		
Fiber stresses in butt welds resulting from bending shall not exceed the values prescribed for tension and compression, respectively. (Such values for welds in tension must be multiplied by the applicable joint efficiency.)		
(d) Shearing		
Pins and turned bolts in reamed or drilled holes	13.5 (93)	12.0 (83)
Unfinished bolts	10.0 (69)	8.0 (55)
Webs of beams and plate girders where h/t is not more than 60, or where web is adequately stiffened, on gross section of web	12.0 (83)	Two-thirds of tension value [Note (1)]
Webs of beams and plate girders where web is not adequately stiffened and h/t is more than 60, on gross section of web where h = clear distance between web flanges, in. (mm) t = thickness of the web, in. (mm)	$\dfrac{18.0}{1+\dfrac{h^2}{7{,}200t^2}}\left(\dfrac{124}{1+\dfrac{h^2}{7\ 200t^2}}\right)$	$\dfrac{\text{Tension value}^1}{1+\dfrac{h^2}{7{,}200t^2}}$
Fillet welds where load is perpendicular to length of weld, on section through throat [Note (2)]	12.6 (87)	70% of tension value [Note (1)]
Fillet welds where load is parallel to length of weld, on section through throat [Note (2)]	9.0 (62)	50% of tension value [Note (1)]
Plug welds or slot welds, on effective faying-surface area of weld [Note (2)]	11.7 (81)	65% of tension value [Note (1)]
Butt welds, on least cross-sectional area in, or at edge of, weld [Note (2)]	14.4 (99)	80% of tension value [Note (1)]
(e) Bearing		
Pins and turned bolts in reamed or drilled holes:		
Load applied to bolt at only one side of member connected	24.0 (165)	1.33 (tension value) [Note (1)]
Load approximately uniformly distributed across thickness of member connected	30.0 (207)	1.67 (tension value) [Note (1)]
Unfinished bolts:		
Load applied to bolt at only one side of member connected	16.0 (110)	0.9 (tension value) [Note (1)]
Load approximately uniformly distributed across thickness of member connected	20.0 (138)	1.1 (tension value) [Note (1)]

NOTES:
(1) See Section II, Part D, Subpart 1, Tables 1A, 1B, and 3.
(2) All values for butt welds in tension or shear shall be multiplied by the applicable joint efficiency. These values are obtained by combining the following: a factor of 80% for shear strength of weld metal; an efficiency factor of approximately 85% for fillet welds or 80% for plug welds and slot welds; and a factor of 100% for perpendicular loading or approximately 75% for parallel loading.

gas pressure and liquid head for that level. The thicknesses required in the main walls of the tank shall then be computed by the applicable procedures given in NC-3932.3.

(b) For tanks having points of marked discontinuity in the direction of the meridional tangent, such as occur at the juncture between a conical or dished roof or bottom and a cylindrical sidewall or at the juncture between a conical reducer and a cylindrical sidewall, the portions of the tank near such points shall be designed in accordance with the provisions of NC-3933.

NC-3932 Design of Sidewalls, Roofs, and Bottoms

NC-3932.1 Nomenclature. The symbols used are defined as follows:

A_T = cross-sectional area of the interior of the tank at the level under consideration, sq in. (mm^2)

F = summation, lb (N), of the vertical components of the forces in all internal or external ties, braces, diaphragms, trusses, columns, skirts, or other structural devices or supports acting on the free body. F shall be given the same sign as P when acting in the same direction as the pressure on the horizontal face of the free body, and the opposite sign when acting in the opposite direction.

P = $P_L + P_G$
= total pressure, psi (kPa), acting at a given level of the tank under a particular condition of loading

P_G = gas pressure, psi (kPa), above the surface of the liquid. The maximum value, a pressure not exceeding 15 psig (100 kPa gage), is the nominal pressure rating of the tank. P_G is positive except in computations for investigating the ability of a tank to withstand a partial vacuum, where its value is negative.

P_L = pressure resulting from the liquid head at the level under consideration in the tank, psi (kPa)

R_1 = radius of curvature of the tank wall in a meridian plane, at the level under consideration, in. (mm). R_1 is to be considered negative when it is on the opposite side of the tank wall from R_2 except as provided in NC-3932.2(f).

R_2 = length, in. (mm), of the normal to the tank wall at the level under consideration, measured from the wall of the tank to its axis of revolution. R_2 is always positive except as provided in NC-3932.2(f).

S_{ca} = allowable compression stress, psi (MPa), as required in NC-3922.3

S_{cc} = calculated compression stress, psi (MPa), at the point under consideration

S_{ta} = allowable tension stress, psi (MPa), as required in NC-3922.2(b)

S_{tc} = calculated tension stress, psi (MPa), at the point under consideration

S_{ts} = maximum allowable stress for simple tension, psi (MPa) (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)

T_1 = meridional unit force in the wall of the tank at the level under consideration, lb/in. (N/mm) of latitudinal arc. T_1 is positive when in tension.

T_2 = latitudinal unit force in the wall of the tank at the level under consideration, lb/in. (N/mm) of meridional arc. T_2 is positive when in tension. In cylindrical sidewalls the latitudinal unit forces are circumferential unit forces.

W = total weight, lb (N), of that portion of the tank and its contents, either above the level under consideration, as in Figure NC-3932.1-1 sketch (b) or below such level, as in Figure NC-3932.1-1 sketch (a) which is treated as a free body in the computations for such level. W shall be given the same sign as P, when acting in the same direction as the pressure on the horizontal face of the free body, and the opposite sign when acting in the opposite direction.

NC-3932.2 Computation of Unit Forces.

(a) At each level of the tank selected for free body analysis as specified in NC-3931 (Figure NC-3932.1-1) and for each condition of gas and liquid loading which must be investigated at such level, the magnitude of the meridional and latitudinal unit forces in the wall of the tank shall be calculated from eqs. (1) and (2)[47] below, except as provided in NC-3932.6 or NC-3933:

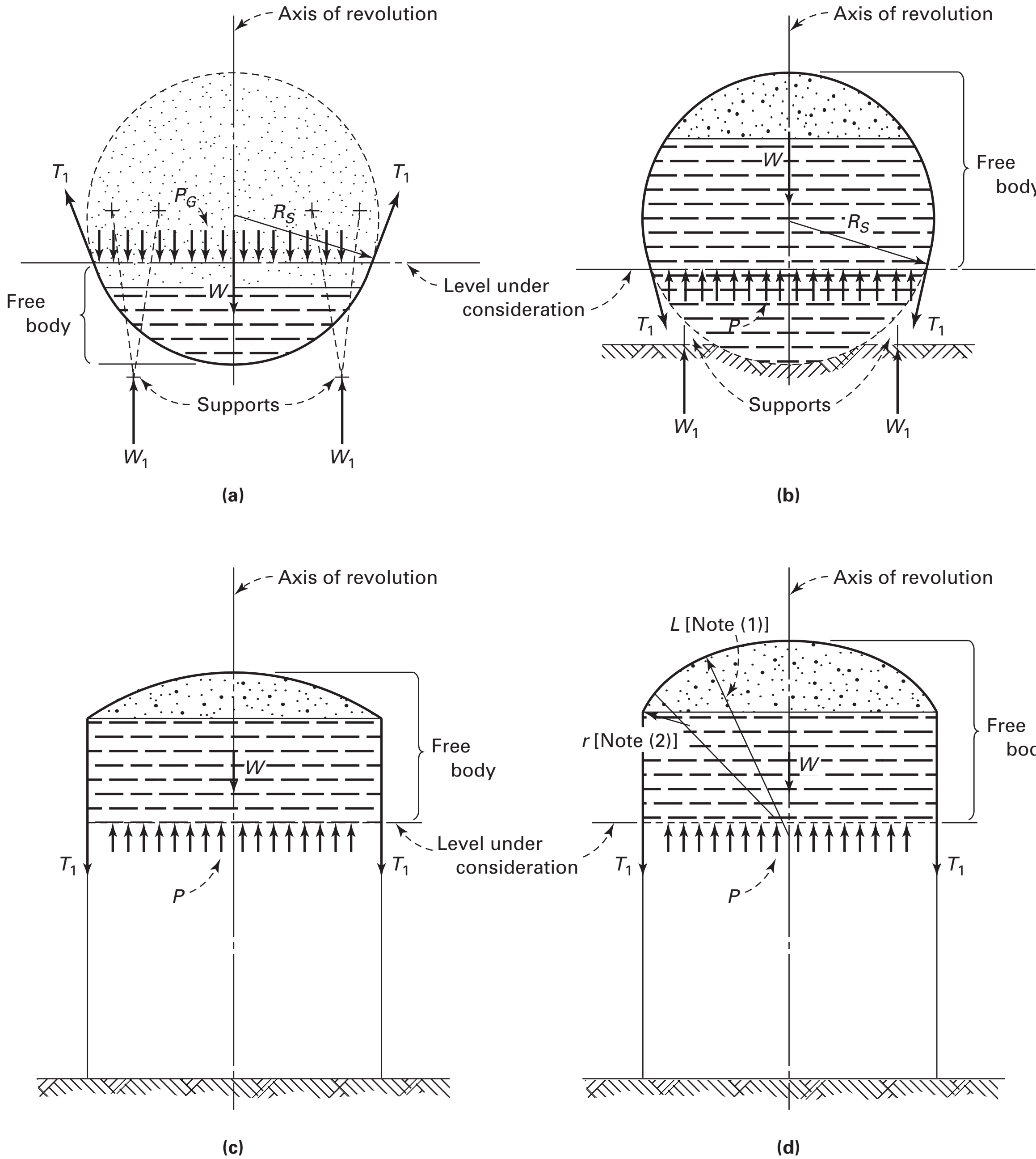
$$T_1 = \frac{R_2}{2}\left(P + \frac{W + F}{A_T}\right) \quad (1)$$

$$\begin{aligned} T_2 &= R_2\left(P - \frac{T_1}{R_1}\right) \\ &= R_2\left[P\left(1 - \frac{R_2}{2R_1}\right) - \frac{R_2}{2R_1}\left(\frac{W + F}{A_T}\right)\right] \end{aligned} \quad (2)$$

(b) Positive values of T_1 and T_2 indicate tensile forces and negative values indicate compressive forces.

(c) It will usually be necessary to make such analyses at the level of each horizontal joint in the sidewalls, roof, and bottom of the tank and at any intermediate levels at which the center of curvature changes significantly. Moreover, the maximum total pressure, liquid head plus gas pressure which can exist at a given level will not necessarily be the governing condition for that level; sufficient analyses shall be made at each level to establish that combination of liquid head and gas pressure or partial vacuum which, in conjunction with the allowable tensile and compressive stresses, will control the design at such level. Even though a tank may normally be operated at a fixed height of liquid contents, it shall be made safe for any conditions which might develop in filling or emptying the tank.

Figure NC-3932.1-1
Some Typical Free Body Diagrams for Certain Shapes of Tanks



NOTES:
(1) L is crown radius.
(2) r is knuckle radius.

(d) The values for a point at a horizontal distance x from the vertical axis of a roof or bottom in which the length of the horizontal semiaxis a is two times the length of the vertical semiaxis b may be determined by multiplying the length a by the factor from Table NC-3932.2(d)-1. Values for ellipsoidal shapes of other proportions shall be calculated from the following equations:

$$R_1 = \frac{b^2}{a^4}\left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2}\right)x^2\right]^{3/2} = \frac{b^2(R_2)^3}{a^4}$$

$$R_2 = \left[\frac{a^4}{b^2} + \left(1 - \frac{a^2}{b^2}\right)x^2\right]^{1/2}$$

(e) Equations (a)(1) and (a)(2) are general equations applicable to any tank having a single vertical axis of revolution and to any free body which is isolated by a horizontal plane which intersects the walls of the tank in only one circle [see (f)]. For shapes most commonly used, these equations reduce to the simplified equations given in (1) through (3) below for the respective shapes indicated.

Table NC-3932.2(d)-1
Factors for Determining Values of R_1 and R_2 for 2:1 Ellipsoidal Roofs and Bottoms

x/a	$u = R_1/a$	$v = R_2/a$
0.00	2.000	2.000
0.05	1.994	1.998
0.10	1.978	1.993
0.15	1.950	1.983
0.20	1.911	1.970
0.25	1.861	1.953
0.30	1.801	1.931
0.35	1.731	1.906
0.40	1.651	1.876
0.45	1.562	1.842
0.50	1.465	1.803
0.55	1.360	1.759
0.60	1.247	1.709
0.65	1.129	1.653
0.70	1.006	1.591
0.75	0.879	1.521
0.80	0.750	1.442
0.85	0.620	1.354
0.90	0.492	1.253
0.95	0.367	1.137
1.00	0.250	1.000

Legend:

R_1 = ua
R_2 = va
x = horizontal distance from point in roof or bottom to axis of revolution
a = horizontal semiaxis of elliptical cross section

(1) For a spherical tank or spherical segment of a tank:

$R_1 = R_2 = R_s$, the spherical radius of the tank or segment, and eqs. (a)(1) and (a)(2) become:

$$T_1 = \frac{R_s}{2}\left(P + \frac{W + F}{A_T}\right) \quad (3)$$

$$T_2 = R_sP - T_1 \quad (4)$$

If the sphere is for gas pressure only and if $W + F/A_T$ is negligible as compared with P_G, eqs. (3) and (4) reduce to:

$$T_1 = T_2 = \frac{1}{2}P_GR_S \quad (5)$$

(2) For a conical roof or bottom:

$$R_1 = \text{infinity, and } R_2 = \frac{R_3}{\cos a}$$

where

R_3 = horizontal radius of the base of the cone at the level under consideration, in.
a = one-half the included apex angle of the conical roof or bottom

For this condition, eqs. (a)(1) and (a)(2) reduce to:

$$T_1 = \left(\frac{R_3}{2\cos a}\right)\left(P + \frac{W + F}{A_T}\right) \quad (6)$$

$$T_2 = \frac{PR_3}{\cos a} \quad (7)$$

(3) For cylindrical sidewalls of a vertical tank: R_1 = infinity, and $R_2 = R_c$, the radius of the cylinder, and eqs. (a)(1) and (a)(2) become:

$$T_1 = \frac{R_c}{2}\left(P + \frac{W + F}{A_T}\right) \quad (8)$$

$$T_2 = PR_c \quad (9)$$

If the cylinder is for gas pressure only, and if $W + F/A_T$ is negligible as compared with P_G, eqs. (8) and (9) reduce to:

$$T_1 = \frac{1}{2}P_GR_c \quad (10)$$

$$T_2 = P_GR_c \quad (11)$$

(f) In the case of a torispherical head shown in Figure NC-3932.1-1(d), applicable equations for the meridional and latitudinal unit forces in the walls of the segment are as in eqs. (12) and (13):

$$T_1 = (in \quad preparation) \tag{12}$$

$$T_2 = (in \quad preparation) \tag{13}$$

NC-3932.3 Required Thickness. The thickness of the tank wall at any given level shall be not less than the largest value of t as determined for the level by the methods prescribed in (a) through (d) below. In addition, provision shall be made by means of additional metal, where needed, for the loadings other than internal pressure or possible partial vacuum enumerated in NC-3921.4 and if the tank walls have points of marked discontinuity in the direction of the meridional tangent, such as occur at the juncture between a conical or dished roof or bottom and a cylindrical sidewall, the portions of the tank near such points shall be designed in accordance with the provisions of NC-3933.

(a) If the unit forces T_1 and T_2 are both positive for the governing combination of gas pressure or partial vacuum and liquid head at a given level of the tank, the larger of the two shall be used for computing the thickness required at such level, as follows:

$$t = \frac{T_1}{S_{ts}} + c \quad \text{or} \quad t = \frac{T_2}{S_{ts}} + c \tag{14}$$

(b) If the unit force T_1 is positive and T_2 is negative for the governing combination of gas pressure or partial vacuum and liquid head at a given level of the tank, or if T_2 is positive and T_1 is negative, the thickness of tank wall required for this condition shall be determined by assuming different thicknesses until one is found for which the simultaneous values of the calculated tension stress S_{tc} and the calculated compression stress S_{cc} satisfy the requirements of NC-3922.2(b) and NC-3922.3(d), respectively. The determination of this thickness will be facilitated by using a graphical solution such as illustrated in Appendix F, Section F.2 of API Standard 620, Feb. 1970 Edition. If the unit force acting in compression does not exceed 5% of the coexistent tensile unit force acting perpendicular to it, the designer may determine the thickness required for this condition by using the method specified in (a).

(c) If the unit forces T_1 and T_2 are both negative and are of equal magnitude for the governing condition of loading at a given level of the tank, the thickness of tank wall required shall be calculated using:

$$t = \frac{T_1}{S_{ca}} + c = \frac{T_2}{S_{ca}} + c \tag{15}$$

where S_{ca} has the appropriate value for the thickness–radius ratio, as required in NC-3922.3(b).

(d) If the unit forces T_1 and T_2 are both negative, but of unequal magnitude, for the governing condition of loading at a given level, the thickness of tank wall required for this condition shall be the largest of those thickness values, calculated by the following procedure, which show a proper correlation with the respective thickness–radius ratios involved in their calculation (Step 2 and Step 4).

Step 1. Calculate the values of

$$t = \frac{\sqrt{(T' + 0.8T'')R'}}{1,342} + c \tag{16}$$

and

$$t = \frac{\sqrt{T'R''}}{1,000} + c \tag{17}$$

using values of T' equal to the larger of the two coexistent unit forces, T'' equal to the smaller of the two unit forces, and taking R' and R'' as equal to R_1 and R_2, respectively, if the larger unit force is latitudinal; but, conversely, taking R' and R'' as equal to R_2 and R_1, respectively, if the larger unit force is meridional.

Step 2. Deduct the corrosion allowance from each of the two thicknesses calculated in Step 1 and check the thickness–radius ratio $(t - c)/R$ for each based on the value of R used in Step 1, eq. (16) and Step 1, eq. (17). If both thickness–radius ratios are less than 0.00667, the larger of the two thicknesses calculated in Step 1 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 3.

Step 3. If one or both thickness–radius ratios determined in Step 2 exceed 0.00667, calculate the values of

$$t = \frac{T' + 0.8T''}{15,000} + c \tag{18}$$

and

$$t = \frac{T''}{8,340} + c \tag{19}$$

Step 4. Deduct the corrosion allowance from each of the two thicknesses calculated in Step 3 and check the thickness–radius ratio $(t - c)/R$ for each using a value of R equal to R' as defined in Step 1 in connection with the thickness determined from Step 3, eq. (18) and a value of R equal to R'' in connection with the thickness determined from Step 3, eq. (19). If both such thickness–radius ratios are greater than 0.0175, the larger of the two thicknesses calculated in Step 3 will be the required thickness for the condition under consideration. Otherwise, proceed with Step 5.

Step 5. If one or more of the thickness–radius ratios determined in Step 2 or Step 4 fall between 0.00667 and 0.0175 and the thickness involved was calculated by Step 1, eq. (16) or Step 3, eq. (18), find a thickness which satisfies the following equation:

$$\frac{10{,}150(t-c)+277{,}400(t-c)^2}{R'} = T' + 0.8T'' \qquad (20)$$

or, if the thickness involved was calculated by Step 1, eq. (17) or Step 3, eq. (19), find a thickness which satisfies the following equation:

$$\frac{5{,}650(t-c)+154{,}200(t-c)^2}{R''} = T'' \qquad (21)$$

Step 6. Make a selection of thickness from the values calculated. Calculate the values of S_{cc} for both T_1 and T_2 and check that the values of S_{cc} satisfy the requirements of NC-3922.3(c). Adjustment in the thickness may be required to make the values of S_{cc} satisfy the requirements of NC-3922.3(c).

NOTE: The procedure described in (d) is predicated on the assumption that the problem is one in which biaxial compression with unit forces of unequal magnitude is the governing condition. In many cases, however, a tentative thickness will have been established previously by other design considerations and only needs to be checked for the external pressure or partial vacuum condition. In such cases, the problem is greatly simplified because the designer has only to calculate the values of S_{cc} for both T_1 and T_2 and then check to see that these values satisfy the requirements of NC-3922.3(c), as specified in Step 6 [see Section F.3 of Appendix I of API Standard 620 Feb. 1970 Edition, for examples illustrating the application of (a)].

NC-3932.4 Least Permissible Thickness. In no event shall the net thickness after fabrication of any plate subject to pressure imposed membrane stresses be less than $^3/_{16}$ in. (5 mm), exclusive of corrosion allowance. For tanks having cylindrical sidewalls with diameters from 60 ft (18 m) up to but not including 120 ft (37 m), such thickness for sidewall plates shall not be less than $^1/_4$ in. (6 mm) exclusive of corrosion allowance.

NC-3932.5 External Pressure Limitations. The thickness computed by the equations and procedures specified in NC-3932, using a negative value of P_G equal to the partial vacuum for which the tank is to be designed, will ensure stability against collapse for tank surfaces of double curvature in which the meridional radius R_1 is equal to or less than R_2 or does not exceed R_2 by more than a very small amount. Data on the stability of sidewall surfaces of prolate spheroids are lacking and it is not intended that the equations and procedures be used for evaluating the stability of such surfaces or of cylindrical surfaces against external pressure. However, cylindrical sidewalls of vertical tanks designed in accordance with these rules for storage of liquids,[48] with the thickness of upper courses not less than specified in NC-3932.4 for the size of tank involved and with increasing thicknesses from top to bottom as required for the combined gas and liquid loadings, may safely be subjected to a partial vacuum in the gas or vapor space not exceeding 1 oz/in.^{2} (0.43 kPa) [49] with the operating liquid level in the tank at any stage from full to empty.

NC-3932.6 Special Considerations Applicable to Bottoms Resting Directly on Foundations.

(a) Uplift Considerations. In the case of tanks with cylindrical sidewalls and flat bottoms, the uplift[50] from the pressure acting on the underside of the roof must not exceed the weight of the sidewalls plus the weight of that portion of the roof which is carried by the sidewalls when no uplift exists, unless such excess is counteracted by increasing the magnitude of the downward acting forces. This shall be a matter of agreement between the Certificate Holder and Owner. Similar precautions shall be taken with flat bottomed tanks of other shapes. All weights used in such calculations shall be based on net thicknesses of the materials, exclusive of corrosion allowance.

(b) Foundation Considerations. The type of foundation used for supporting the tank shall be taken into account in the design of bottom plates and welds. For recommended practice for construction of foundations, see API Standard 620, Feb. 1970 Edition, Appendix C.

NC-3933 Design of Roof and Bottom Knuckle Regions and Compression Rings

NC-3933.1 Nomenclature. The symbols used are defined as follows:

A_c = net area, in.^{2} (mm^2), of the vertical cross section of metal required in the compression ring region, exclusive of all corrosion allowances

Q = total circumferential force, lb (N), acting on a vertical cross section through the compression ring region

R_2 = length, in. (mm), of the normal to the roof or bottom at the juncture between the roof or bottom and the sidewalls, measured from the roof or bottom to the tank's vertical axis of revolution

R_c = horizontal radius, in. (mm), of the cylindrical sidewall at its juncture with the roof or bottom

S_{ts} = maximum allowable stress value for simple tension, psi (MPa) (Section II, Part D, Subpart 1, Tables 1A, 1B, and 3)

T_1 = meridional unit force in the roof or bottom of the tank at its juncture with the sidewall, lb/in. (kN/m) of circumferential arc

T_2 = corresponding latitudinal unit force[51] in the roof or bottom, lb/in. (N/mm) of meridian arc

T_{2s} = circumferential unit force[51] in the cylindrical sidewall of the tank at its juncture with the roof or bottom, lb/in. (N/mm), measured along an element of the cylinder

t_c = corresponding thickness, in. (mm), of the cylindrical sidewalls at and near such juncture

t_h = thickness, in. (mm), of the roof or bottom plate at and near the juncture of the roof or bottom and sidewalls, including corrosion allowance

W_c = corresponding width, in. (mm), of the participating sidewall plate

W_h = width, in. (mm), of the roof or bottom plate considered to participate in resisting the circumferential force acting on the compression ring region

α = angle between the direction of T_1 and a vertical line. In a conical surface it is also one-half of the total vertex angle of the cone.

NC-3933.2 General Requirements. When the roof or bottom of a tank is a cone or partial sphere and is attached to cylindrical sidewalls, the membrane stresses in the roof or bottom act inward on the periphery of the sidewalls. This results in circumferential compressive forces at the juncture, which shall be resisted either by a knuckle curvature in the roof or bottom or by a limited zone at the juncture of the intersecting roof or bottom plates and sidewall plates, supplemented in some cases by an angle, a rectangular bar, or a ring girder.

NC-3933.3 Requirements for Knuckle Regions.

(a) If a curved knuckle is provided, a ring girder or other form of compression ring shall not be used and there shall be no sudden changes in the direction of a meridional line at any point. In addition, the radius of curvature of the knuckle in a meridional plane shall not be less than 6%, and preferably not less than 12%, of the diameter of the sidewalls.[52] Subject to the provisions of (b) below, the thickness of the knuckle at all points shall satisfy the requirements of NC-3932.

(b) Application of the equations in NC-3932.2 to levels immediately above and below a point where two surfaces of differing meridional curvature have a common meridional tangent, as at the juncture between the knuckle region and the spherically dished portion of a torispherical roof, will result in the calculation of two latitudinal unit forces, differing in magnitude and possibly in sign, at the same point. The latitudinal unit force at such a point will be between the two calculated values, depending on the geometry of the tank wall in that area.

(15) **NC-3933.4 Requirements for Compression Rings.**

(a) If a curved knuckle is not provided, forces shall be resisted by other means in the compression ring region of the tank walls. The zone of the tank walls at the juncture between the roof or bottom and the sidewalls includes that width of plate on each side of the juncture which is considered to participate in resisting these forces [Figure NC-3933.4(a)-1]. The thickness of the wall plate on either side of the juncture shall not be less than the thickness needed to satisfy the requirements of NC-3932, and the widths of plate making up the compression ring region shall be computed from the following equations:

$$w_h = 0.6\sqrt{R_2(t_h - c)} \tag{22}$$

$$w_c = 0.6\sqrt{R_c(t_c - c)} \tag{23}$$

(b) The magnitude of the total circumferential force acting on any vertical cross section through the compression ring region shall be computed as follows:

$$Q = T_2 w_h + T_{2s} w_c - T_1 R_c \sin\alpha \tag{24}$$

and the net cross-sectional area provided in the compression ring region shall not be less than that found to be required by the following equation:

(U.S. Customary Units)

$$A_c = \frac{Q}{15,000} \quad \text{or} \quad \frac{Q}{S_{ts}} \tag{25}$$

(SI Units)

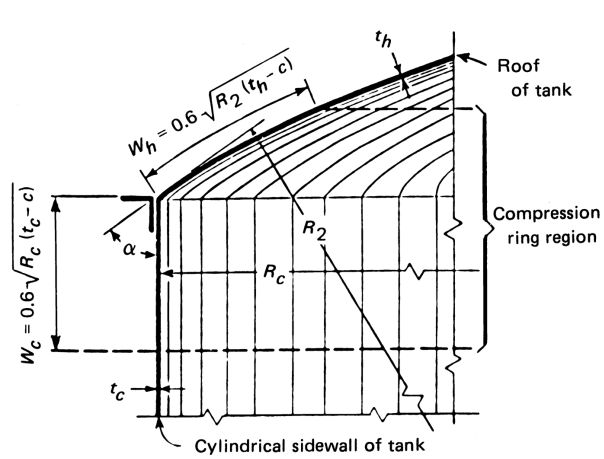
$$A_c = \frac{Q}{103}$$

depending on whether the value of Q as determined by eq. (24) is negative[53] or positive.

NC-3933.5 Details of Compression Ring Regions.

(a) If the force Q is negative, indicating compression, the horizontal projection of the effective compression ring region shall have a width in a radial direction not less than 0.015 times the horizontal radius of the tank wall at the level of the juncture between the roof or bottom and

Figure NC-3933.4(a)-1
Compression Ring Region



the sidewalls. If such projected width does not meet this requirement, appropriate corrective measures shall be taken as specified in this subparagraph.

(b) Whenever the circumferential force Q determined in accordance with NC-3933.4 is of such magnitude that the area required by eq. NC-3933.4(b)(25) is not provided in a compression ring region with plates of the minimum thicknesses established by the requirements of NC-3932, or when Q is compressive and the horizontal projection of the width w_h is less than specified in (a), the compression ring region shall be reinforced either by thickening the roof or bottom and sidewall plates as required to provide a compression ring region having the necessary cross-sectional area and width as determined on the basis of the thicker plates,[54] or by adding an angle, a rectangular bar, or a ring girder at the juncture of the roof or bottom and sidewall plates, or by a combination of these alternatives.

(c) An angle, bar, or ring girder, if used, may be located either inside or outside of the tank[55] and shall have a cross section of such dimensions that:

(1) its area makes up the deficiency between the area A_c, required by eq. NC-3933.4(b)(25), and the cross-sectional area provided by the compression ring region in the walls of the tank;

(2) the horizontal width of the angle, bar, or ring girder is not less than 0.015 times the horizontal radius R_c of the tank wall at the level of the juncture of the roof or bottom and the sidewalls, except that, when the cross-sectional area to be added in an angle or bar is not more than one-half of the total area required by eq. NC-3933.4(b)(25), the width requirement for this member may be disregarded, provided the horizontal projection of the width w_h of participating roof or bottom plates alone is equal to or greater than $0.015R_c$ or, with an angle or bar located on the outside of a tank, the sum of the projection of the width w_h and the horizontal width of the added angle or bar is equal to or greater than $0.015R_c$.

(3) when bracing must be provided as specified in (h), the moment of inertia of the cross section about a horizontal axis shall be not less than that required by eq. (h)(26).

(d) When the vertical leg of an angle ring or a vertical flange of a ring girder is located on the sidewall of the tank, it may be built into the sidewall if its thickness is not less than that of the adjoining wall plates. However, if this construction is not used, the leg, edge, or flange of the compression ring next to the tank shall make contact with the wall of the tank around the entire circumference and, except as provided in (e) below, shall be attached along both the top and bottom edges by continuous fillet welds. These welds shall be of sufficient size to transmit the portion, Q_p of the total circumferential force Q, to the compression ring angle, bar, or girder, assuming, in the case of welds separated by the width of a leg or flange of a structural member as shown in Figure NC-3933.5(d)-1 sketches (a) and (d), that only the weld nearest the roof or bottom is effective. The part thicknesses and weld sizes in Table NC-4247.6(d)-1 relate to dimensions in the as-welded condition before deduction of corrosion allowances, but all other part thicknesses and weld sizes referred to, in this subparagraph, relate to dimensions after deduction of corrosion allowance.

(e) If a continuous weld is not needed for strength or as a seal against corrosive elements, attachment welds along the lower edge of a compression ring on the outside of a tank may be intermittent, provided:

(1) the summation of their lengths is not less than one-half the circumference of the tank;

(2) the unattached width of tank wall between the ends of welds does not exceed eight times the tank wall thickness exclusive of corrosion allowance;

(3) the welds are of such size as needed for strength but in no case smaller than specified in Table NC-4247.6(d)-1.

(f) The projecting part of a compression ring shall be placed as close as possible to the juncture between the roof or bottom plates and the sidewall plates.

(g) If a compression ring on either the inside or outside of a tank is of such shape that liquid may be trapped, it shall be provided with adequate drain holes uniformly distributed along its length. Similarly, if the shape of a compression ring on the inside of a tank is such that gas would be trapped on the underside thereof when the tank is being filled with liquid, adequate vent holes shall be provided along its length. Where feasible, such drain or vent holes shall be not less than $^3/_4$ in. (19 mm) in diameter.

(h) The projecting part of a compression ring without an outer vertical flange need not be braced, provided the width of such projecting part in a radial vertical plane does not exceed 16 times its thickness. With this exception, the horizontal part of the compression ring shall be braced at intervals around the circumference of the tank with brackets or other suitable members securely attached to both the ring and the tank wall to prevent such part of the ring from buckling laterally. When such bracing is required, the moment of inertia of the cross section of the angle, bar, or ring girder about a horizontal axis shall be not less than that calculated to be required by the following equation:[56] **(15)**

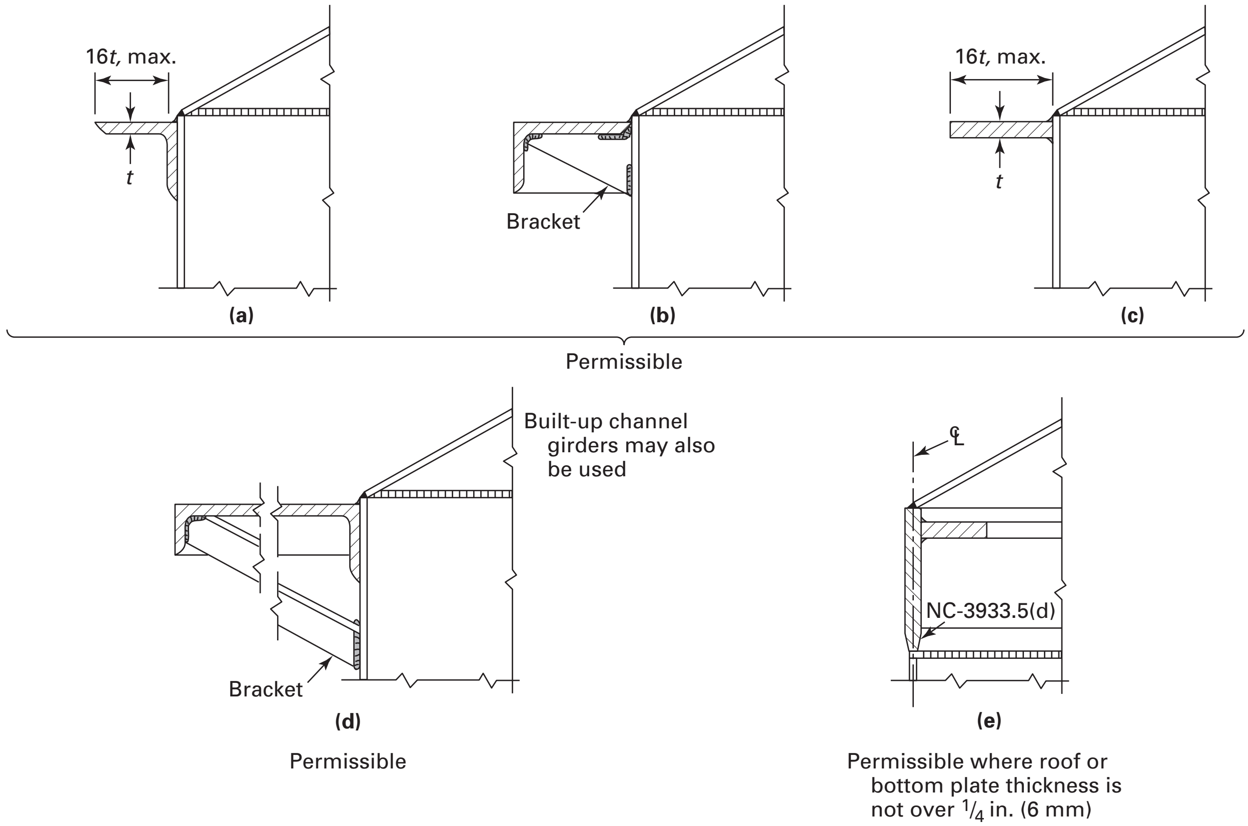
(U.S. Customary Units)

$$I_1 = \frac{1.44 Q_p R_c^{\,2}}{29{,}000{,}000k} = 5\frac{Q_p R_c^{\,2}}{k} \times 10^{-8} \qquad (26)$$

(SI Units)

$$I_1 = \frac{1.44 Q_p R_c^{\,2}}{200\,000k} = 7.2\frac{Q_p R_c^{\,2}}{k} \times 10^{-6}$$

Figure NC-3933.5(d)-1
Permissible Details of Compression Ring



GENERAL NOTE: NC-3350 gives limitations concerning location where various types of welded joints may be used.

where

I_1 = required moment of inertia, in.^{4} (mm^4), for the cross section of a steel compression ring with respect to a horizontal axis through the centroid of the section, not taking credit for any portion of the tank wall, except that, in the case of an angle ring whose vertical leg is attached to or forms a part of the tank wall, the moment of inertia of only the horizontal leg shall be considered, and it shall be figured with respect to a horizontal axis through the centroid of such leg[55]

k = a constant whose value depends on the magnitude of the angle θ, subtended at the central axis of the tank by the space between adjacent brackets, or other supports, which value shall be determined from the following tabulation in which n is the number of brackets or other supports evenly spaced around the circumference of the tank

Some Values for k Based on n, θ

n	30	24	20	18	15	12
***θ*, deg**	12	15	18	20	24	30
k	186.6	119.1	82.4	66.6	45.0	29.1

Table continued

n	10	9	8	6	5	4
***θ*, deg**	36	40	45	60	72	90
k	20.0	16.0	12.5	6.7	4.4	2.6

GENERAL NOTE: In no case shall θ be larger than 90 deg.

Q_p = that portion of the total circumferential force Q, lb (N), [eq. NC-3933.4(b)(24)] that is carried by the compression ring angle, bar, or girder, as computed from the ratio of the cross-sectional area of the compression ring to the total area of the compression zone

R_c = horizontal radius, in. (mm), of the cylindrical sidewall of the tank at its juncture with the roof or bottom

NC-3934 Nozzle Piping Transitions

The stress limits of Table NC-3921.8-1 shall apply to all portions of nozzles which lie within the limits of reinforcement given in NC-3334, except as provided in

NC-3935. Stresses in the extension of any nozzle beyond the limits of reinforcement shall be subject to the stress limits of NC-3600.

NC-3935 Consideration of Standard Reinforcement

(a) Where a nozzle-to-shell junction is reinforced in accordance with the rules of NC-3334, the stresses in this region due to internal pressure may be considered to satisfy the limits of Table NC-3921.8-1. Under these conditions, no analysis is required to demonstrate compliance for pressure-induced stresses in the nozzle region.

(b) Where external piping loads are to be designed for, membrane plus bending stresses due to these loads shall be calculated in the nozzle, and membrane stresses shall be calculated in the local nozzle-to-shell region. These stresses, in conjunction with pressure-induced stresses, shall meet the limits of Table NC-3921.8-1 for (σ_m or σ_L) + σ_b. In this case the pressure-induced stresses in the (σ_m or σ_L) + σ_b category may be assumed to be no greater than the limit specified for σ_m in Table NC-3921.8-1 for a given condition.

NC-3940 ALTERNATE RULES FOR AXIAL COMPRESSIVE MEMBRANE STRESSES IN THE CYLINDRICAL WALLS OF 0 psi TO 15 psi (0 kPa TO 100 kPa) STORAGE TANKS

The rules of this subsubarticle provide an alternative to the allowable compressive stress rules of NC-3922.3 for loadings associated with Service Limits A, B, C, and D. The remaining rules of the subarticle are still applicable.

NC-3941 Limits of Application

The application of this subsubarticle is subject to the following limitations:

(a) The rules apply to the right circular cylindrical walls of tanks otherwise designed to the rules of NC-3900.

(b) The specific criteria given herein are for the establishment of allowable axial membrane compressive stresses for those locations on the cylindrical walls where the corresponding total internal radial pressure (e.g., hydrostatic pressure + vapor over pressure + hydrodynamic pressures from loading such as earthquake) is equal to or greater than the external pressure. Except as noted in (c), no specific provisions are given for locations on the cylindrical walls where the internal pressure is less than the external pressure.

(c) These provisions do not provide criteria for hoop compressive membrane stresses. If applicable, the design specification shall provide for such conditions. However, the use of this subsubarticle requires that eqs. NC-3946(38a), NC-3946(38b), NC-3946(38c) and NC-3946(38d) be satisfied for those locations where the hoop stress is compressive and the axial stress is tensile.

(d) This subsubarticle applies for tanks where the height of the cylindrical wall, H, divided by the radius of the midsurface of wall, R, is equal to or less than 0.95 times the square root of the ratio of the radius to the thickness of the wall [i.e., $(H/R) \leq 0.95\sqrt{R/t}$]. See NC-3942 for definitions of H, R, and t.

(e) This subsubarticle is not applicable to tanks where the main joints are lap welded.

(f) This subsubarticle does not address long column buckling.

(g) All other requirements of NC-3900 shall be satisfied.

NC-3942 Nomenclature

The symbols used in this subsubarticle have the following definitions:

DF = design factor applied to $\sigma_{a,u}$ in order to establish $\sigma_{a,\text{allow}}$; dimensionless (see NC-3945)

E = modulus of elasticity of the cylindrical wall material, at the corresponding temperature, given in the appropriate Section II, Part D, Subpart 2, Table TM; ksi (MPa)

H = height of the right circular cylindrical wall portion of the tank; in. (mm)

L_x = length of measurement over which construction tolerance deviations are measured; in. (mm) (see NC-3947)

P = net internal radial pressure, i.e., internal radial pressure minus external pressure; ksi (MPa) [see NC-3941(b)]

R = nominal radius of the midsurface of the cylindrical wall; in. (mm)

S = allowable tensile stress of the cylindrical wall material, at the corresponding temperature, given in the appropriate Section II, Part D, Subpart 1, Table 1A or Table 1B; ksi (MPa)

S_y = yield strength of the cylindrical wall material, at the corresponding temperature, given in Section II, Part D, Subpart 1, Table Y-1; ksi (MPa)

t = nominal (supplied) thickness of the cylindrical wall minus any allowances established in the design specification for corrosion, erosion, etc.; in. (mm)

α_0 = buckling capacity reduction factor for a cylindrical wall with no net internal radial pressure; dimensionless [see eqs. NC-3943(27a) and NC-3943(27b)]

α_p = buckling capacity reduction factor that includes the effect of net internal radial pressure; dimensionless [see eq. NC-3943(b)(29)]

β = nondimensional parameter used in the formulation of axial compressive stress criteria; dimensionless [see eq. NC-3943(g)(33)]

Δ_x = geometric imperfection; in. (mm) (see NC-3947)

λ_p = slenderness parameter that includes the effect of net internal radial pressure; dimensionless [see eq. NC-3943(g)(34)]

u = Poisson's ratio of the cylindrical wall material given in Section II, Part D, Subpart 2, Table NF-1; dimensionless. If no value is given for the material, use u = 0.3

ρ = parameter involving internal pressure; dimensionless [see eq. NC-3943(a)(28)]

σ_a = axial membrane compressive stress (compressive stress is positive); ksi (MPa) (see NC-3946)

$\sigma_{a,\text{allow}}$ = allowable value of the axial membrane compressive stress (compressive stress is positive); ksi (MPa) [see eq. NC-3944(b)(37)]

$\sigma_{a,u}$ = lower bound for the axial membrane buckling stress (compressive stress is positive); ksi (MPa) (see NC-3943)

σ_{cl} = classical linear elastic (bifurcation) buckling stress (compressive stress is positive) for a cylinder of perfect geometry ideal boundary conditions; ksi (MPa) [see eq. NC-3943(d)(30)]

σ_{eff} = lower bound for the total effective membrane buckling or collapse stress; ksi (MPa) (see NC-3943)

σ_h = hoop membrane stress (tensile stress is positive); ksi (MPa) [see eq. NC-3943(e)(31)]

NC-3943 Axial Compressive Stress Criteria

The allowable axial membrane compressive stress is expressed as a function of the lower bound value of stress at which buckling could be expected to occur, $\sigma_{a,u}$, and a design factor. The design factor is specified in NC-3495 for different service levels. The quantity $\sigma_{a,u}$ is established from the criteria set forth in this paragraph. A buckling capacity reduction factor, α_0, is defined by eq. (27a) or eq. (27b).

$$\alpha_0 = \frac{0.83}{\sqrt{1.0 + 0.01R/t}} \text{ for } R/t \le 212 \tag{27a}$$

$$\alpha_0 = \frac{0.70}{\sqrt{1.0 + 0.01R/t}} \text{ for } R/t > 212 \tag{27b}$$

(a) This buckling capacity factor, α_0, corresponds to a cylinder subjected to axial compression with no net internal radial pressure. The influence of a net internal radial pressure acting on the cylindrical walls is expressed with the aid of a dimensionless parameter, ρ, defined by eq. (28).

$$\rho = \frac{P}{E}\left(\frac{R}{t}\right)^{\frac{3}{2}} \tag{28}$$

(b) A value of the buckling capacity reduction factor that acknowledges the benefit of a net internal radial pressure, α_p, is determined from eq. (29).

$$\alpha_p = \alpha_o + (1 - \alpha_o)\frac{\rho}{\rho + 0.007} \tag{29}$$

(c) For the purpose of establishing the allowable axial compressive stress at any location on the cylindrical wall, the value of the net internal radial pressure that exists at that location, coincident with the compressive stress, shall be used to establish ρ and hence α_p. When more than one value of net internal pressure may accompany a given axial stress, it shall be demonstrated that the controlling combination of internal pressure and axial stress has been established. This is accomplished by implementing the procedures established in this subsubarticle using both the minimum and the maximum values of the net internal pressures that may exist for the condition being evaluated.

(d) The classical linear elastic buckling stress for a cylinder of perfect geometry subjected to compressive axial loads is given by eq. (30).

$$\sigma_{cl} = \frac{E}{\sqrt{3(1 - \nu^2)}}\left(\frac{t}{R}\right) \tag{30}$$

(e) The hoop tensile stress from internal pressure that accompanies the axial compressive stress shall be established from membrane theory in accordance with eq. (31).

$$\sigma_h = P\frac{R}{t} \tag{31}$$

(f) Here the value of the net internal radial pressure acting on the wall, p, shall be the same as that used to compute ρ in eq. (a)(28). Hoop tensile stress is considered positive.

(g) With the values of the parameters established above, the required quantity $\sigma_{a,u}$ is one of four unknowns ($\sigma_{a,u}$, σ_{eff}, β, and λ_p) in the four simultaneous equations given as eqs. (32), (33), (34), (35a), and (35b)

$$\sigma_{\text{eff}} = \sqrt{\sigma_{a,u}^2 + \sigma_h^2 + \sigma_{a,u}\sigma_h} \tag{32}$$

$$\beta = \frac{\sigma_{a,u}}{\sigma_{\text{eff}}} \tag{33}$$

$$\lambda_p = \sqrt{\frac{\beta S_y}{\alpha_p \sigma_{cl}}} \tag{34}$$

$$\frac{\sigma_{\text{eff}}}{S_y} = \frac{0.75}{\lambda_p^2} \text{ for } \lambda_p \ge 1.414 \tag{35a}$$

$$\frac{\sigma_{eff}}{S_y} = (1.0 - 0.4123\lambda_p^{1,2}) \text{ for } \lambda_p < 1.414 \tag{35b}$$

(h) When the hoop stress is zero, these equations can be solved explicitly for $\sigma_{a,u}$. In the more general case, a method such as outlined in NC-3944 must be used.

NC-3944 Allowable Axial Membrane Compressive Stresses

Any method of solving the system of equations given in NC-3943 is satisfactory. Provided herein is one acceptable method. Note that eq. NC-3943(g)(32) can be rearranged as shown in eq. (36).

$$\sigma_{a,u} = \sqrt{(\sigma_{eff}^2 - 0.75\sigma_h^2)} - 0.5\sigma_h \tag{36}$$

(a) The algorithm proceeds as follows:

Step 1. Compute parameters α_0, ρ, α_p, σ_{cl}, and σ_h for the set of conditions being evaluated.

Step 2. Estimate a value of β [note eq. NC-3943(g)(33)] and call the value β'.

Step 3. Compute λ_p from eq. NC-3943(g)(34) using β' for β.

Step 4. Compute σ_{eff} from eqs. NC-3943(g)(35a) and NC-3943(g)(35b).

Step 5. Compute $\sigma_{a,u}$ from eq. (36).

Step 6. Compute β from eq. NC-3943(g)(33).

Step 7. Compare the computed value of β (Step 6) with the estimated value of β'. If the computed value of β is close to the estimated value of β' (i.e., within ±2%), note the value of $\sigma_{a,u}$ obtained from Step 5 for use as described below. If not, select a revised β estimate, β', and return to Step 3.

(b) The allowable value of the axial compressive membrane stress, $\sigma_{a,allow}$, shall be established from eq. (37).

$$\sigma_{a,allow} = \frac{\sigma_{a,u}}{DF} \tag{37}$$

(c) In eq. (b)(37), the minimum values of the design factors against buckling, DF, are provided in NC-3945 for the different service levels.

(d) As an alternative to solving the equations of NC-3943 by methods as described above, the plotted curves provided in Figures NC-3944-1 through NC-3944-6 may be used for ferrous materials of various yield strengths at temperatures not exceeding 300°F (150°C).

These curves establish the allowable axial membrane compressive stress at a location on the tank wall where the net internal radial pressure is equal to or greater than zero. Linear interpolation between the curves is permitted. To establish the allowable axial membrane compressive stress for a given service level, the value read from the ordinate of the curve shall be divided by the appropriate design factor, DF, consistent with the service level assigned by the design specification to the loading combination being evaluated. The value of S_y shall be the yield strength of the material at the corresponding temperature, obtained from Section II, Part D, Subpart 1, Table Y-1.

The value of ρ [see eq. NC-3943(a)(28)] shall be computed from the pressure at the location of interest and under the same loading conditions as those that produce the axial membrane compressive stress being evaluated.

Note that the tabular representation of the data in Figures NC-3944-1 through NC-3944-6 are for ferrous materials at temperatures equal to or less than 300°F (150°C). Other Code temperature limits may also apply.

NC-3945 Axial Compressive Stress Design Factors

The design factors, DF, for use in establishing the allowable values of axial membrane compressive stress with eq. NC-3944(b)(37) shall be as follows:

Service Level	Design Factors, *DF*
A	2
B	2
C	5/3
D	4/3

NC-3946 Corresponding Allowable Hoop Membrane Stresses

When the allowable axial membrane compressive stress is established by the use of this subsubarticle, the requirements of this paragraph, expressed in eqs. (38a) through (38d), shall also be satisfied. The hoop membrane stress may be computed by use of eq. NC-3943(e)(31), or results from more detailed stress analyses may be used, but the largest value of coincident pressure shall be considered for each value of corresponding axial stress. For designs qualified by use of this subsubarticle, the requirements of eqs. (38a) through (38d) shall also apply for those situations where the cylindrical wall is in a state of hoop membrane compression in combination with axial membrane tension. With the value of S established from the appropriate Section II, Part D, Subpart 1, Table 1A or Table 1B, the following requirements expressed as eqs. (38a), (38b), (38c), and (38d) shall be satisfied:

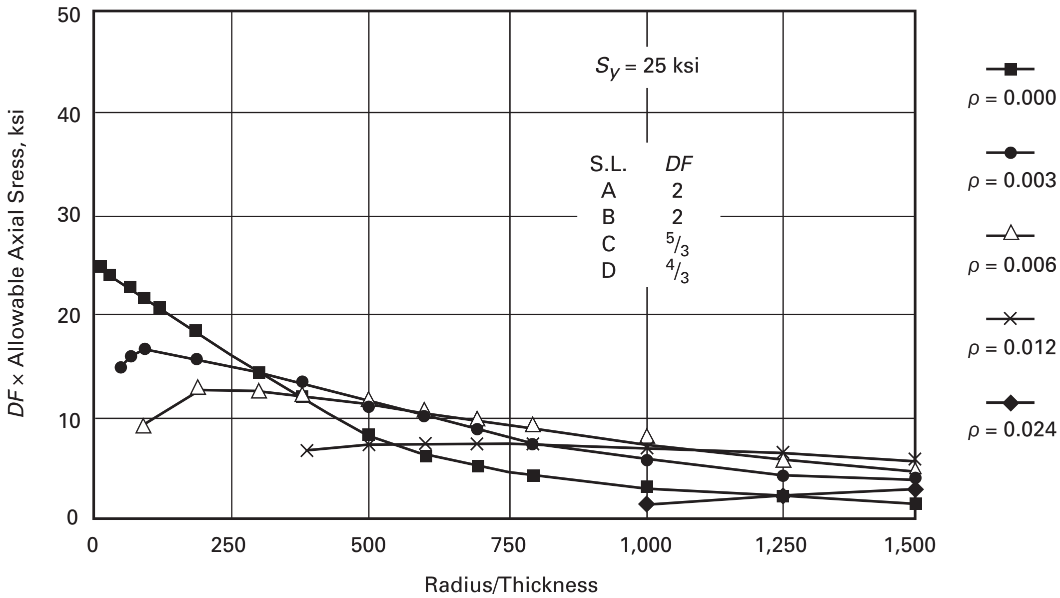
$$|\sigma_a| + |\sigma_h| \leq 1.0\,S, \text{ for Service Level A} \tag{38a}$$

$$|\sigma_a| + |\sigma_h| \leq 1.1\,S, \text{ for Service Level B} \tag{38b}$$

$$|\sigma_a| + |\sigma_h| \leq 1.5\,S, \text{ for Service Level C} \tag{38c}$$

$$|\sigma_a| + |\sigma_h| \leq 2.0\,S, \text{ for Service Level D} \tag{38d}$$

Figure NC-3944-1
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 25 ksi at Temperatures ≤ 300°F

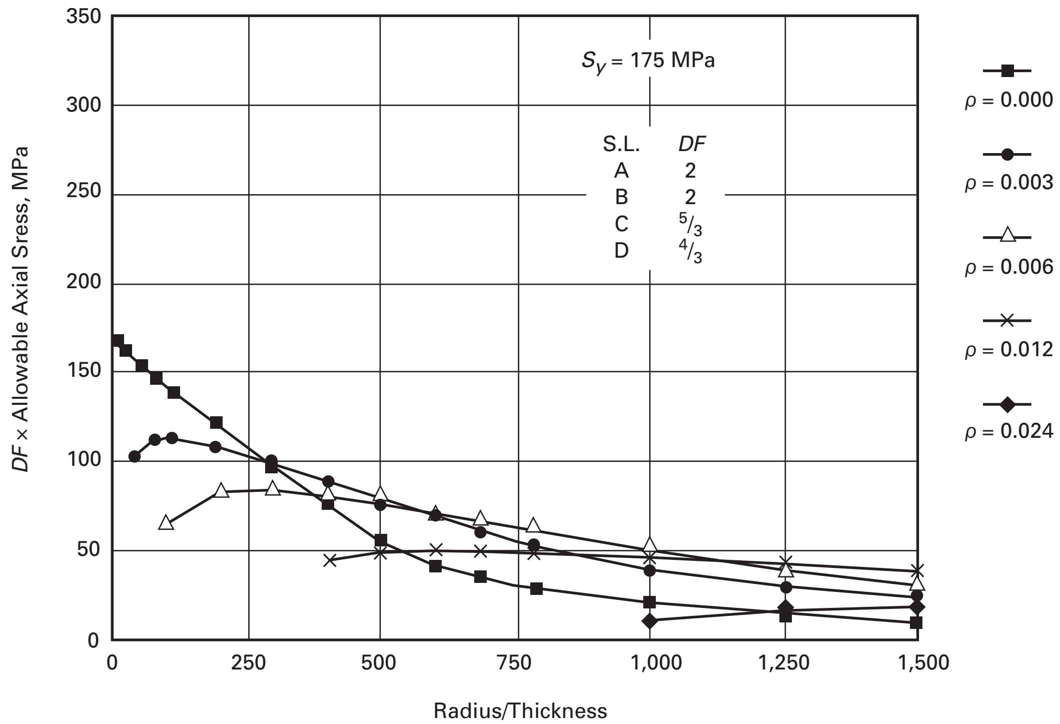


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	24.05	...	...	...	...
25	23.30	...	...	...	...
50	22.28	14.72	...	...	...
75	21.36	15.83	...	...	...
100	20.50	16.17	9.16	...	...
200	17.29	15.60	11.96	...	...
300	14.01	14.21	12.07	...	...
400	10.79	12.73	11.56	6.27	...
500	7.88	11.30	10.87	6.97	...
600	6.00	9.94	10.11	7.23	...
700	4.77	8.67	9.34	7.26	...
800	3.91	7.50	8.60	7.16	...
1,000	2.80	5.77	7.23	6.76	1.53
1,250	2.01	4.45	5.77	6.13	2.42
1,500	1.53	3.61	4.73	5.48	2.87

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 300°F; other code temperature limits may also apply.

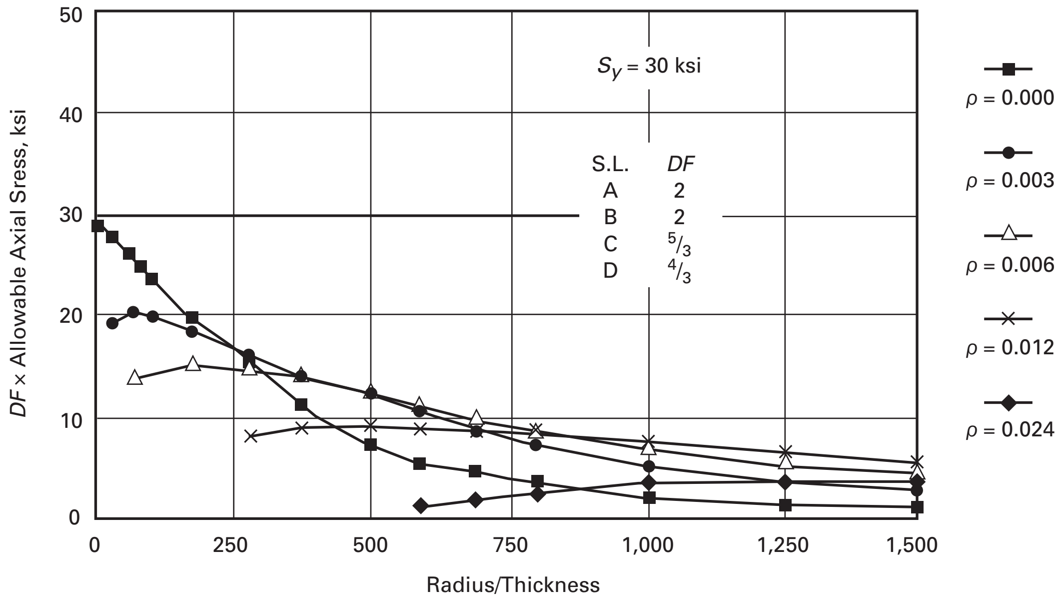
Figure NC-3944-1M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 175 MPa at Temperatures ≤ 150°C



Tabular Values					
R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	165.825	...	...	...	...
25	160.654	...	...	...	...
50	153.621	101.494	...	...	...
75	147.277	109.148	...	...	...
100	141.348	111.492	63.158	...	...
200	119.215	107.562	82.464	...	...
300	96.599	97.978	83.223	...	...
400	74.397	87.773	79.706	43.232	...
500	54.333	77.914	74.949	48.058	...
600	41.370	68.536	69.708	49.851	...
700	32.889	59.780	64.399	50.058	...
800	26.959	51.713	59.297	49.368	...
1,000	19.306	39.784	49.851	46.610	10.549
1,250	13.859	30.683	39.784	42.266	16.686
1,500	10.549	24.891	32.613	37.785	19.789

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 150°C; other code temperature limits may also apply.

Figure NC-3944-2
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 30 ksi at Temperatures ≤ 300°F

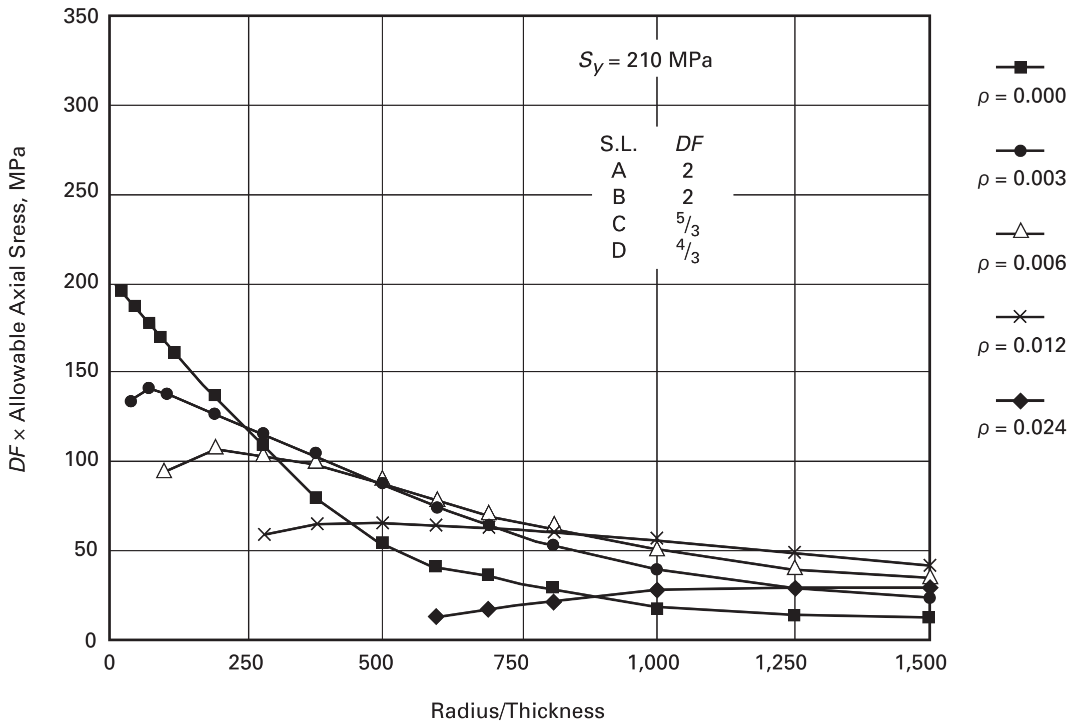


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	28.73	...	...	...	...
25	27.72	...	...	...	...
50	26.35	19.31	...	...	...
75	25.13	20.02	...	...	...
100	23.97	20.06	13.82	...	...
200	19.69	18.59	15.47	...	...
300	15.28	16.45	14.84	8.55	...
400	10.98	14.32	13.76	9.47	...
500	7.88	12.31	12.57	9.64	...
600	6.00	10.45	11.39	9.49	1.07
700	4.77	8.79	10.27	9.17	2.14
800	3.91	7.50	9.22	8.77	2.92
1,000	2.80	5.77	7.37	7.88	3.82
1,250	2.01	4.45	5.77	6.80	4.28
1,500	1.53	3.61	4.73	5.48	4.36

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 300°F; other code temperature limits may also apply.

Figure NC-3944-2M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 210 MPa at Temperatures ≤ 150°C

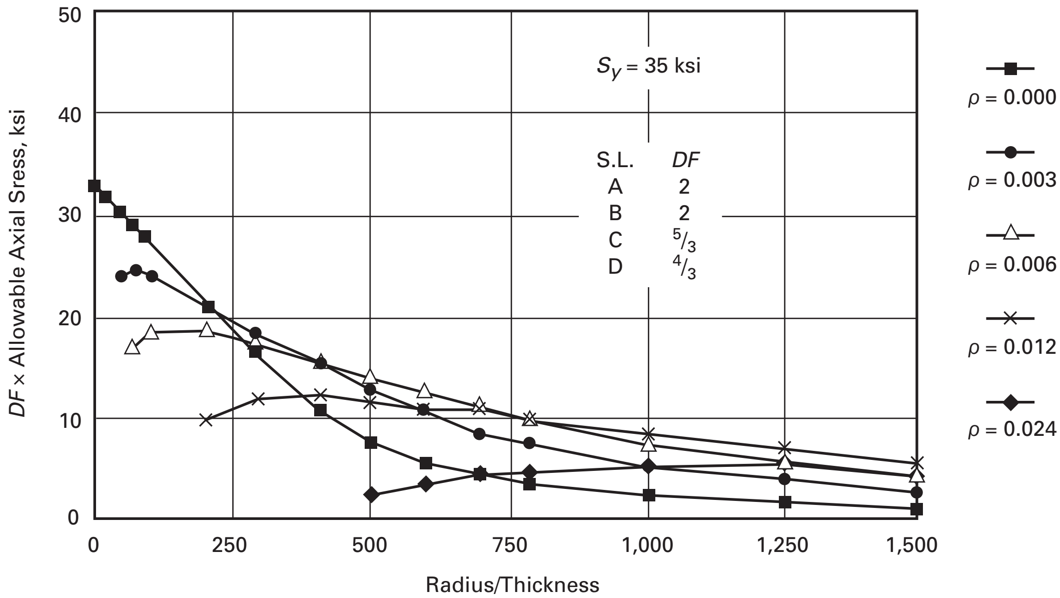


Tabular Values

R/*t*	*ρ* = 0.000	*ρ* = 0.003	*ρ* = 0.006	*ρ* = 0.012	*ρ* = 0.024
10	198.093	...	...	...	...
25	191.129	...	...	...	...
50	181.683	133.142	...	...	...
75	173.271	138.038	...	...	...
100	165.273	138.314	95.289	...	...
200	135.763	128.178	106.666	...	...
300	105.356	113.423	102.322	58.952	...
400	75.707	98.736	94.875	65.296	...
500	54.333	84.877	86.670	66.468	...
600	41.370	72.053	78.534	65.434	7.378
700	32.889	60.607	70.812	63.227	14.755
800	26.959	51.713	63.572	60.469	20.133
1,000	19.306	39.784	50.816	54.333	26.339
1,250	13.859	30.683	39.784	46.886	29.511
1,500	10.549	24.891	32.613	37.785	30.062

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 150°C; other code temperature limits may also apply.

Figure NC-3944-3
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 35 ksi at Temperatures ≤ 300°F

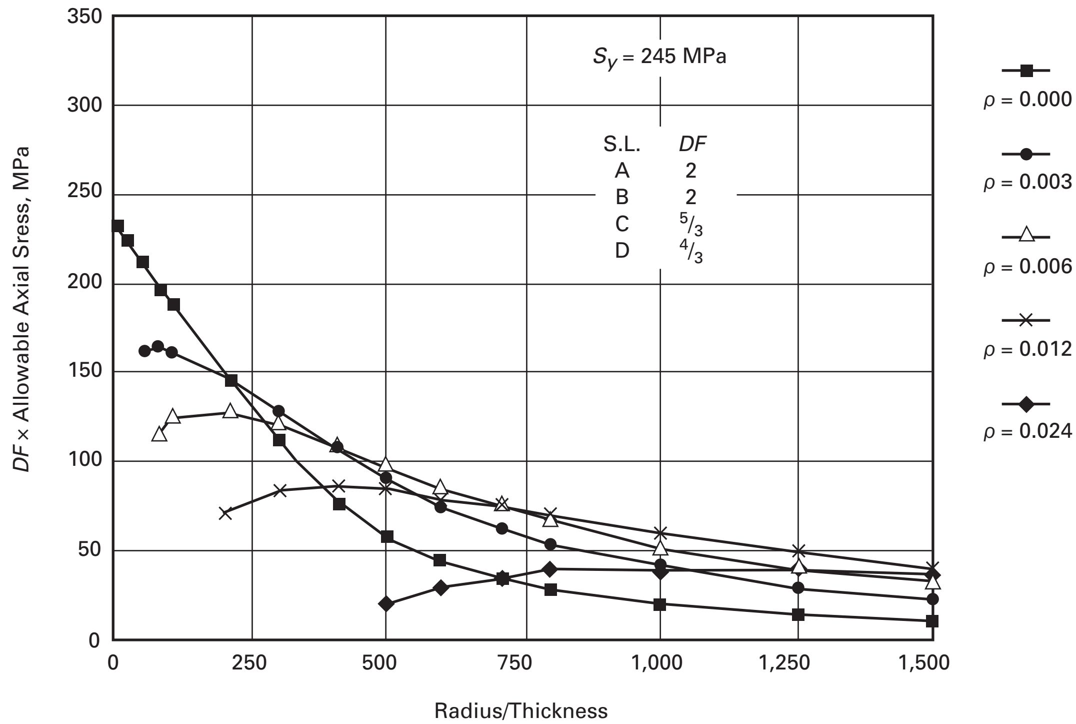


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	33.38	...	...	...	...
25	32.08	...	...	...	...
50	30.33	23.68	...	...	...
75	28.77	24.02	16.71	...	...
100	27.29	23.76	18.08	...	...
200	21.80	21.32	18.65	9.98	...
300	16.17	18.36	17.27	11.90	...
400	10.98	15.52	15.57	12.16	...
500	7.88	12.91	13.88	11.84	2.54
600	6.00	10.56	12.27	11.27	3.91
700	4.77	8.79	10.78	10.61	4.76
800	3.91	7.50	9.43	9.91	5.26
1,000	2.80	5.77	7.37	8.57	5.69
1,250	2.01	4.45	5.77	7.11	5.67
1,500	1.53	3.61	4.73	5.91	5.40

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 300°F; other code temperature limits may also apply.

Figure NC-3944-3M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 245 MPa at Temperatures ≤ 150°C

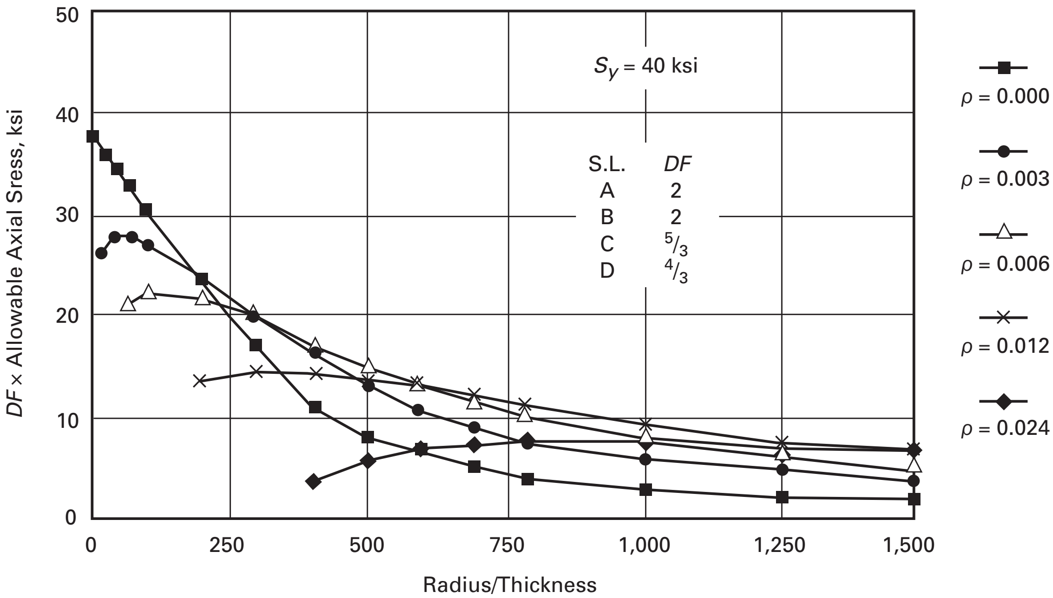


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	230.155	...	...	...	...
25	221.192	...	...	...	...
50	209.125	163.274	...	...	...
75	198.369	165.618	115.215	...	...
100	188.165	163.825	124.662	...	...
200	150.311	147.001	128.592	68.812	...
300	111.492	126.592	119.077	82.051	...
400	75.707	107.010	107.355	83.843	...
500	54.333	89.014	95.703	81.637	17.513
600	41.370	72.811	84.602	77.707	26.959
700	32.889	60.607	74.328	73.156	32.820
800	26.959	51.713	65.020	68.329	36.268
1,000	19.306	39.784	50.816	59.090	39.233
1,250	13.859	30.683	39.784	49.023	39.095
1,500	10.549	24.891	32.613	40.749	37.233

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 150°C; other code temperature limits may also apply.

Figure NC-3944-4
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 40 ksi at Temperatures ≤ 300°F

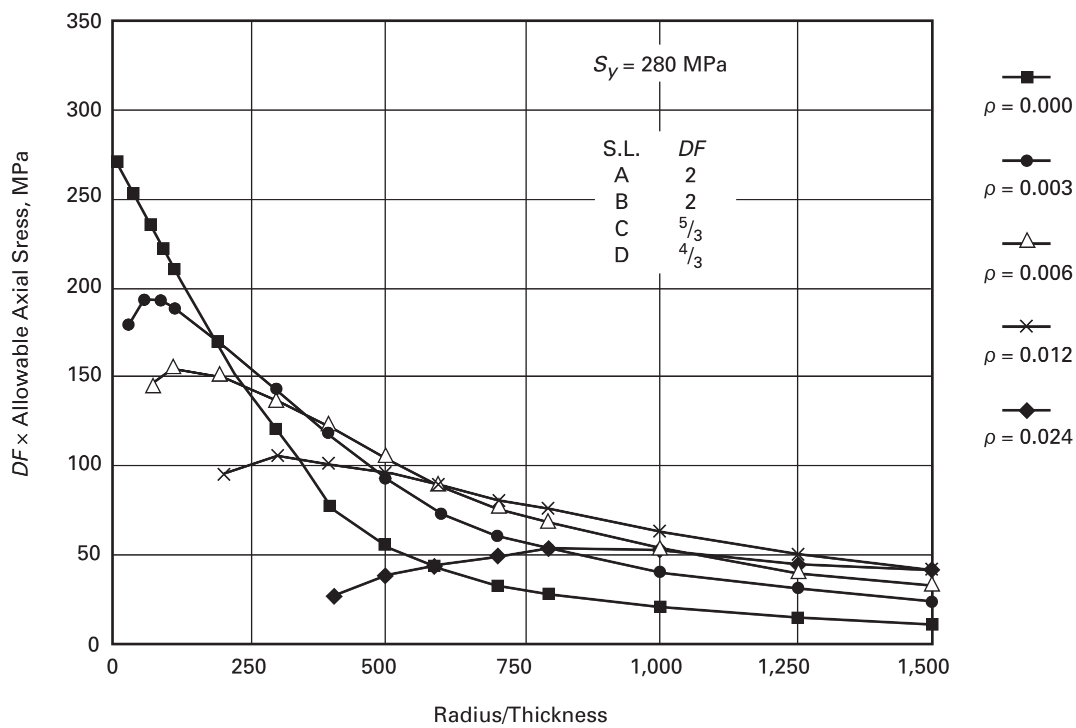


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	38.00	...	...	...	...
25	36.39	25.91	...	...	...
50	34.22	27.90	...	...	...
75	32.28	27.86	21.10	...	...
100	30.45	27.28	22.06	...	...
200	23.66	23.82	21.56	13.80	...
300	16.68	19.98	19.40	14.83	...
400	10.98	16.38	17.06	14.46	3.62
500	7.88	13.14	14.83	13.64	5.53
600	6.00	10.56	12.78	12.67	6.49
700	4.77	8.79	10.95	11.67	6.99
800	3.91	7.50	9.44	10.70	7.20
1,000	2.80	5.77	7.37	8.94	7.14
1,250	2.01	4.45	5.77	7.16	6.68
1,500	1.53	3.61	4.73	5.91	6.10

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 300°F; other code temperature limits may also apply.

Figure NC-3944-4M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 280 MPa at Temperatures ≤ 150°C

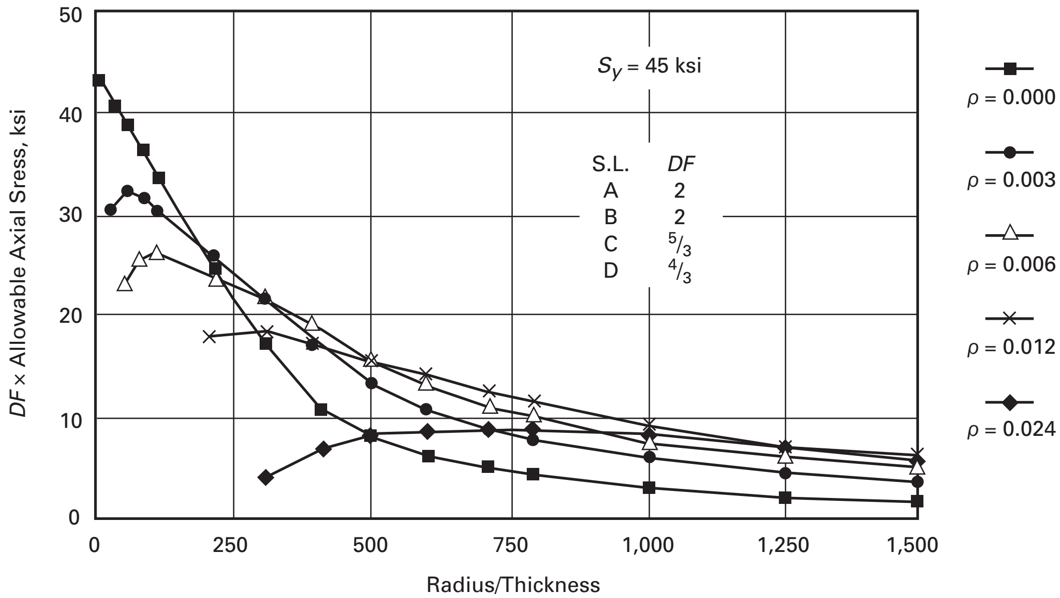


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	262.010	...	...	...	...
25	250.909	178.649	...	...	...
50	235.947	192.371	...	...	...
75	222.571	192.095	145.485	...	...
100	209.953	188.096	152.104	...	...
200	163.136	164.239	148.656	95.151	...
300	115.009	137.762	133.763	102.253	...
400	75.707	112.940	117.629	99.702	24.960
500	54.333	90.600	102.253	94.048	38.129
600	41.370	72.811	88.118	87.360	44.749
700	32.889	60.607	75.500	80.465	48.196
800	26.959	51.713	65.089	73.777	49.644
1,000	19.306	39.784	50.816	61.641	49.230
1,250	13.859	30.683	39.784	49.368	46.059
1,500	10.549	24.891	32.613	40.749	42.060

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 150°C; other code temperature limits may also apply.

Figure NC-3944-5
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 45 ksi at Temperatures ≤ 300°F

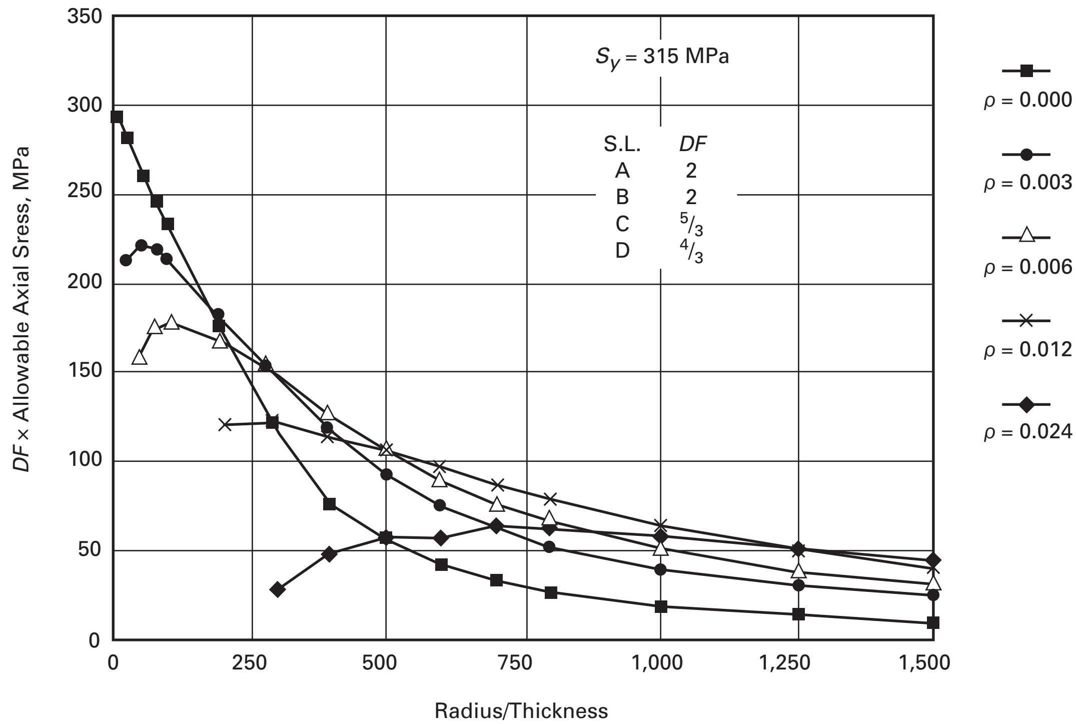


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	42.58	...	...	...	...
25	40.64	30.56	...	...	...
50	38.02	32.00	23.10	...	...
75	35.68	31.56	25.24	...	...
100	33.47	30.66	25.81	...	...
200	25.27	26.11	24.24	17.26	...
300	16.84	21.32	21.25	17.43	3.73
400	10.98	16.93	18.25	16.43	6.76
500	7.88	13.14	15.48	15.12	8.13
600	6.00	10.56	13.00	13.74	8.13
700	4.77	8.79	10.95	12.41	8.85
800	3.91	7.50	9.44	11.18	8.76
1,000	2.80	5.77	7.37	9.06	8.24
1,250	2.01	4.45	5.77	7.16	7.39
1,500	1.53	3.61	4.73	5.91	6.54

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 300°F; other code temperature limits may also apply.

Figure NC-3944-5M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 315 MPa at Temperatures ≤ 150°C

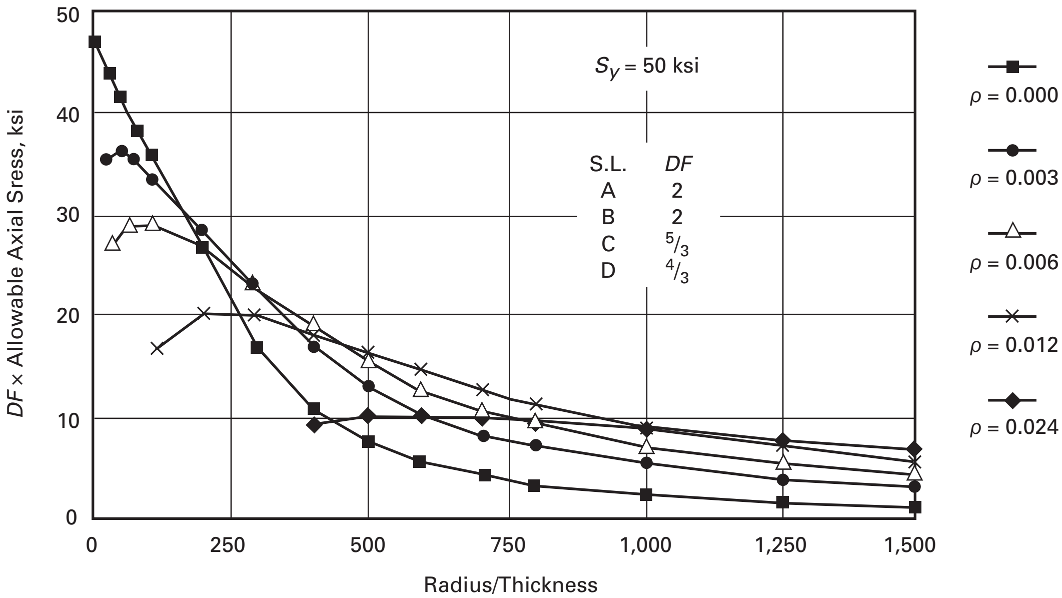


Tabular Values

R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	293.589	...	...	...	...
25	280.213	210.711	...	...	...
50	262.148	220.640	159.275	...	...
75	246.014	217.606	174.030	...	...
100	230.776	211.401	177.960	...	...
200	174.237	180.028	167.135	119.008	...
300	116.112	147.001	146.519	120.180	25.718
400	75.707	116.732	125.834	113.285	46.610
500	54.333	90.600	106.735	104.252	56.056
600	41.370	72.811	89.635	94.737	56.056
700	32.889	60.607	75.500	85.567	61.021
800	26.959	51.713	65.089	77.086	60.400
1,000	19.306	39.784	50.816	62.469	56.815
1,250	13.859	30.683	39.784	49.368	50.954
1,500	10.549	24.891	32.613	40.749	45.093

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 150°C; other code temperature limits may also apply.

Figure NC-3944-6
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 50 ksi at Temperatures ≤ 300°F

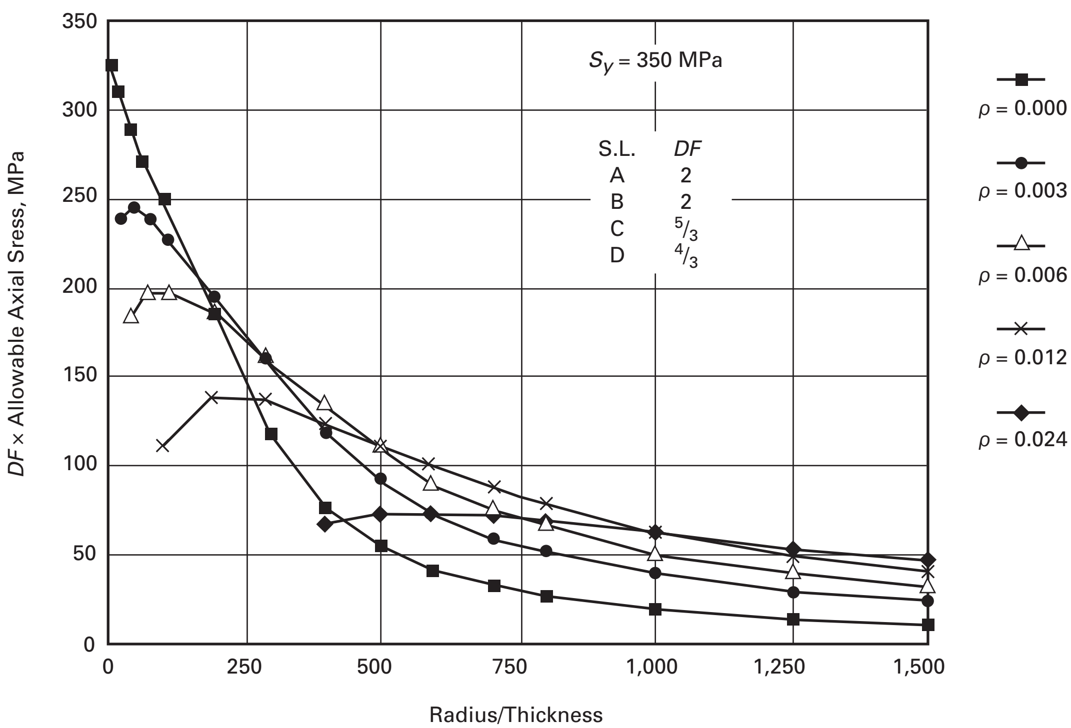


Tabular Values

R/*t*	*ρ* = 0.000	*ρ* = 0.003	*ρ* = 0.006	*ρ* = 0.012	*ρ* = 0.024
10	47.14	...	...	...	...
25	44.84	35.09	...	...	...
50	41.74	35.98	27.58	...	...
75	38.97	35.15	29.20	...	...
100	36.35	33.89	29.39	16.19	...
200	26.64	28.19	26.71	20.42	...
300	16.84	22.41	22.87	19.74	...
400	10.98	17.19	19.17	18.12	9.56
500	7.88	13.14	15.85	16.30	10.42
600	6.00	10.56	13.01	14.53	10.57
700	4.77	8.79	10.95	12.89	10.38
800	3.91	7.50	9.44	11.42	10.01
1,000	2.80	5.77	7.37	9.06	9.06
1,250	2.01	4.45	5.77	7.16	7.86
1,500	1.53	3.61	4.73	5.91	6.79

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 300°F; other code temperature limits may also apply.

Figure NC-3944-6M
Design Factor Times Allowable Axial Membrane Compressive Stress Versus Radius Over Thickness for Ferrous Materials With Yield Strengths of 350 MPa at Temperatures ≤ 150°C



Tabular Values

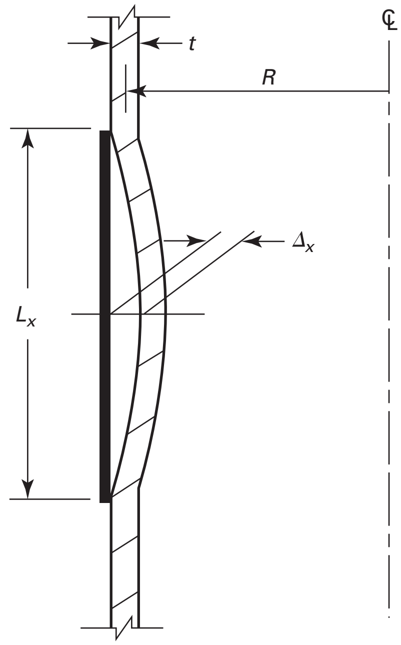
R/t	ρ = 0.000	ρ = 0.003	ρ = 0.006	ρ = 0.012	ρ = 0.024
10	325.030	...	...	...	...
25	309.172	241.946	...	...	...
50	287.797	248.082	190.164	...	...
75	268.698	242.359	201.334	...	...
100	250.633	233.672	202.644	111.630	...
200	183.683	194.370	184.165	140.796	...
300	116.112	154.517	157.689	136.107	...
400	75.707	118.525	132.177	124.937	65.916
500	54.333	90.600	109.286	112.389	71.846
600	41.370	72.811	89.704	100.184	72.880
700	32.889	60.607	75.500	88.877	71.570
800	26.959	51.713	65.089	78.741	69.019
1,000	19.306	39.784	50.816	62.469	62.469
1,250	13.859	30.683	39.784	49.368	54.195
1,500	10.549	24.891	32.613	40.749	46.817

GENERAL NOTE: Curves are for ferrous materials, temperature ≤ 150°C; other code temperature limits may also apply.

NC-3947 Construction Tolerances

In addition to the applicable requirements established in NC-4220, a tolerance shall apply on bulges or flat spots in the cylindrical walls that result from vertical elements of the cylinder being other than straight lines. This tolerance is expressed in terms of the quantities illustrated in Figure NC-3947-1. A straight rod is to be positioned either inside or outside the tank, as appropriate, for the deviation being evaluated. The length of the rod, L_x, shall be $4\sqrt{R/t} \pm 10\%$. The amplitude of the deviation, Δ_x, shall not exceed 1% of L_x. These tolerance requirements, which are in addition to those given in NC-4220, apply only to regions of the cylindrical walls where allowable compressive stresses are established by the rules of this subsubarticle.

Figure NC-3947-1
Meridional Straightness Tolerance



ARTICLE NC-4000
FABRICATION AND INSTALLATION

NC-4100 GENERAL REQUIREMENTS

NC-4110 INTRODUCTION

(a) Components, parts, and appurtenances shall be fabricated and installed in accordance with the rules of this Article and shall be manufactured from materials which meet the requirements of Article NC-2000.

(b) Vessels designed to the requirements of NC-3200 shall meet the requirements of this Article except for NC-4240 and NC-4433. In this case, the requirements of NC-4260 apply.

(c) Atmospheric and 0 psig to 15 psig (0 kPa to 100 kPa) storage tanks shall be fabricated in accordance with the rules of this Article.

NC-4120 CERTIFICATION OF MATERIALS AND FABRICATION BY COMPONENT CERTIFICATE HOLDER

NC-4121 Means of Certification

The Certificate Holder for an item shall certify, by application of the appropriate Certification Mark and completion of the appropriate Data Report in accordance with Article NCA-8000, that the materials used comply with the requirements of Article NC-2000 and that the fabrication or installation complies with the requirements of this Article.

NC-4121.1 Certification of Treatments, Tests, and Examinations. If the Certificate Holder or Subcontractor performs treatments, tests, repairs, or examinations required by other Articles of this Subsection, the Certificate Holder shall certify that this requirement has been fulfilled (NCA-3862). Reports of all required treatments and of the results of all required tests, repairs, and examinations performed shall be available to the Inspector.

NC-4121.2 Repetition of Tensile or Impact Tests. If during the fabrication or installation of the item the material is subjected to heat treatment that has not been covered by treatment of the test coupons (NC-2200) and that may reduce either tensile or impact properties below the required values, the tensile and impact tests shall be repeated by the Certificate Holder on test specimens taken from test coupons which have been taken and treated in accordance with the requirements of Article NC-2000.

NC-4121.3 Repetition of Surface Examination After Machining. During the fabrication or installation of an item, if materials for pressure-containing parts are machined, then the Certificate Holder shall reexamine the surface of the material in accordance with NC-2500 when:

(a) the surface was required to be examined by the magnetic particle or liquid penetrant method in accordance with NC-2500; and

(b) the amount of material removed from the surface exceeds the lesser of $\frac{1}{8}$ in. (3 mm) or 10% of the minimum required thickness of the part.

NC-4122 Materials Identification

(a) Material for pressure-retaining parts shall carry identification markings which will remain distinguishable until the component is assembled or installed. If the original identification markings are cut off or the material is divided, either the marks shall be transferred to the parts cut or a coded marking shall be used to ensure identification of each piece of material during subsequent fabrication or installation. In either case, an as-built sketch or a tabulation of materials shall be made identifying each piece of material with the Certified Material Test Report, where applicable, and the coded marking. For studs, bolts, nuts, and heat exchanger tubes, it is permissible to identify the Certified Material Test Reports for material in each component in lieu of identifying each piece of material with the Certified Material Test Report and the coded marking. Material supplied with a Certificate of Compliance and welding and brazing materials shall be identified and controlled so that they can be traced to each component or installation of a piping system, or else a control procedure shall be employed which ensures that the specified materials are used.

(b) Material from which the identification marking is lost shall be treated as nonconforming material until appropriate tests or other verifications are made and documented to assure material identification. Testing is required unless positive identification can be made by other documented evidence. The material may then be remarked upon establishing positive identification.

NC-4122.1 Marking Materials. Material shall be marked in accordance with NC-2150.

NC-4123 Examinations

Visual examination activities that are not referenced for examination by other specific Code paragraphs, and are performed solely to verify compliance with requirements of Article NC-4000, may be performed by the persons who perform or supervise the work. These visual examinations are not required to be performed by personnel and procedures qualified to NC-5100 and NC-5500, respectively, unless so specified.

NC-4125 Testing of Welding and Brazing Materials

All welding and brazing materials shall meet the requirements of NC-2400.

NC-4130 REPAIR OF MATERIAL

Material originally accepted on delivery in which defects exceeding the limits of NC-2500 are known or discovered during the process of fabrication or installation is unacceptable. The material may be used, provided the condition is corrected in accordance with the requirements of NC-2500 for the applicable product form, except that:

(a) the limitation on the depth of the weld repair does not apply;

(b) the time of examination of the weld repairs to weld edge preparations shall be in accordance with NC-5130;

(c) radiographic examination is not required for weld repairs to seal membrane material when the material thickness is $^1/_4$ in. (6 mm) or less;

(d) radiographic examination is not required for welded repairs in material used in storage tanks, provided that the welded joints in these materials are not required to be radiographed, the extent of the welded repair does not exceed 10 in.^{2} (6 500 mm^2) of the surface area, and the magnetic particle or liquid penetrant examination of the repair is made as required by NC-2539.4.

NC-4200 FORMING, CUTTING, AND ALIGNING

NC-4210 CUTTING, FORMING, AND BENDING

NC-4211 Cutting

Materials may be cut to shape and size by mechanical means, such as machining, shearing, chipping, or grinding, or by thermal cutting.

NC-4211.1 Preheating Before Thermal Cutting. When thermal cutting is performed to prepare weld joints or edges, to remove attachments or defective material, or for any other purpose, consideration shall be given to preheating the material, using preheat schedules such as suggested in Section III Appendices, Nonmandatory Appendix D.

NC-4212 Forming and Bending Processes

Any process may be used to hot or cold form or bend pressure-retaining materials, including weld metal, provided the required dimensions are attained (see NC-4214 and NC-4220), and provided the impact properties of the materials, when required, are not reduced below the minimum specified values, or they are effectively restored by heat treatment following the forming operation. *Hot forming* is defined as forming with the material temperature higher than 100°F (56°C) below the lower transformation temperature of the material. When required, the process shall be qualified for impact properties as outlined in NC-4213. When required, the process shall be qualified to meet thickness requirements as outlined in NC-4223.1.

NC-4213 Qualification of Forming Processes for Impact Property Requirements

When impact testing is required by the Design Specifications, a procedure qualification test shall be conducted using specimens taken from materials of the same specification, grade or class, heat treatment, and with similar impact properties, as required for the material in the component. These specimens shall be subjected to the equivalent forming or bending process and heat treatment as the material in the component. Applicable tests shall be conducted to determine that the required impact properties of NC-2300 are met after straining.

NC-4213.1 Exemptions. Procedure qualification tests are not required for material listed in (a) through (f) below:

(a) hot formed material, such as forgings, in which the hot forming is completed by the Material Manufacturer prior to removal of the impact test specimens;

(b) hot formed materials represented by test coupons required in either NC-2211 or NC-4121.2 which have been subjected to heat treatment representing the hot forming procedure and the heat treatments to be applied to the parts;

(c) materials which do not require impacts in accordance with NC-2300;

(d) materials which have a final strain less than 0.5%;

(e) material where the final strain is less than that of a previously qualified procedure for that material;

(f) material from which the impact testing required by NC-2300 is performed on each heat and lot, as applicable, after forming.

NC-4213.2 Procedure Qualification Test. The procedure qualification test shall be performed in the manner stipulated in (a) through (f) below.

(a) The tests shall be performed on three different heats of material, both before straining and after straining and heat treatment, to establish the effects of the forming and subsequent heat treatment operations.

(b) Specimens shall be taken in accordance with the requirements of Article NC-2000 and shall be taken from the tension side of the strained material.

(c) The percent strain shall be established by the following equations:

(1) For cylinders

$$\% \text{ strain} = \frac{50t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

(2) For spherical or dished surfaces

$$\% \text{ strain} = \frac{75t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

(3) For pipe

$$\% \text{ strain} = \frac{100r}{R}$$

where

R = nominal bending radius to the center line of the pipe
r = nominal radius of the pipe
R_f = final radius to center line of shell
R_o = original radius (equal to infinity for a flat part)
t = nominal thickness

(d) The procedure qualification shall simulate the maximum percent surface strain, employing a bending process similar to that used in the fabrication of the material or by direct tension on the specimen.

(e) Sufficient C_v test specimens shall be taken from each of the three heats of material to establish a transition curve showing both the upper and lower shelves. On each of the three heats, tests consisting of three impact specimens shall be conducted at a minimum of five different temperatures distributed throughout the transition region. The upper and lower shelves may be established by the use of one test specimen for each shelf. Depending on the product form, it may be necessary to plot the transition curves using both the lateral expansion and energy level data (NC-2300). In addition, drop weight tests shall be made when required by NC-2300.

(f) Using the results of the impact test data from each of three heats, taken both before and after straining, determine either:

(1) the maximum change in NDT temperature along with

(-a) the maximum change of lateral expansion and energy at the temperature under consideration; or

(-b) the maximum change in temperature at the lateral expansion and energy levels under consideration; or

(2) where lateral expansion is the acceptance criteria (NC-2300), either the maximum change in temperature or the maximum change in lateral expansion.

NC-4213.3 Acceptance Criteria for Formed Material. To be acceptable, the formed material used in the component shall have impact properties, before forming, sufficient to compensate for the maximum loss of impact properties due to the qualified forming procedure used.

NC-4213.4 Requalification. A new procedure qualification test is required when any of the changes in (a), (b), or (c) below are made.

(a) The actual postweld heat treatment time at temperature is greater than previously qualified considering NC-2211. If the material is not postweld heat treated, the procedure must be qualified without postweld heat treatment.

(b) The maximum calculated strain of the material exceeds the previously qualified strain by more than 0.5%.

(c) Where preheat over 250°F (120°C) is used in the forming or bending operation but not followed by a subsequent postweld heat treatment.

NC-4214 Minimum Thickness of Fabricated Material

If any fabrication operation reduces the thickness below the minimum required to satisfy the rules of NC-2124 and Article NC-3000, the material may be repaired in accordance with NC-4130.

NC-4220 FORMING TOLERANCES

NC-4221 Tolerance for Vessel Shells

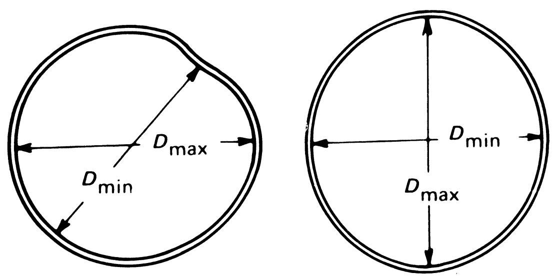
Cylindrical, conical, or spherical shells of a completed vessel, except formed heads covered by NC-4222, shall meet the requirements of the following subparagraphs at all cross sections.

NC-4221.1 Maximum Difference in Cross-Sectional Diameters. The difference in inches (millimeters) between the maximum and minimum diameters at any cross-section shall not exceed the smaller of $(D + 50)/200$ $[(D + 1\ 250)/200]$ and $D/100$, where D is the nominal inside diameter, in. (mm), at the cross section under consideration. The diameters may be measured on the inside or outside of the vessel. If measured on the outside, the diameters shall be corrected for the plate thickness at the cross section under consideration (Figure NC-4221.1-1). When the cross section passes through an opening, the permissible difference in inside diameters given herein may be increased by 2% of the inside diameter of the opening.

NC-4221.2 Maximum Deviation From True Theoretical Form for External Pressure. Vessels designed for external pressure shall meet the tolerances given in (a) through (e) below.

(a) The maximum plus or minus deviation from the true circular form of cylinders or the theoretical form of other shapes, measured radially on the outside or inside of the component, shall not exceed the maximum permissible deviation obtained from Figure NC-4221.2(a)-1.

Figure NC-4221.1-1
Maximum Difference in Cross-Sectional Diameters



Measurements shall be made from a segmental circular template having the design inside or outside radius depending on where the measurements are taken and a chord length equal to twice the arc length obtained from Figure NC-4221.2(a)-2. For Figure NC-4221.2(a)-1, the maximum permissible deviation e need not be less than $0.3t$. For Figure NC-4221.2(a)-2, the arc length need not be greater than $0.30D_o$. Measurements shall not be taken on welds or other raised parts.

(b) The value of t, in., at any cross section is the nominal plate thickness less corrosion allowance for sections of constant thickness and the nominal thickness of the thinnest plate less corrosion allowance for sections having plates of more than one thickness.

(c) The value of L in Figures NC-4221.2(a)-1 and NC-4221.2(a)-2 is determined by (1), (2), and (3) below.

(1) For cylinders, L is as given in NC-3133.2.

(2) For cones, L is the axial length of the conical section if no stiffener rings are used or, if stiffener rings are used, the axial length from the head bend line at the large end of the cone to the first stiffener ring, with D_o taken as the outside diameter in inches (millimeters) of the cylinder at the large end of the cone.

(3) For spheres, L is one-half of the outside diameter D_o, in. (mm).

(d) The dimensions of a completed vessel may be brought within the requirements by any process which will not impair the strength of the material.

(e) Sharp bends and flat spots shall not be permitted unless provision is made for them in the design.

NC-4221.3 Deviations From Tolerances. Deviations from the tolerance requirements stipulated in NC-4221.1 and NC-4221.2 are permitted, provided the drawings are modified and reconciled with the design calculations.

NC-4221.4 Tolerance Deviations for Vessel Parts Fabricated From Pipe. Vessel parts subjected to either internal or external pressure and fabricated from pipe, meeting all other requirements of this Subsection, may have variations of diameter and deviations from circularity permitted by the specification for such pipe.

NC-4221.5 Localized Thin Areas. Localized thin areas are permitted if the adjacent areas surrounding each have sufficient thickness to provide the necessary reinforcement according to the rules for reinforcement in NC-3330.

NC-4222 Tolerances for Formed Vessel Heads

The tolerance for formed vessel heads shall be as set forth in the following subparagraphs.

NC-4222.1 Maximum Difference in Cross-Sectional Diameters. The skirt or cylindrical end of a formed head shall be circular to the extent that the difference in inches between the maximum and minimum diameters does not exceed the lesser of $(D + 50)/200$ $[(D + 1\,250)/200]$ and $(D + 12)/100$ $[(D + 300)/100]$, where D is the nominal inside diameter, in. (mm), and shall match the cylindrical edge of the adjoining part within the alignment tolerance specified in NC-4232.

NC-4222.2 Deviation From Specified Shape.

(a) The inner surface of a torispherical or ellipsoidal head shall not deviate outside the specified shape by more than $1\frac{1}{4}$% of D, nor inside the specified shape by more than $\frac{5}{8}$% of D, where D is nominal inside diameter of the vessel. Such deviations shall be measured perpendicular to the specified shape and shall not be abrupt. The knuckle radius shall not be less than specified. For 2:1 ellipsoidal heads, the knuckle radius may be considered to be 17% of the diameter of the vessel.

(b) Hemispherical heads and any spherical portion of a formed head shall meet the local tolerances for spheres as given in NC-4221.2, using L as the outside spherical radius in inches (millimeters) and D_o as 2 times L.

(c) Deviation measurements shall be taken on the surface of the base material and not on welds.

NC-4223 Tolerances for Formed or Bent Piping

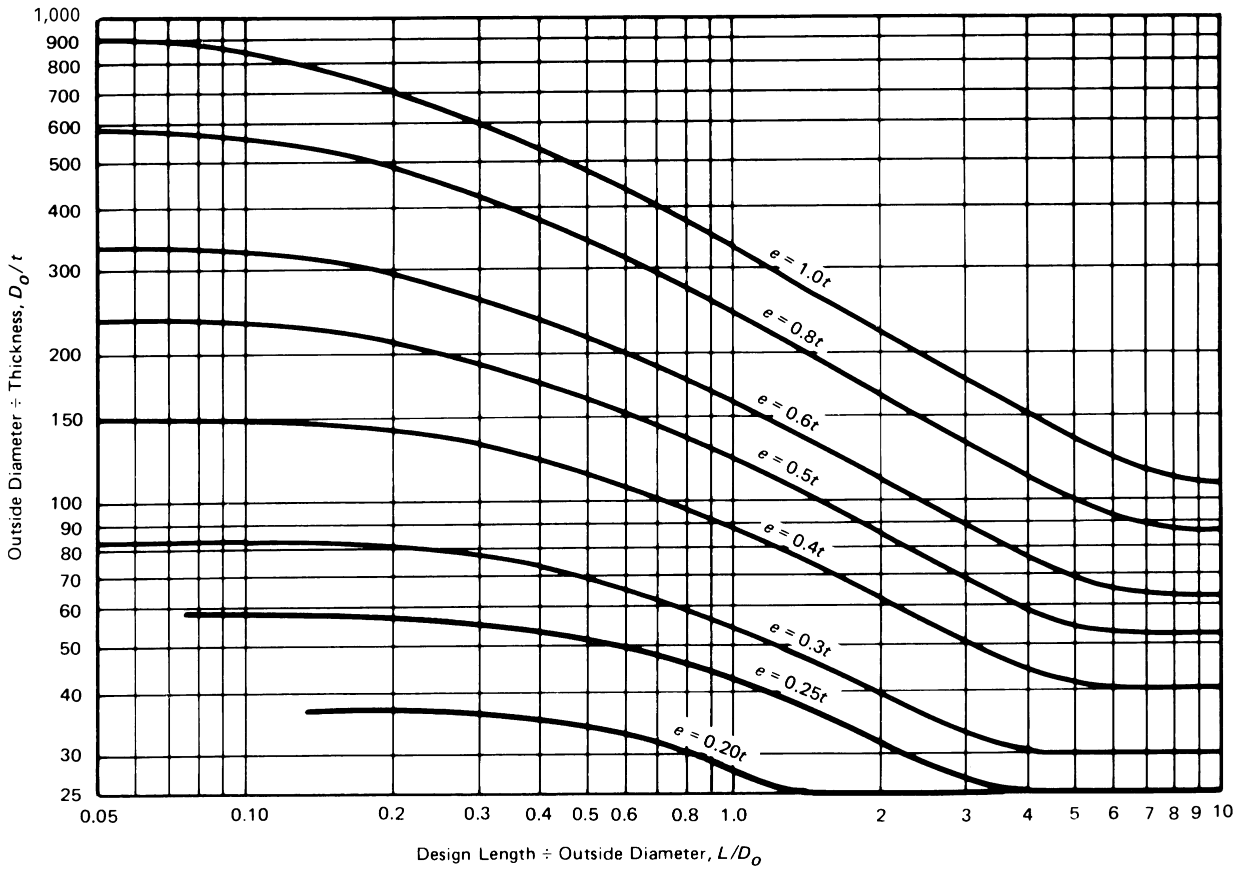
The tolerances for formed or bent piping shall be as set forth in the following subparagraphs.

NC-4223.1 Minimum Wall Thickness. In order to ensure that the wall thickness requirements of the design calculations are met, the actual thickness shall be measured, or the process shall be qualified by demonstrating that it will maintain the required wall thickness. (**15**)

NC-4223.2 Ovality Tolerance. Unless otherwise justified by the design calculations, the ovality of piping after bending shall not exceed 8% as determined by

$$100 \times (D_{max} - D_{min}) / D_o$$

Figure NC-4221.2(a)-1
Maximum Permissible Deviation *e* From a True Circular Form



where

D_{min} = the minimum outside diameter after bending or forming

D_{max} = the maximum outside diameter after bending or forming

D_o = the nominal pipe outside diameter

NC-4224 Tolerances for Storage Tanks

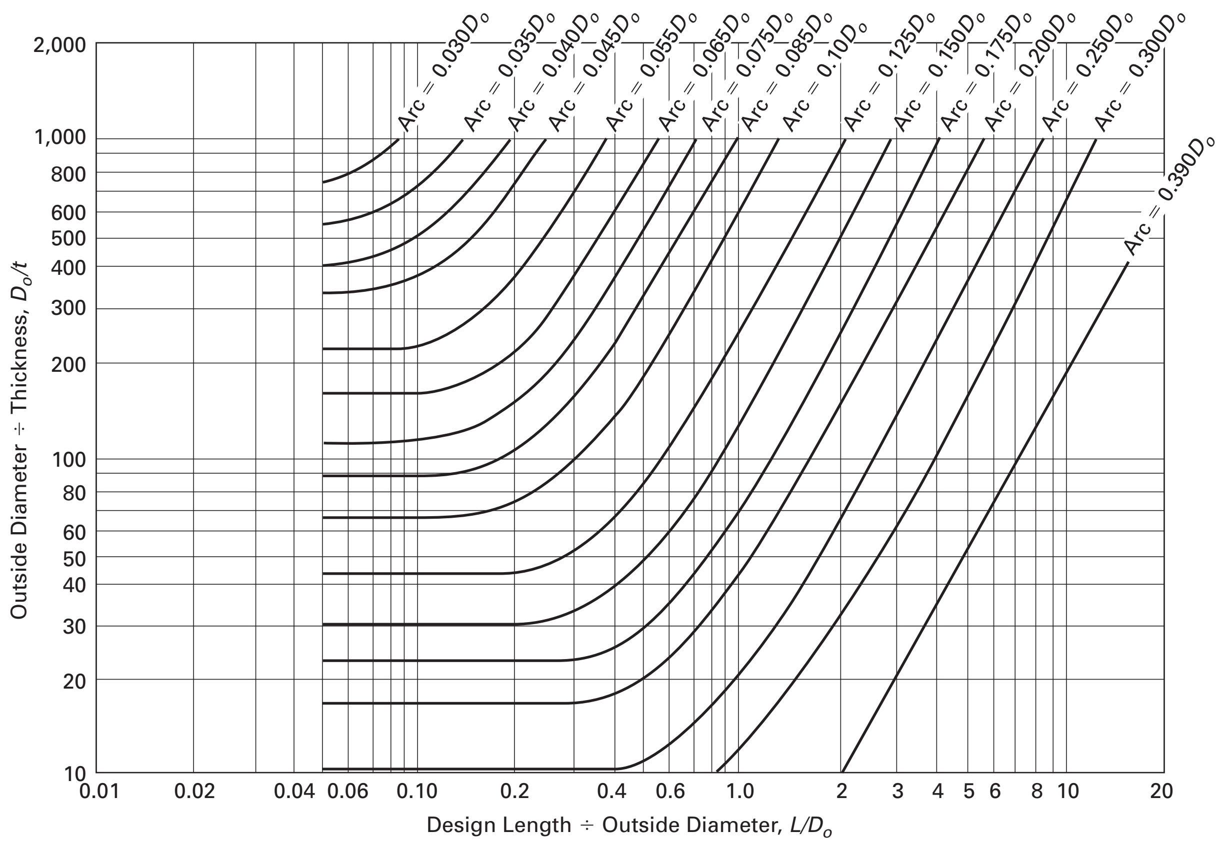
The horizontal circular cross section of storage tanks shall be sufficiently true to round so that the difference between the maximum and minimum diameters measured inside or outside at any section in a cylindrical wall shall not exceed 1% of the average diameter or 12 in. (300 mm), whichever is less, measured 6 ft (2 m) or one plate width from the top and bottom juncture, respectively, if these junctures are of a type which offers serious restraint when the tank is filled or under the specified maximum vapor pressure. At any section in a sidewall having double curvature, this difference in diameter shall not exceed $^1/_2$% of the average diameter or 6 in. (150 mm), whichever is less.

NC-4224.1 Maximum Difference in Cross-Sectional Diameters for Tanks of Double Curvature. For tanks of double curvature, the meridian curvature of the plate surface shall not deviate from the design shape by more than $^1/_2$% of the radius, measured radially, and shall not show abrupt changes. Plate surfaces shall merge smoothly into the adjoining surfaces in all directions. Local inward deviations, such as flat spots, shall be limited by NC-4224.2.

NC-4224.2 Local Inward Deviations. Local inward deviations, such as flat spots, if present on wall or bottom surfaces having double curvature, shall not be greater than the plate thickness, and shall not have a diameter d greater than $\sqrt{8Rt}$, where R is the radius of the tank and t is the thickness of the plate involved. R shall be taken as R_1, with d being the chord in a meridional direction, and as R_2, with d being the chord in a latitudinal direction.

NC-4224.3 Tolerance Measurements. The tolerance measurements are given for a tank while empty and shall be taken with a steel tape, making corrections for temperature, sag, and wind.

Figure NC-4221.2(a)-2
Maximum Arc Length for Determining Plus or Minus Deviation



NC-4230 FITTING AND ALIGNING

NC-4231 Fitting and Aligning Methods

Parts that are to be joined by welding may be fitted, aligned, and retained in position during the welding operation by the use of bars, jacks, clamps, tack welds, or temporary attachments.

NC-4231.1 Tack Welds. Tack welds used to secure alignment shall either be removed completely when they have served their purpose, or their stopping and starting ends shall be properly prepared by grinding or other suitable means so that they may be satisfactorily incorporated into the final weld. Tack welds shall be made by qualified welders using qualified welding procedures. When tack welds are to become part of the finished weld, they shall be visually examined and defective tack welds removed.

NC-4232 Alignment Requirements When Components Are Welded From Two Sides

(a) Alignment of sections which are welded from two sides shall be such that the maximum offset of the finished weld will not be greater than the applicable amount listed in Table NC-4232(a)-1, where t is the nominal thickness of the thinner section at the joint.

Table NC-4232(a)-1
Maximum Allowable Offset in Final Welded Joints

	Direction of Joints	
Section Thickness, in. (mm)	Longitudinal	Circumferential
Up to $^1/_2$ (13), incl.	$^1/_4t$	$^1/_4t$
Over $^1/_2$ to $^3/_4$ (13 to 19), incl.	$^1/_8$ in. (3 mm)	$^1/_4t$
Over $^3/_4$ to $1^1/_2$ (19 to 38), incl.	$^1/_8$ in. (3 mm)	$^3/_{16}$ in. (5 mm)
Over $1^1/_2$ to 2 (38 to 50), incl.	$^1/_8$ in. (3 mm)	$^1/_8t$
Over 2 (50)	Lesser of $^1/_{16}t$ or $^3/_8$ in. (10 mm)	Lesser of $^1/_8t$ or $^3/_4$ in. (19 mm)

(b) Joints in spherical vessels, joints within heads and joints between cylindrical shells and hemispherical heads shall meet the requirements in Table NC-4232(a)-1 for longitudinal joints.

NC-4232.1 Fairing of Offsets. Any offset within the allowable tolerance provided above shall be faired to at least 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal beyond what would otherwise be the edge of the weld.

NC-4233 Alignment Requirements When Inside Surfaces Are Inaccessible

(a) When the inside surfaces of items are inaccessible for welding or fairing in accordance with NC-4232, alignment of sections shall meet the requirements of (1) and (2) below.

(1) See (-a) and (-b) below

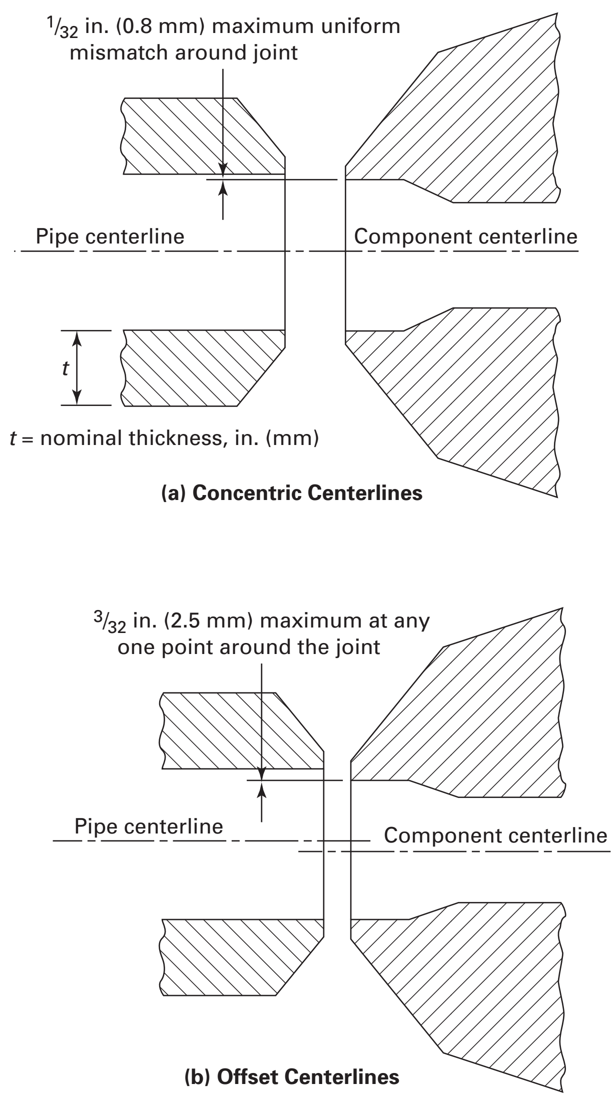
(-a) For circumferential joints the inside diameters shall match each other within $^1/_{16}$ in. (1.5 mm) When the items are aligned concentrically, a uniform mismatch of $^1/_{32}$ in. (0.8 mm) all around the joint can result, as shown in Figure NC-4233-1 sketch (a). However, other variables not associated with the diameter of the item often result in alignments that are offset rather than concentric. In these cases, the maximum misalignment at any one point around the joint shall not exceed $^3/_{32}$ in. (2.5 mm), as shown in Figure NC-4233-1 sketch (b). Should tolerances on diameter, wall thickness, out-of-roundness, etc., result in inside diameter variation which does not meet these limits, the inside diameters shall be counterbored, sized, or ground to produce a bore within these limits, provided the requirements of NC-4250 are met.

(-b) Offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(2) For longitudinal joints the misalignment of inside surfaces shall not exceed $^3/_{32}$ in. (2.5 mm), and the offset of outside surfaces shall be faired to at least a 3:1 taper over the width of the finished weld or, if necessary, by adding additional weld metal.

(b) Single-welded joints may meet the alignment requirements of (a)(1) and (a)(2) above in lieu of the requirements of NC-4232.

Figure NC-4233-1
Butt Weld Alignment and Mismatch Tolerances for Unequal I.D. and O.D. When Components Are Welded From One Side and Fairing Is Not Performed



GENERAL NOTE: The weld end transitions are typical and are not intended as requirements. Refer to NC-4250 for weld end transition requirements.

NC-4240 REQUIREMENTS FOR WELD JOINTS IN COMPONENTS[57]

NC-4241 Category A Weld Joints in Vessels and Longitudinal Weld Joints in Other Components

Category A weld joints in vessels and longitudinal weld joints in other components shall be full penetration butt joints. Joints that have been welded from one side with backing that has been removed, and those welded from one side without backing, are acceptable as full penetration welds provided the weld root side of the joints meet the requirements of NC-4424.

NC-4242 Category B Weld Joints in Vessels and Circumferential Weld Joints in Other Components

Category B weld joints in vessels and circumferential weld joints in other components shall be full penetration butt joints, except that piping NPS 2 (DN 50) and smaller may be socket welded. Joints prepared with opposing lips to form an integral backing ring and joints with backing strips which are not later removed are acceptable, provided the requirements of NC-3352.2 are met.

NC-4243 Category C Weld Joints in Vessels and Similar Weld Joints in Other Components

Category C weld joints in vessels and similar weld joints in other components shall be full penetration joints, as shown in Figures NC-4243-1 and NC-4243-2, except that socket welded flanges of NPS 2 (DN 50) and less and slip-on flanges may be used.

NC-4243.1 Flat Heads and Tubesheets With Hubs. Hubs for butt welding to the adjacent shell, head, or other pressure part, as in Figure NC-4243.1-1, shall not be machined from rolled plate. The component having the hub shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material, in a direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen, subsize if necessary, taken in this direction and as close to the hub as is practical.[58] In no case shall the height of the hub be less than 1.5 times the thickness of the pressure part to which it is welded.

NC-4244 Category D Weld Joints in Vessels and Branch and Piping Connection Weld Joints in Other Components

Category D weld joints in vessels and similar weld joints in other components shall be welded using one of the details of (a) through (e) below.

(a) Butt Welded Nozzles and Branch Piping Connections. Nozzles and branch piping connections shall be attached by full penetration butt welds through the wall of the component, nozzle, or branch as shown in Figure NC-4244(a)-1. Backing strips, if used, may be left in place.

(b) Corner Welded Nozzles and Branch Piping Connections. Nozzles and branch piping connections shall be joined to the component by full penetration welds through the wall of the component, nozzle, or branch similar to those shown in Figure NC-4244(b)-1. When complete joint penetration cannot be verified by visual examination or other means permitted, backing strips or equivalent shall be used with full penetration welds deposited from only one side. Backing strips, if used, may be left in place.

(c) Deposited Weld Metal of Opening for Nozzles and Branch Piping Connections. Nozzles and branch piping connections shall be joined to the component by full penetration weld to built-up weld deposits applied to the component, nozzle, or branch as shown in Figure NC-4244(c)-1. Backing strips, if used, may be left in place. Fillet welds shall be used only to provide a transition between the parts joined or to provide a seal. The fillet welds, when used, shall be finished by grinding to provide a smooth surface having a transition radius at its intersection with either part being joined.

(d) Partial Penetration Welded Nozzles and Branch Piping Connections. Partial penetration welds in components and branch piping connections, shall meet the weld design requirements of NC-3352.4(d) and NC-3359. Nozzles shall be attached as shown in Figure NC-4244(d)-1. Reinforcing plates of nozzles attached to the outside of a vessel shall be provided with at least one telltale hole, maximum size $^1/_4$ in. (6 mm) pipe tap, that may be tapped for a preliminary compressed air and soapsuds test for tightness of welds. These telltale holes may be left open or may be plugged when the vessel is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the vessel wall.

(e) Attachment of Fittings With Internal Threads.[59] Internally threaded fittings shall be attached by a full penetration groove weld or for NPS 3 (DN 80) and less, by two fillet or partial penetration welds, one on each face of the vessel wall, or by a fillet groove weld from the outside only as shown in Figure NC-4244(e)-1 sketch (c-3). Internally threaded fitting and bolting pads not exceeding NPS 3 (DN 80), as shown in Figure NC-4244(e)-2, may be attached to components having a wall thickness not greater than $^3/_8$ in. (10 mm) by a fillet weld deposited from the outside only. The design requirements of NC-3352.4(e) shall be met for all components.

NC-4245 Complete Joint Penetration Welds

Complete joint penetration is considered to be achieved when the acceptance criteria for the examinations specified by this Subsection have been met. No other examination is required to assess that complete penetration has been achieved.

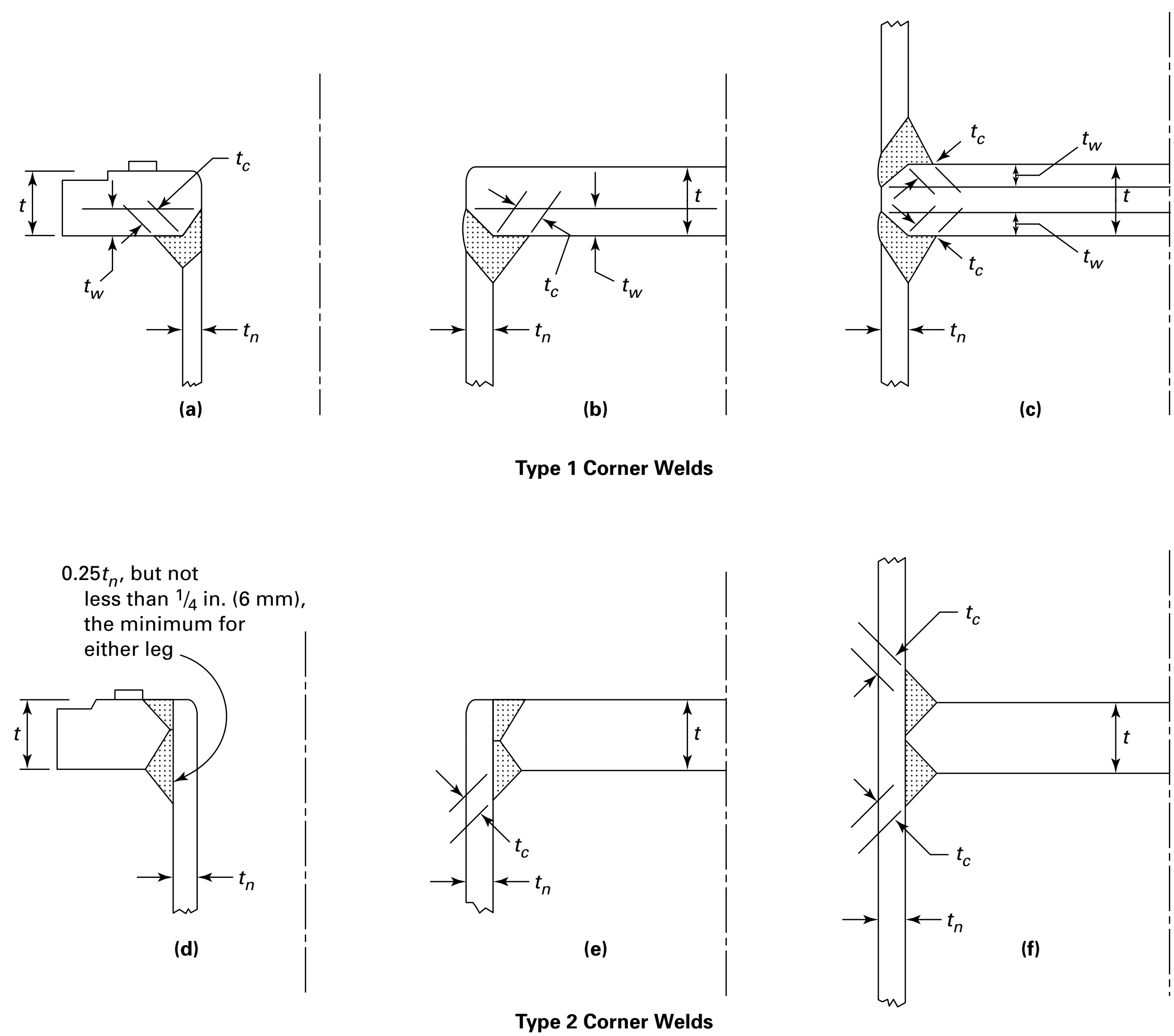
NC-4246 Atmospheric Storage Tank Special Joints

Requirements for special joints for atmospheric storage tanks are given below.

NC-4246.1 Bottom Plates. Bottoms shall be built to either one of the alternative methods of construction given in (a) and (b) below.

(a) Lap-welded bottom plates shall be reasonably rectangular and square edged. Three plate laps in tank bottoms shall not be closer than 12 in. (300 mm) from each other and also from the tank shell. Bottom plates need be welded on the top side only with a continuous full fillet weld on all seams [Figure NC-4246.1(a)-1]. The plates under the bottom ring shell connection shall have

Figure NC-4243-1
Acceptable Full Penetration Weld Details for Category C Joints



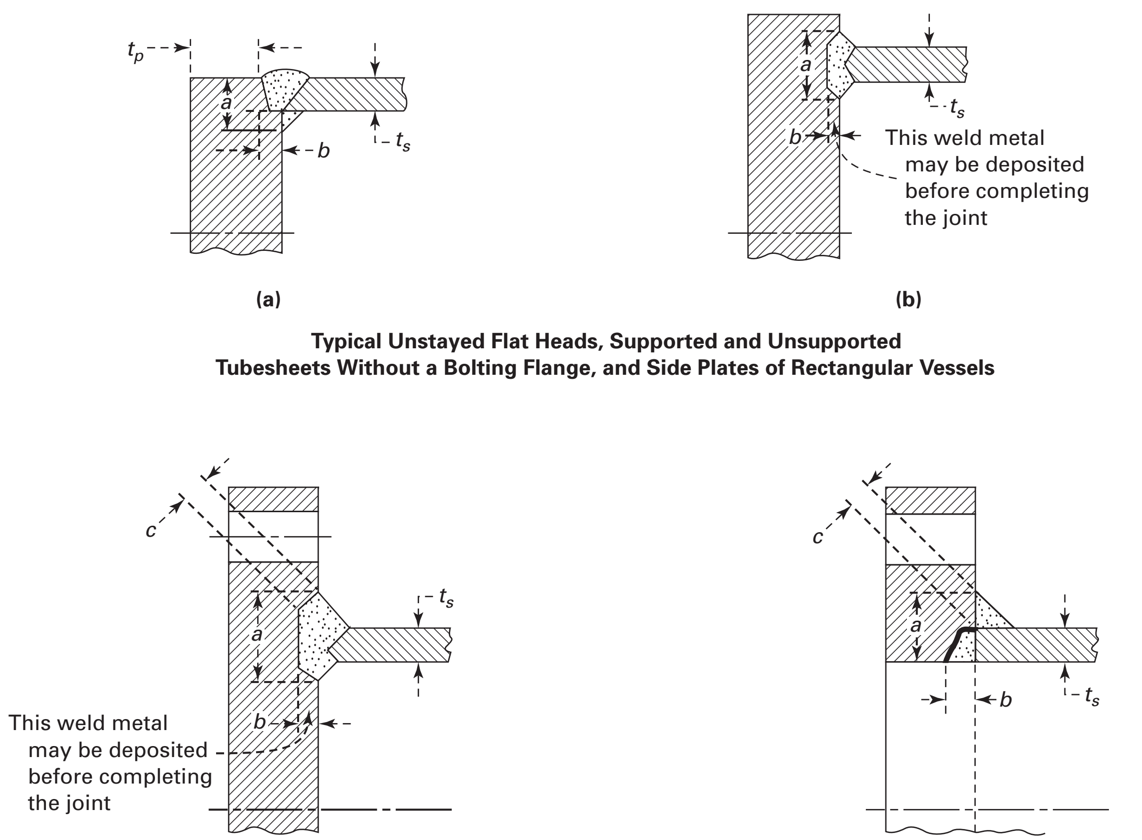
GENERAL NOTE: For definitions of nomenclature, see NC-3358.3(e)(1).

the outer ends of the joints fitted and lap welded to form a smooth bearing for the shell plates as shown in Figure NC-4246.1(a)-1.

(b) Butt welded bottom plates shall have the parallel edges prepared for butt welding with either square or V-grooves. If square grooves are employed, the root opening shall be not less than $^1/_4$ in. (6 mm). The butt welds shall be made by applying a backing strip $^1/_8$ in. (3 mm) thick or heavier by tack welding to the underside of the plate [Figure NC-4246.1(a)-1]. A metal spacer shall be used, if necessary, to maintain the root opening between the adjoining plate edges. The Certificate Holder may submit other methods of butt welding the bottom for the Owner's approval. Three plate joints in tank bottoms shall not be closer than 12 in. (300 mm) from each other and also from the tank shell.

NC-4246.2 Shell-to-Bottom Attachment. The attachment between the bottom edges of the lowest course shell plate and the bottom plate shall be a continuous full wall thickness weld with a cover fillet on each side of shell plate [Figure NC-4246.1(a)-1] or, for tanks not exceeding 35 ft (11 m) in diameter, the bottom plates may be flanged and butt welded to the bottom shell course. The flanged tank bottom plates shall be butt welded and have a thickness equal to the thickness of the bottom shell course. The inside radius of the bend shall be neither less than 1.75t nor more than 3t.

Figure NC-4243-2
Attachment of Pressure Parts to Plates to Form a Corner Joint



(c) Typical Supported and Unsupported Tubesheets With a Bolting Flange

(d) Typical Bolted Flange Connections

GENERAL NOTE: For definitions of nomenclature, see NC-3358.3(e)(2).

NC-4246.3 Roof-to-Sidewall Attachment. Roof plates shall be attached to the top angle of the tank with a continuous fillet weld on the top side only (Figure NC-4246.3-1). Roof plates of supported cone roofs shall not be attached to the supporting members. For cone roofs the fillet weld shall be $^3/_{16}$ in. (5 mm) or smaller.

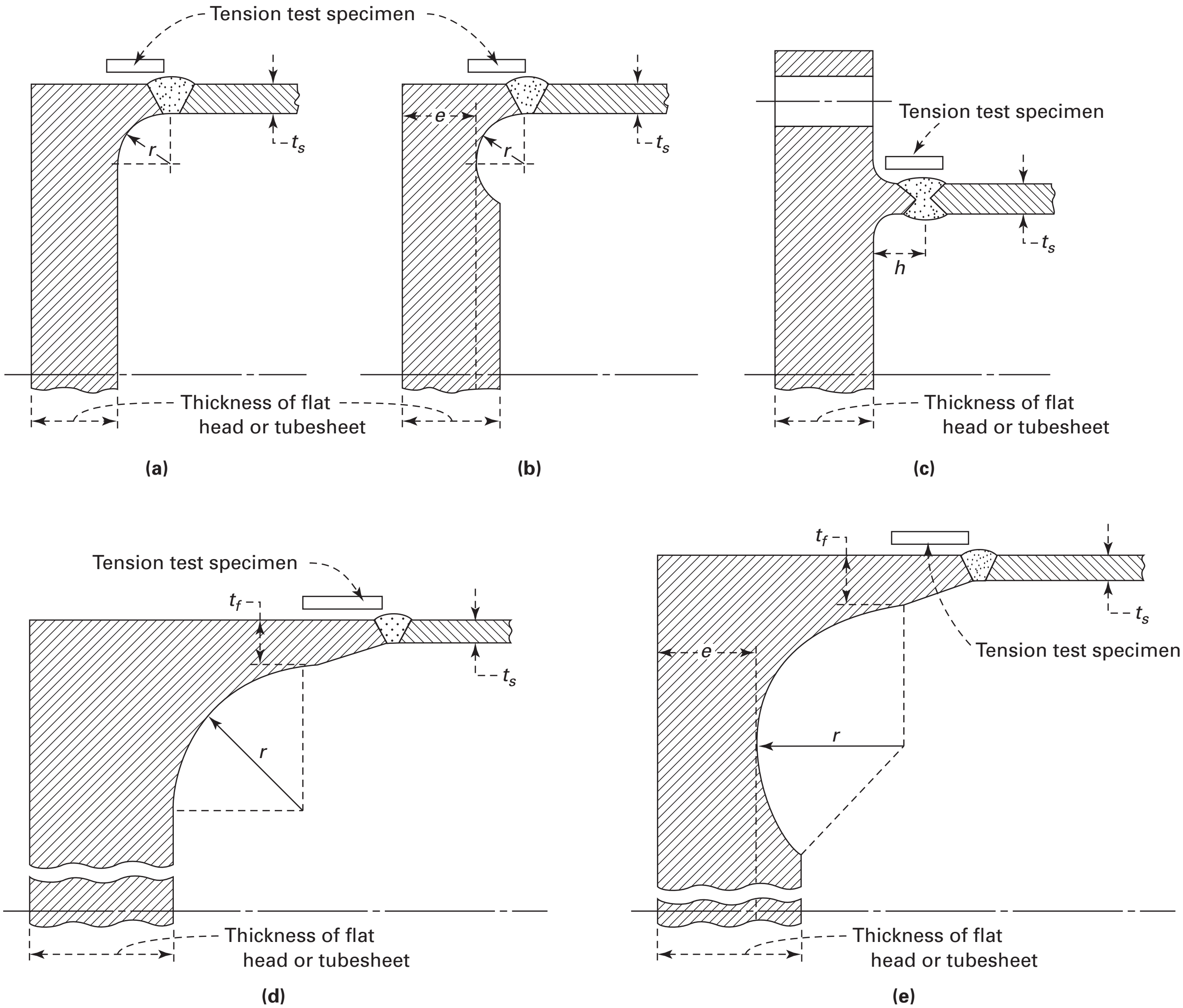
NC-4246.4 Roof Plates. Roof plates shall be attached at least by a continuous full fillet lap joint on the top side (Figure NC-4246.3-1). The top angle sections for self supporting roofs shall be joined by full penetration butt welds.

NC-4246.5 Nozzle, Manhole, and Bottom Outlet. Nozzles, manholes, and outlets shall be attached by full fillet welds as shown in Figures NC-4246.5-1 through NC-4246.5-4.

NC-4246.6 Flanges to Roof Nozzles, Manholes, and Bottom Outlets. Flanges to roof nozzles, manholes, and bottom outlets shall be attached by fillet welds as shown in Figures NC-4246.5-1, NC-4246.5-2, and NC-4246.5-4.

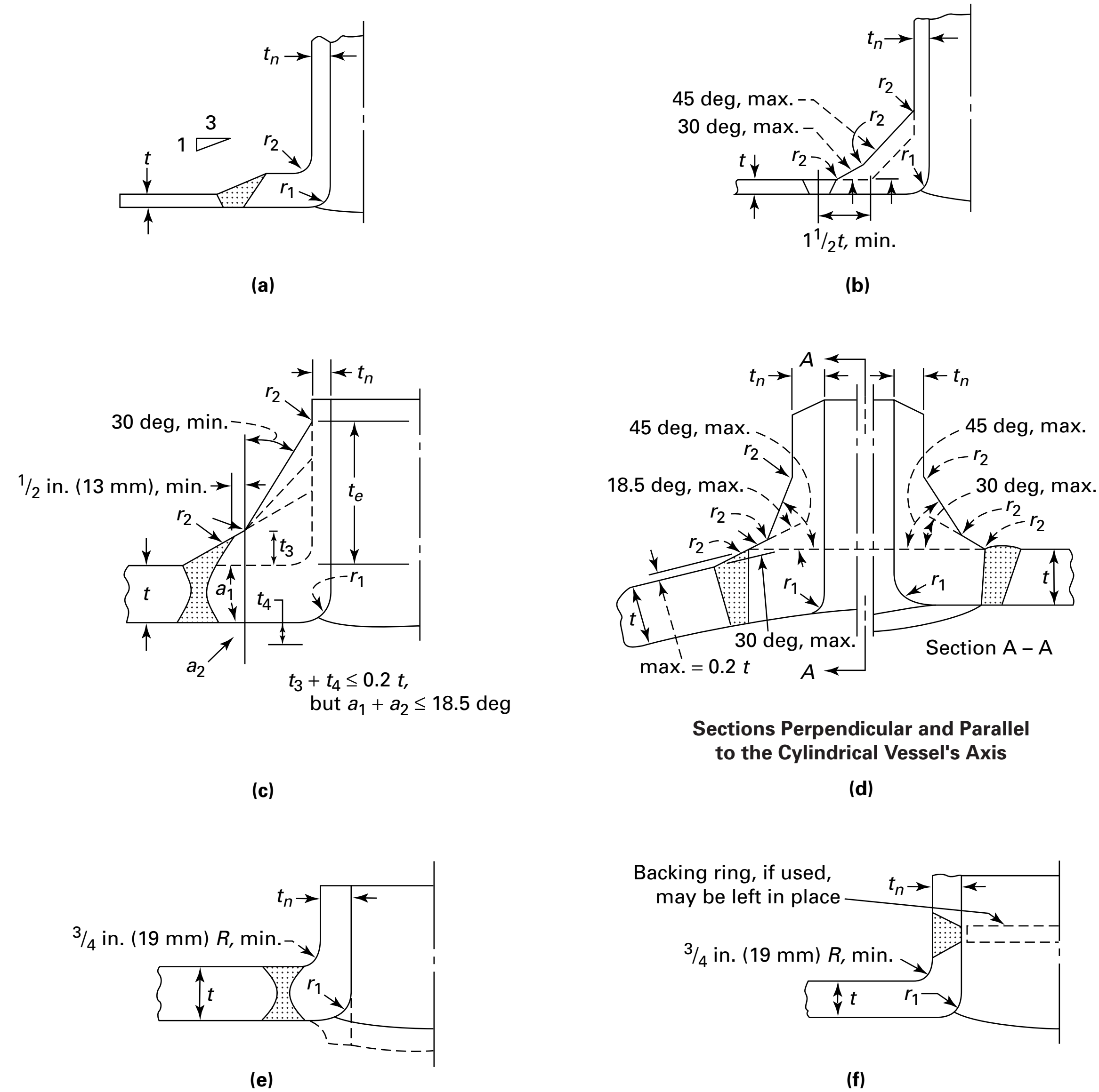
(15)

Figure NC-4243.1-1
Typical Flat Heads and Supported and Unsupported Tubesheet With Hubs



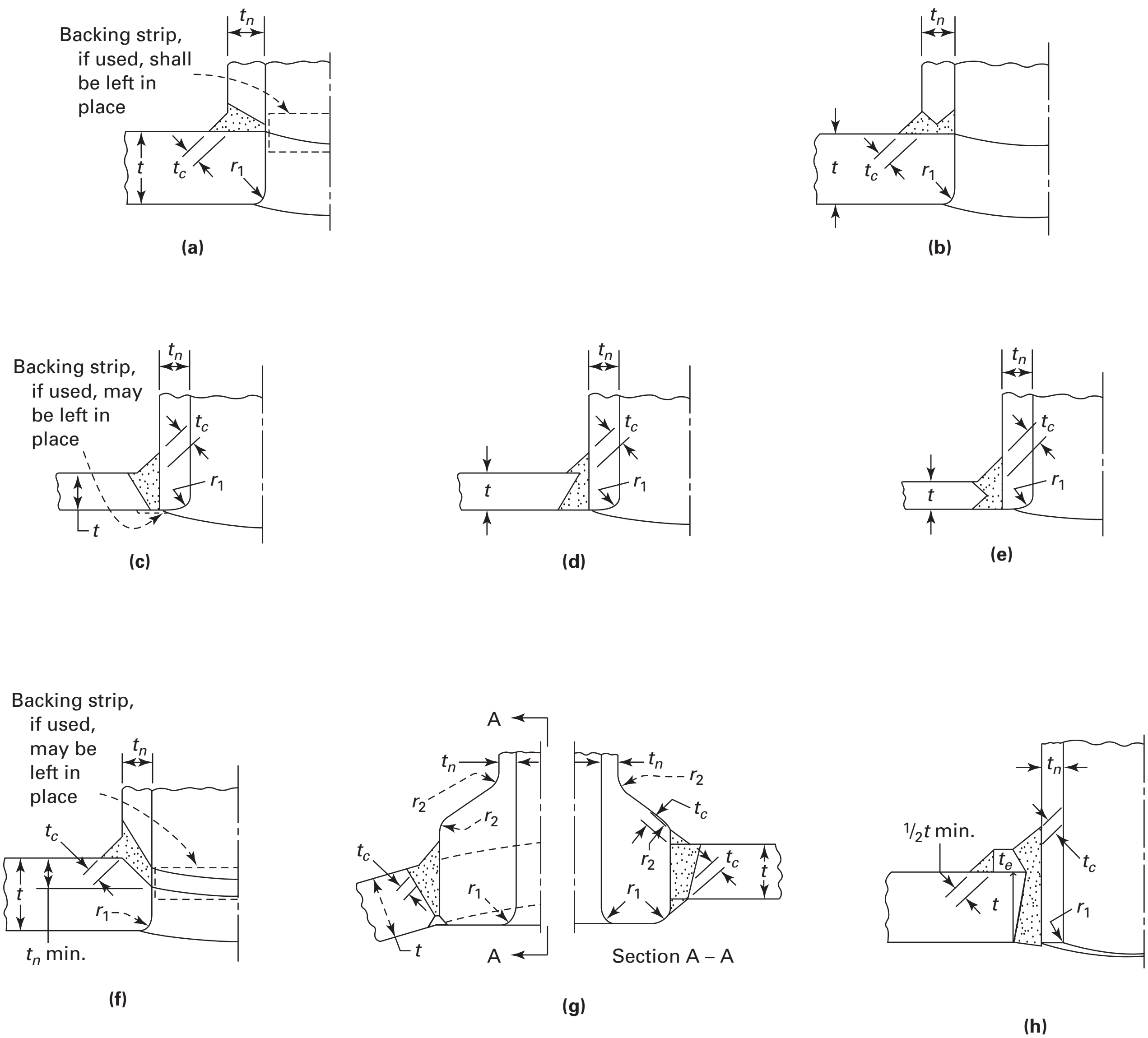
GENERAL NOTES:
(a) For definitions of nomenclature, see NC-3358.4.
(b) Not permissible if machined from rolled plate. The tension test specimen may be located, when possible, inside the forged hub, instead of outside, as shown.

Figure NC-4244(a)-1
Nozzles, Branch, and Piping Connections Joined by Full Penetration Butt Welds



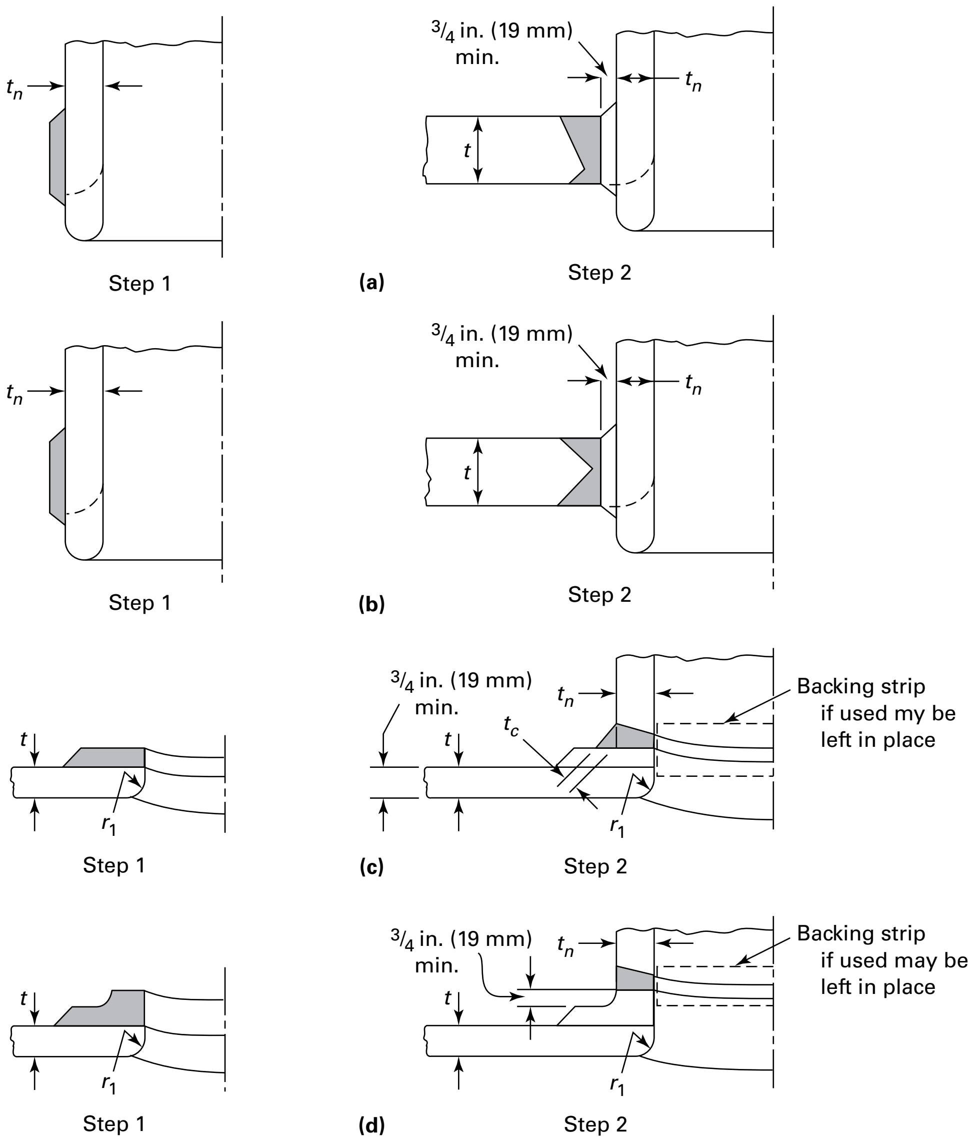
GENERAL NOTE: For definition of symbols, see NC-3352.4(a).

Figure NC-4244(b)-1
Nozzles, Branch, and Piping Connections Joined by Full Penetration Corner Welds



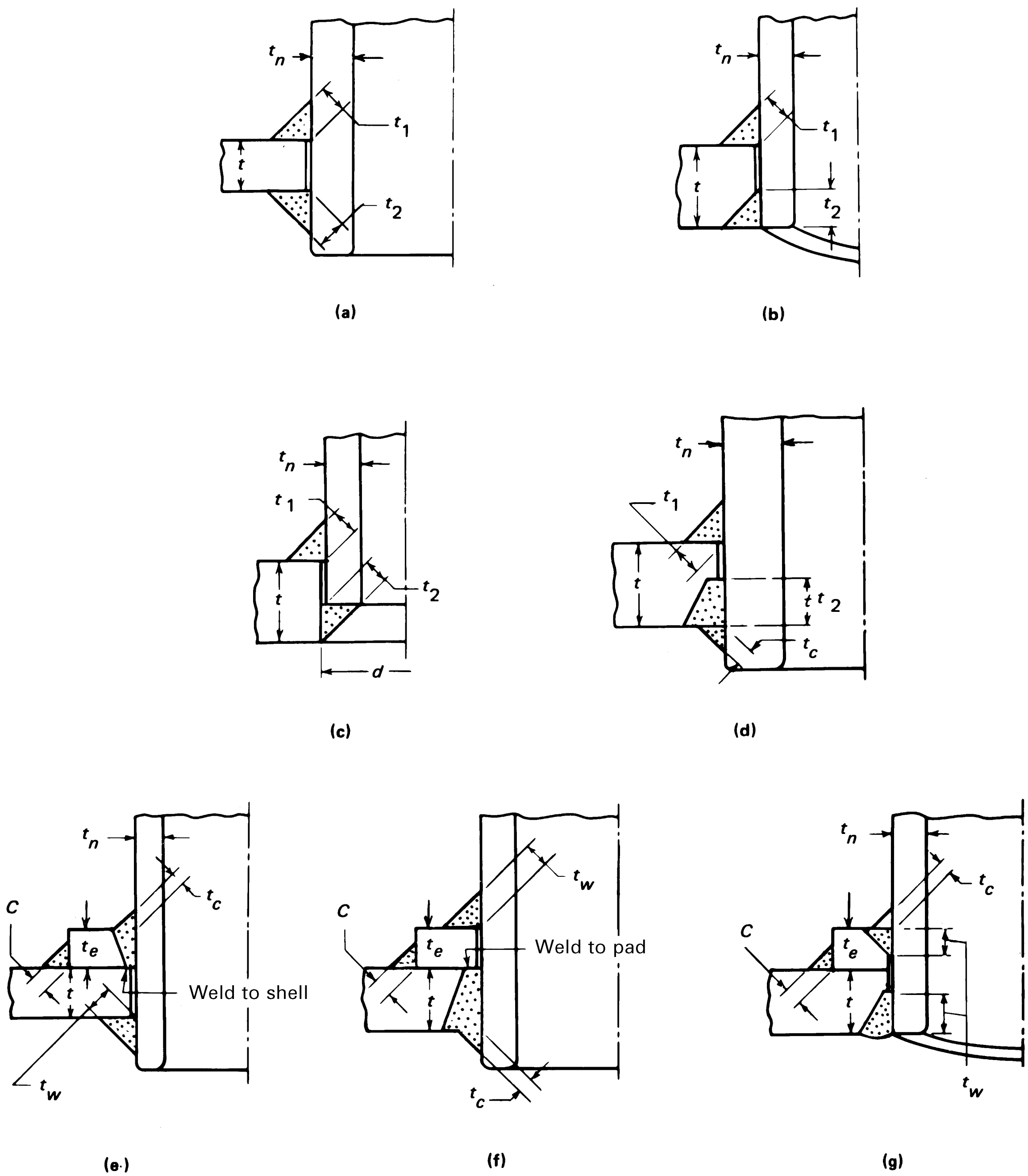
GENERAL NOTE: For definition of symbols, see NC-3352.4(b).

Figure NC-4244(c)-1
Deposited Weld Metal Used as Reinforcement of Openings for Nozzles, Branch, and Piping Connections



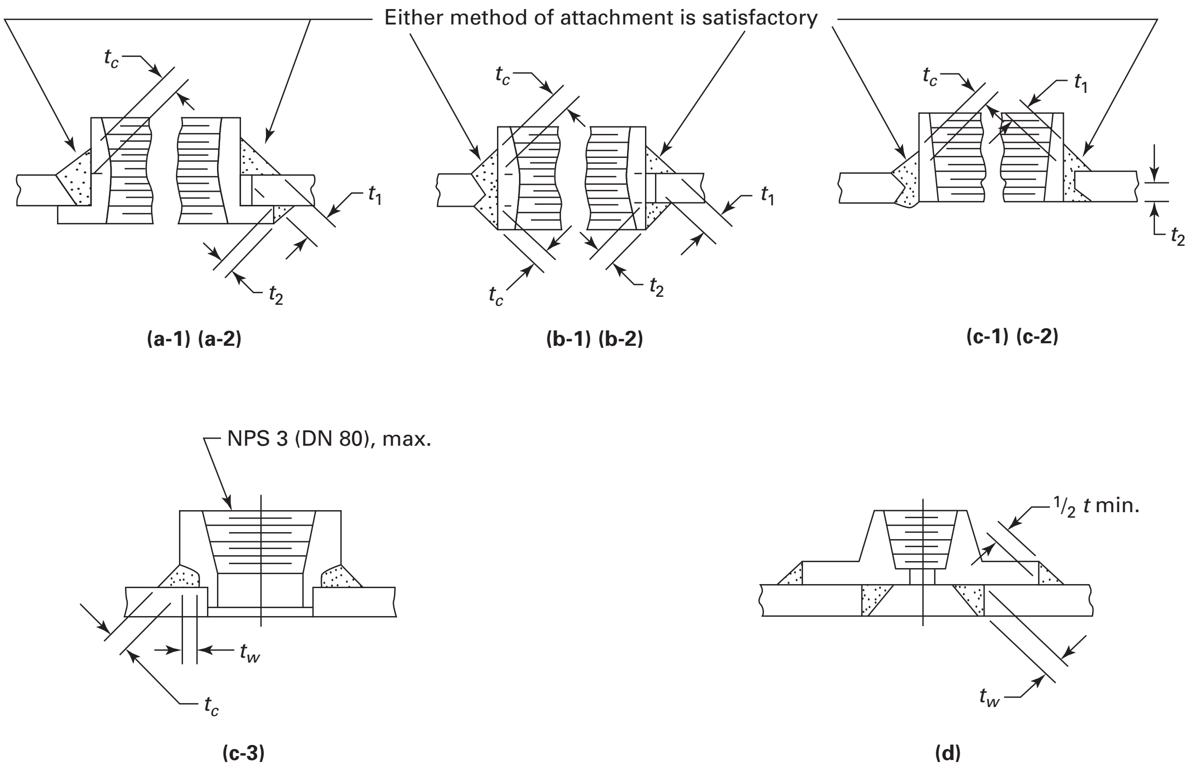
GENERAL NOTE: For definition of symbols, see NC-3352.4(c).

Figure NC-4244(d)-1
Some Acceptable Types of Welded Nozzles, Branch, and Piping Connections



GENERAL NOTE: For definition of symbols, see NC-3352.4(d).

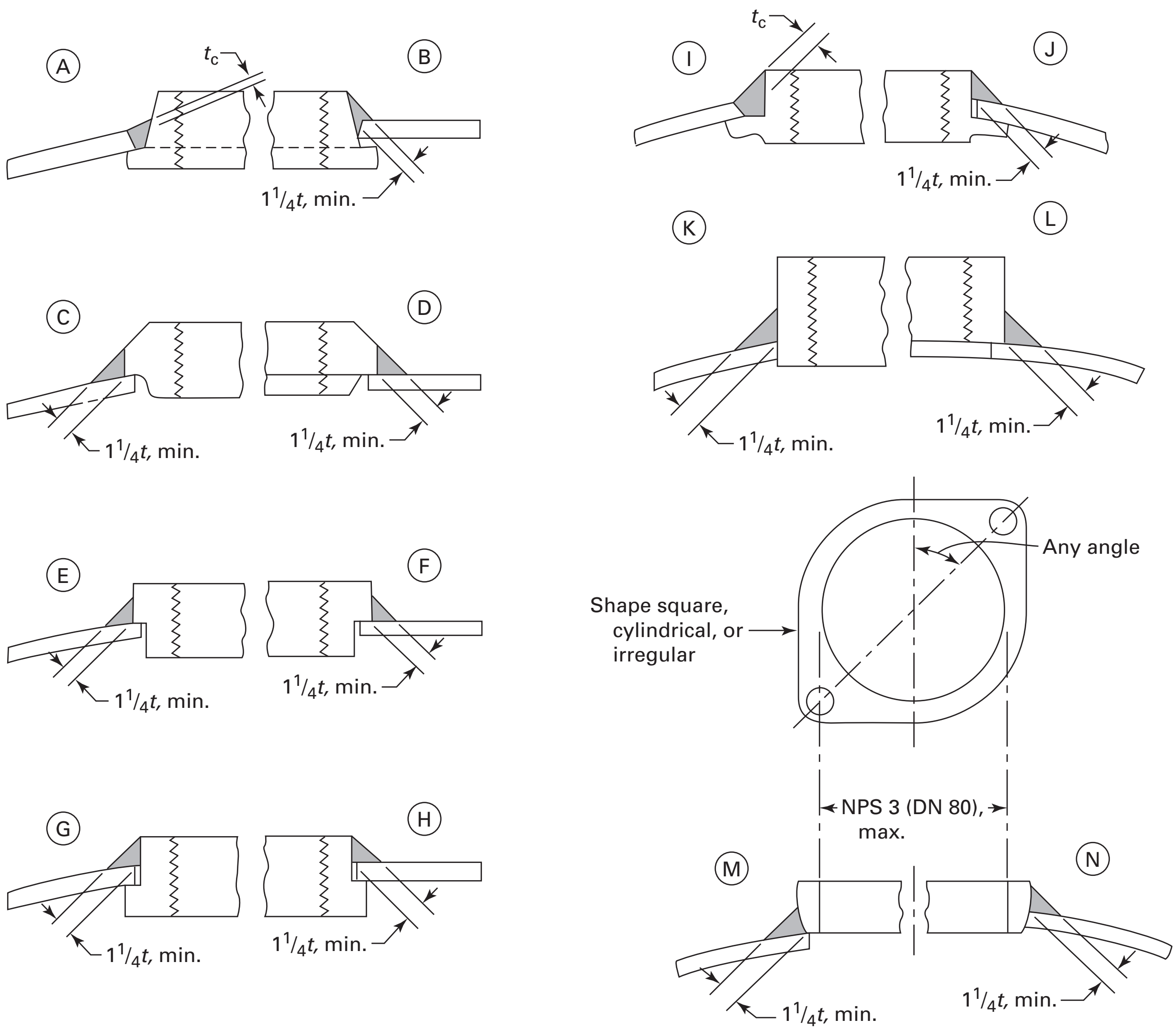
Figure NC-4244(e)-1
Some Acceptable Types of Welded Nozzles



GENERAL NOTE: For definition of symbols, see NC-3352.4(e).

(15)

Figure NC-4244(e)-2
Some Acceptable Types of Small Fittings



GENERAL NOTES:

(a) For definitions of nomenclature, see NC-3352.4(e).
(b) Maximum shell thickness = $^3/_8$ in. (10 mm).
(c) Maximum internal thread diameter = $3^1/_2$ in. (89 mm).
(d) Maximum dimension of opening in shell = no greater than $5^3/_8$ in. (135 mm) or 0.5 × shell diameter.

Figure NC-4246.1(a)-1
Typical Bottom and Bottom-to-Shell Joints

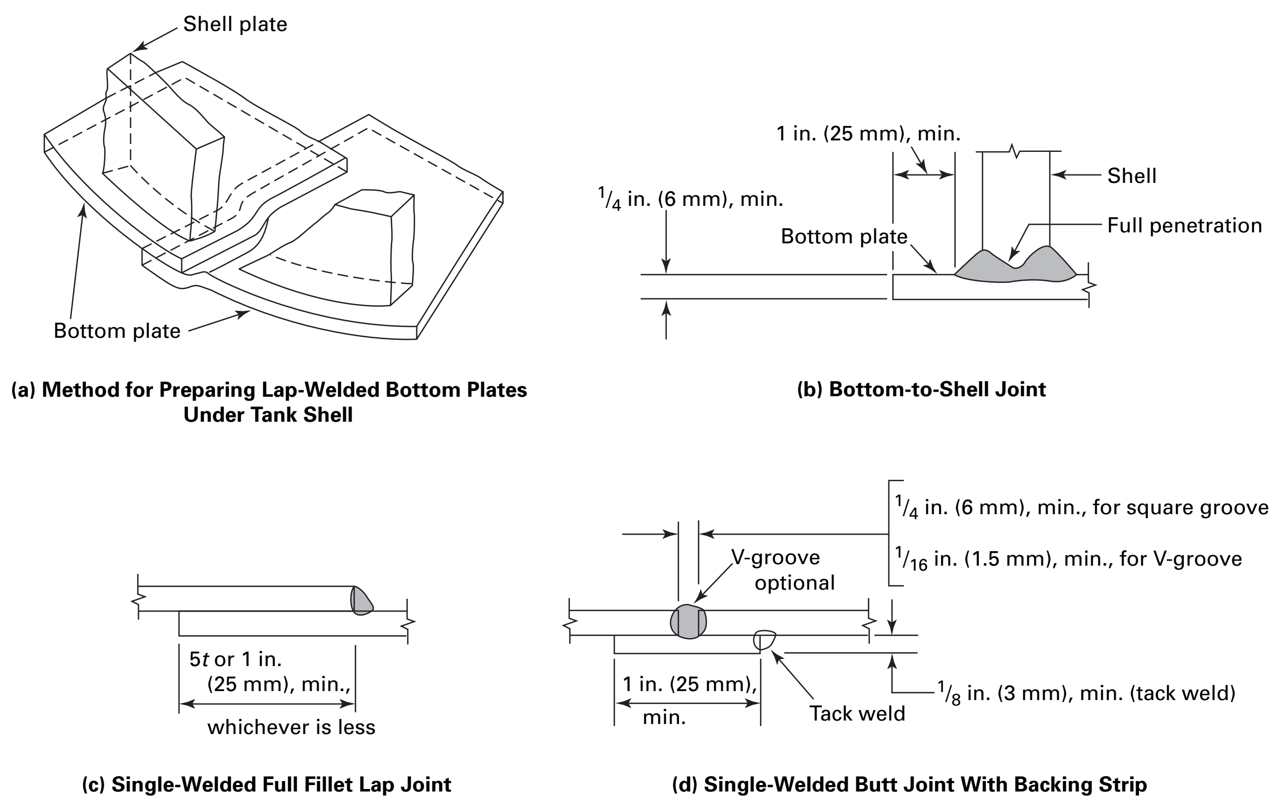
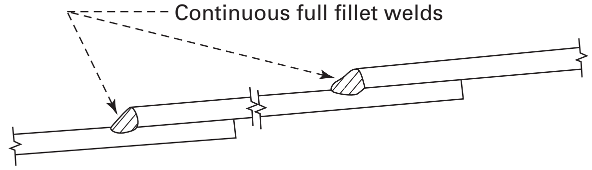
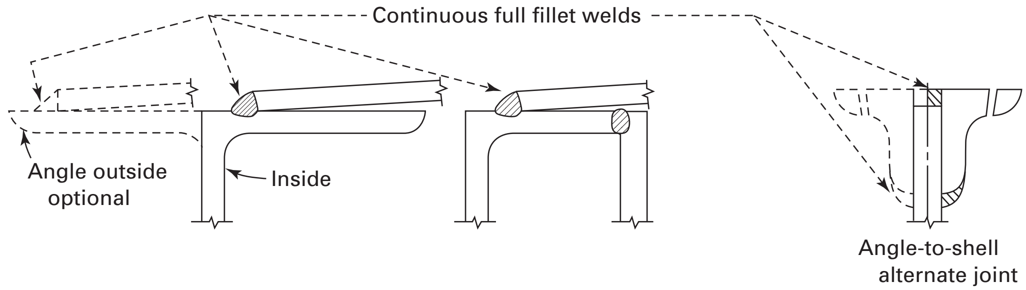


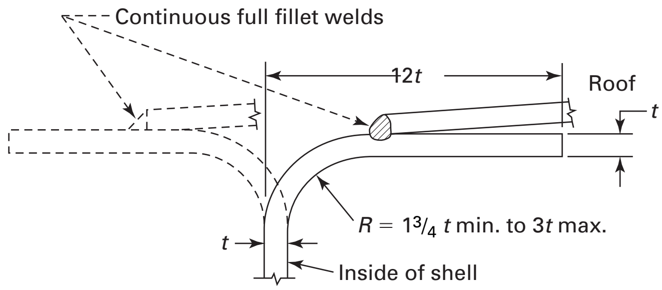
Figure NC-4246.3-1
Typical Roof and Roof-to-Shell Joints



(a) Roof Plate Joint

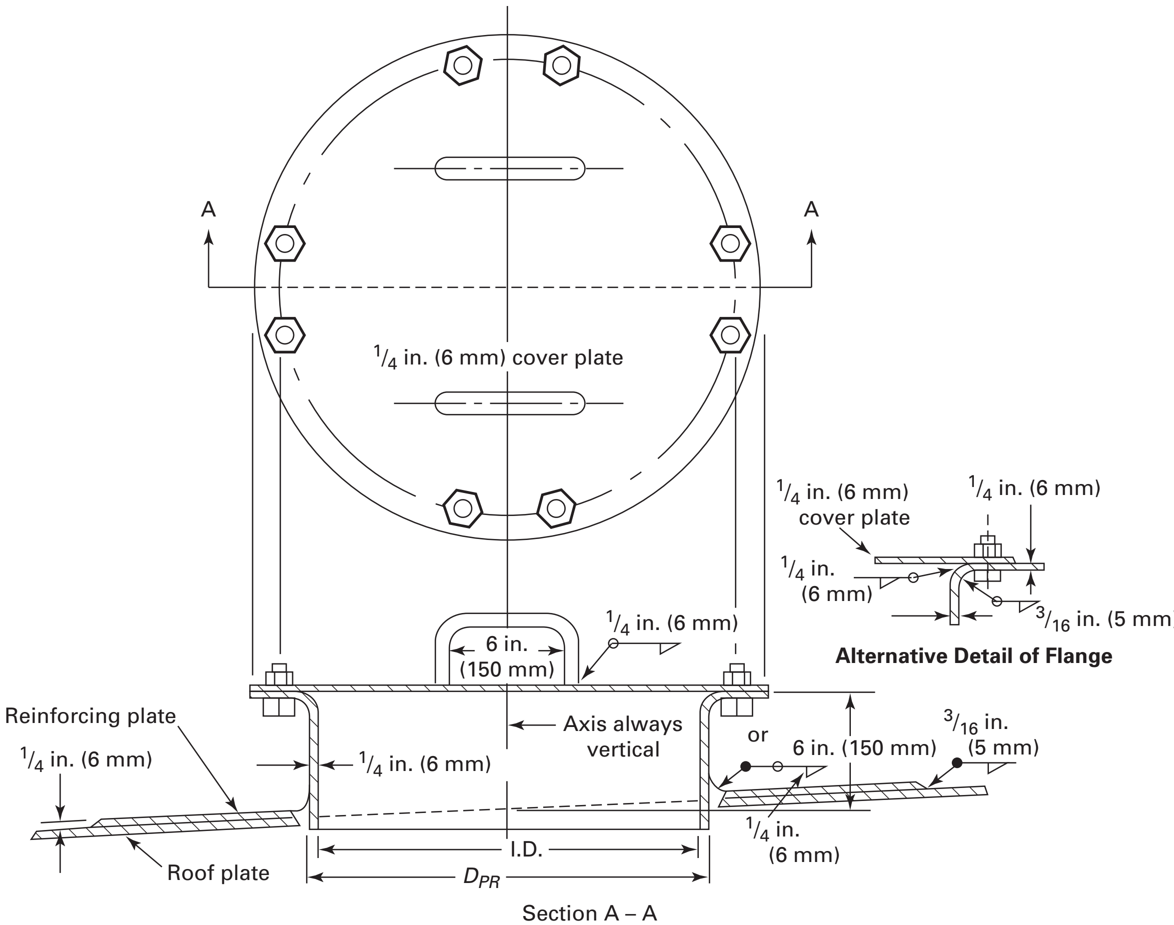


(b) Roof-to-Shell Joints

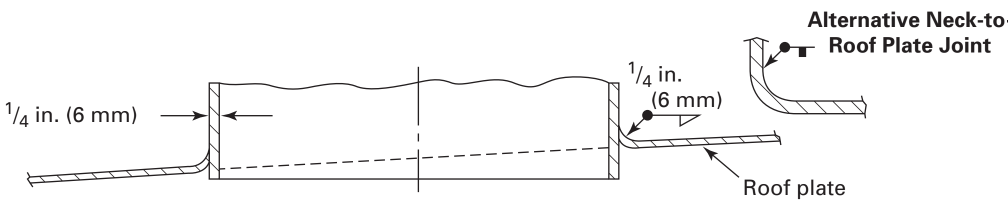


(c) Alternate Roof-to-Shell Joint [Subject to Limitations of NC-3843(c)]

Figure NC-4246.5-1
Roof Manholes

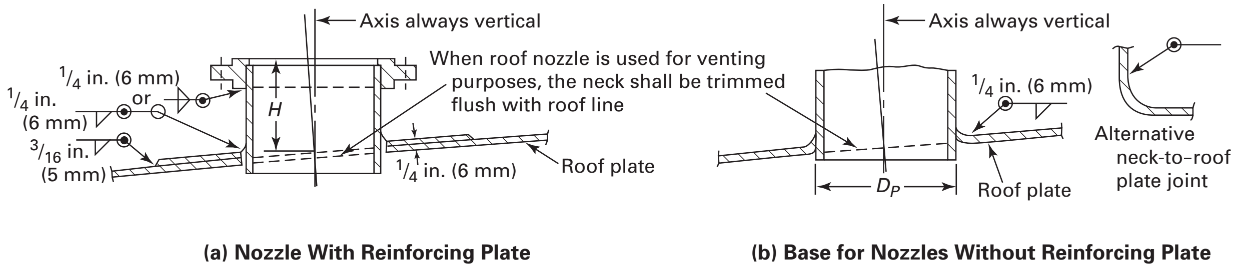


(a) Roof Manhole With Reinforcing Plate



(b) Base for Roof Manhole Without Reinforcing Plate

Figure NC-4246.5-2
Flanged Roof Nozzles



GENERAL NOTES:
(a) Slip-on welding and welding neck flanges shall conform to the requirements for 150 lb forged carbon steel raised face flanges as given in ASME B16.5.
(b) Plate ring flanges shall conform to all dimensional requirements for slip-on welding flanges, except that the extended hub on the back of the flange may be omitted.

NC-4246.7 Special Requirements. Special weld requirements for storage tanks are given in (a) through (d) below.

(a) The minimum size of fillet welds shall be as follows: plates $^3/_{16}$ in. (5 mm) thick, full fillet welds; plates over $^3/_{16}$ in. (5 mm) thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of $^3/_{16}$ in. (5 mm).

(b) Lap-welded joints, as tack welded, shall be lapped not less than five times the nominal thickness of the thinner plate joined; but in the case of double welded lap joints the lap need not exceed 2 in. (50 mm), and in the case of single-welded lap joints the lap need not exceed 1 in. (25 mm).

(c) For plates over $^1/_2$ in. (13 mm) thick in the sidewalls, roof, or bottom of the tank, if the thickness of two adjacent plates which are to be butt welded together differs more than $^1/_8$ in. (3 mm), the thicker plate shall be trimmed to a smooth taper extending for a distance at least three times the offset between the abutting surfaces so that the adjoining edges will be approximately the same thickness (Figure NC-3361-1). The length of the required taper may include the width of the weld.

(d) Top angle sections for self-supporting roofs shall be joined by full penetration butt welds.

NC-4246.8 Other Weld Joints. The fabrication requirements for weld joints not specifically covered by NC-4246, such as sidewall weld joints and nozzle-to-flange weld joints, are the same as given in NC-4240 for Category A, B, and C weld joints for vessels.

NC-4247 Zero psi to 15 psi (0 kPa to 100 kPa) Storage Tank Special Joints

Requirements for special joints for 0 psi to 15 psi (0 kPa to 100 kPa) storage tanks are given below.

NC-4247.1 Bottoms. All welds in flat bottoms supported directly on foundations shall be single full fillet lap joints as a minimum. For other bottoms, all welds shall be butt welds.

Figure NC-4246.5-3
Screwed or Socket Weld Roof Nozzles

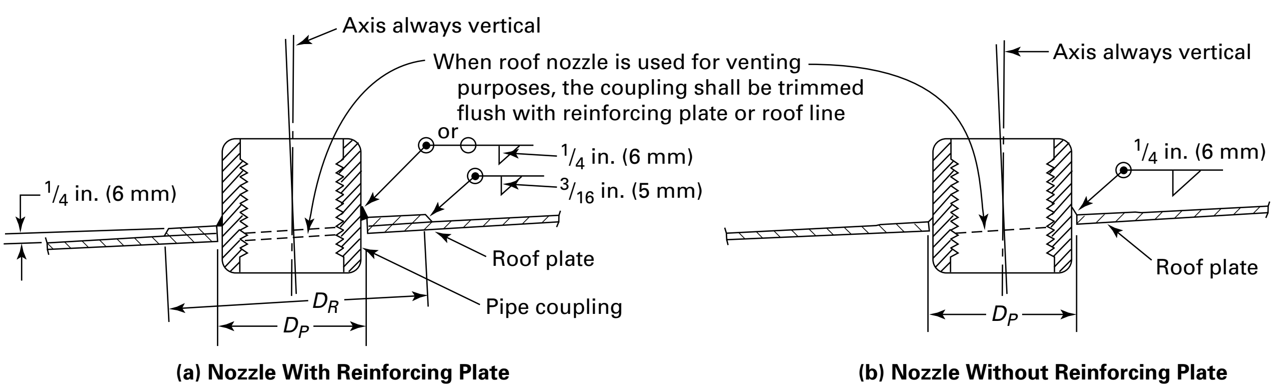
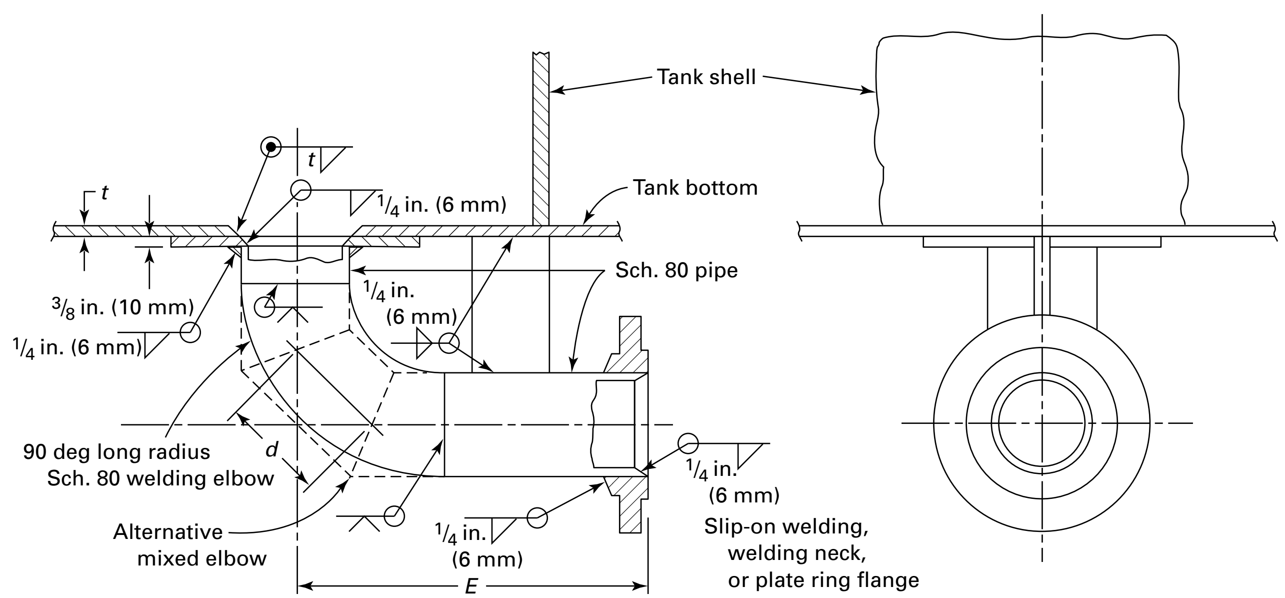


Figure NC-4246.5-4
Welded Bottom Outlet Elbow



NC-4247.2 Bottom-to-Sidewall. All welds shall meet the design requirements of NC-3933. Flat bottoms shall be attached to sidewalls by full penetration welds and fillet welds on each side as a minimum.

NC-4247.3 Roof-to-Sidewall. Roof-to-sidewall joints shall be in accordance with the design requirements of NC-3933. The joints shall have continuous full fillet welds as a minimum.

NC-4247.4 Roofs. Roofs shall be in accordance with the design requirements of NC-3933 and shall meet the requirements of NC-4241.

NC-4247.5 Nozzles. Nozzle welds shall meet the requirements of NC-4244.

NC-4247.6 Special Requirements. Special weld requirements for storage tanks are given in (a) through (d) below.

(a) The minimum size of fillet welds. shall be as follows: plates $^3/_{16}$ in. (5 mm) thick, full fillet welds; plates over $^3/_{16}$ in. (5 mm) thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of $^3/_{16}$ in. (5 mm).

(b) Lap-welded joints, as tack welded, shall be lapped not less than five times the nominal thickness of the thinner plate joined; but in the case of double welded lap joints the lap need not exceed 2 in. (50 mm), and in the case of single-welded lap joints the lap need not exceed 1 in. (25 mm).

(c) For plates over $^1/_2$ in. (13 mm) thick in the sidewalls, roof, or bottom of the tank, if the thickness of two adjacent plates which are to be butt welded together differs more than $^1/_8$ in. (3 mm), the thicker plate shall be trimmed to a smooth taper extending for a distance at least three times the offset between the abutting surfaces so that the adjoining edges will be approximately the same thickness (Figure NC-3361-1). The length of the required taper may include the width of the weld.

(d) The size of any weld along either edge of a compression ring shall not be less than the thickness of the thinner of the two parts joined or $^1/_4$ in. (6 mm), whichever is less, nor shall the size of the corner welds between the shell and a girder bar, such as shown in Figure NC-3933.5(d)-1 sketches (d) and (e), or between the horizontal and vertical members of a compression ring assembly, such as shown in sketches (f) and (i), be less than the applicable value specified in Table NC-4247.6(d)-1.

Table NC-4247.6(d)-1
Minimum Size for Fillet Welds

Thickness of the Thicker of the Two Parts Joined, in. (mm)	Minimum Size of Fillet Weld, in. (mm)
Not over $^1/_4$ (6)	$^3/_{16}$ (5)
Over $^1/_4$ through $^3/_4$ (6 through 19)	$^1/_4$ (6)
Over $^3/_4$ through $1^1/_4$ (19 through 32)	$^5/_{16}$ (8)
Over $1^1/_4$ (32)	$^3/_8$ (10)

NC-4247.7 Other Weld Joints. The fabrication requirements for weld joints not specifically covered by NC-4247, such as sidewall weld joints and nozzle-to-flange weld joints, are the same as given in NC-4240 for Category A, B, and C weld joints for vessels.

NC-4250 WELDING END TRANSITIONS — MAXIMUM ENVELOPE

The welding ends of items or fittings shall provide a gradual change in thickness from the item or fitting to the adjoining item. Any welding end transition which lies entirely within the envelope shown in Figure NC-4250-1 is acceptable, provided that:

(a) the wall thickness in the transition region is not less than the min. wall thickness of the adjoining pipe; and

(b) sharp reentrant angles and abrupt changes in slope in the transition region are avoided. When the included angle between any two adjoining surfaces of a taper transition is less than 150 deg, the intersection or corner (except for the weld reinforcement) shall be provided with a radius of at least $0.05t_{min}$.

NC-4260 SPECIAL REQUIREMENTS FOR WELD JOINTS IN VESSELS DESIGNED TO NC-3200

NC-4261 General

Except for NC-4240, all other requirements of Article NC-4000 apply. The requirements of NC-4260 are to be used instead of those in NC-4240.

NC-4262 Description and Limitations of Joint Types

The description of the joint types are as follows.

(a) Type No. 1 Butt Joints. Type No. 1 butt joints are those produced by double welding or by other means which produce the same quality of deposited weld metal on both inside and outside weld surfaces. Welds using backing strips which remain in place do not qualify as Type No. 1 butt joints. Type No. 1 butt joints shall have complete joint penetration and full fusion and shall meet the requirements of NC-4424 and NC-4426.

(b) Type No. 2 Butt Joints. Type No. 2 butt joints are single-welded butt joints having backing strips which remain in place. NC-3252.2 gives stress concentration factors to be applied to Type No. 2 joints when a fatigue analysis is required. When Type No. 2 butt joints are used, care shall be taken on aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joints for their full length. However, weld reinforcement need be supplied only on the side opposite the backing strip. The requirements of NC-4424 and NC-4426 shall be met.

(c) Full Penetration Corner Joints. Corner joints are those connecting two members approximately at right angles to each other in the form of an *L* or *T* and shall be made with full penetration welds.

(d) Fillet Welded Joints. Fillet welded joints, permitted by the rules of this subarticle, are those of approximately triangular cross section, joining two surfaces at approximately right angles to each other and having a throat dimension at least 70% of the smaller thickness of the parts being joined but not less than $^1/_4$ in. (6 mm).

NC-4263 Category A Weld Joints

Category A weld joints shall be Type No. 1 butt joints.

NC-4264 Category B Weld Joints

Category B weld joints shall be Type No. 1 or Type No. 2 butt joints. Backing strips shall be removed from Type No. 2 joints unless access conditions prevent their removal. Backing strips shall be continuous, and any splices shall be butt welded. Circumferential single-welded butt joints with one plate offset to form a backing strip are prohibited.

NC-4265 Category C Weld Joints

Category C weld joints shall be Type No. 1 butt joints or full penetration corner joints. Welds in full penetration corner joints shall be groove welds extending completely through at least one of the parts being joined and shall be fully fused to each part. Typical details are shown in Figures NC-4265-1 and NC-4265-2.

NC-4265.1 Flat Heads and Tubesheets With Hubs.

(a) Hubs for butt welding to the adjacent shell, head, or other pressure parts, as shown in Figure NC-4243.1-1 for flat heads, shall not be machined from flat plate. The hubs shall be forged in such a manner as to provide in the hub the full minimum tensile strength and elongation specified for the material in the direction parallel to the axis of the vessel. Proof of this shall be furnished by a tension test specimen (subsize, if necessary) taken in this direction and as close to the hub as is practical.[58] The minimum height of the hub shall be the lesser of $1^1/_2$ times the thickness of the pressure part to which it is welded or $^3/_4$ in. (19 mm), but need not be greater than 2 in. (50 mm).

(b) Hubbed flanges, as shown in Section III Appendices, Mandatory Appendix XI, Figure XI-3120-1 sketches (6), (6a), and (6b), shall not be machined from flat plate.

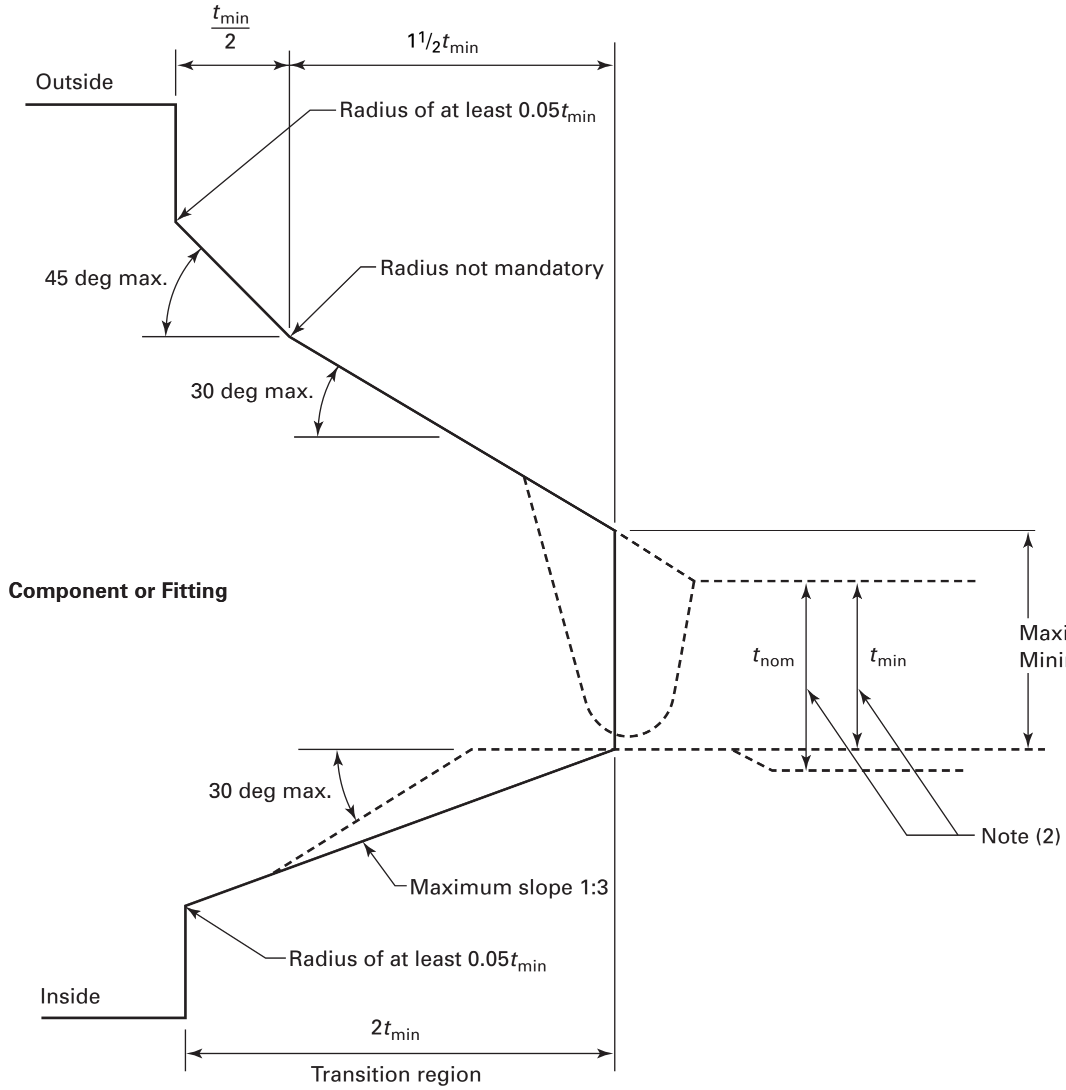
NC-4266 Category D Weld Joints (15)

Category D and similar weld joints shall be welded using one of the details of (a) through (d) below.

(a) Butt Welded Attachments. Nozzles shall be attached by Type No. 1 butt welds through either the vessel or the nozzle wall as shown in Figure NC-4266(a)-1.

(b) Full Penetration Corner Welded Attachment. Nozzles shall be attached by full penetration welds through the wall of the vessel or nozzle as shown in Figure NC-4266(b)-1. The welds shall be groove welds extending completely through at least one of the parts being joined and shall be fully fused to each part. Backing strips shall

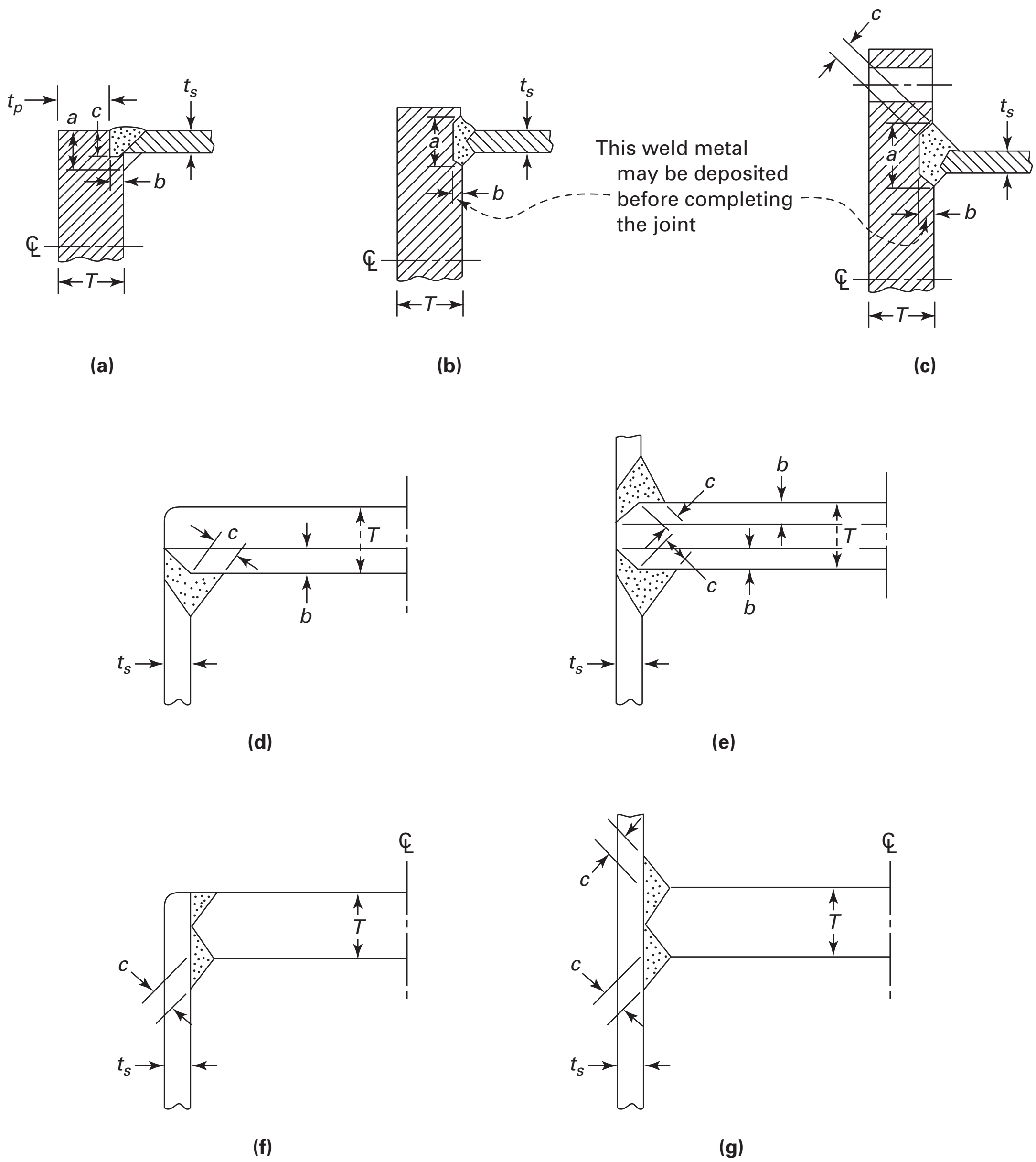
Figure NC-4250-1
Welding End Transitions Maximum Envelope



GENERAL NOTES:
(a) Weld bevel is shown for illustration only.
(b) The weld reinforcement permitted by NC-4426 may lie outside the maximum envelope.

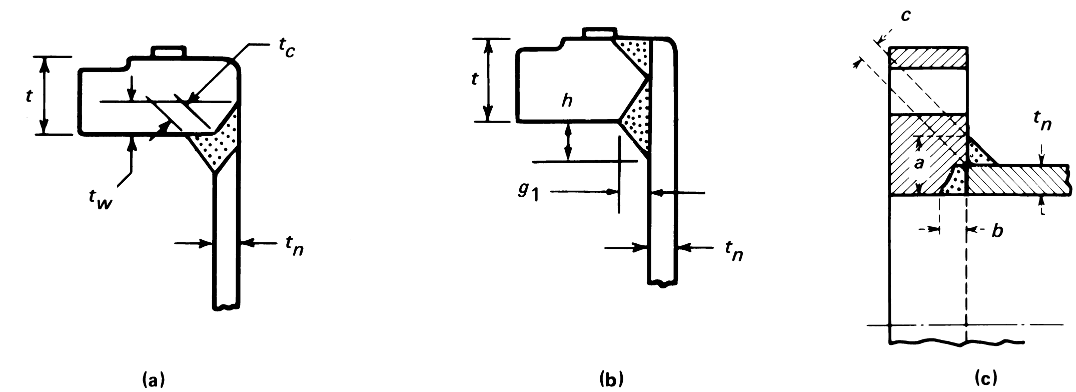
NOTES:
(1) The maximum thickness at the end of the component is:
(a) the greater of t_{min} + 0.15 in. (3.8 mm) or $1.15t_{min}$ when ordered on a minimum wall basis;
(b) the greater of t_{min} + 0.15 in. (3.8 mm) or 1.0 t_{nom} when ordered on a nominal wall basis.
(2) The value of t_{min} is whichever of the following is applicable:
(a) the minimum ordered wall thickness of the pipe;
(b) 0.875 times the nominal wall thickness of pipe ordered to a pipe schedule wall thickness that has an under tolerance of 12.5%;
(c) the minimum ordered wall thickness of the cylindrical welding end of a component or fitting (or the thinner of the two) when the joint is between two components.

Figure NC-4265-1
Acceptable Full Penetration Details to Form a Corner Joint



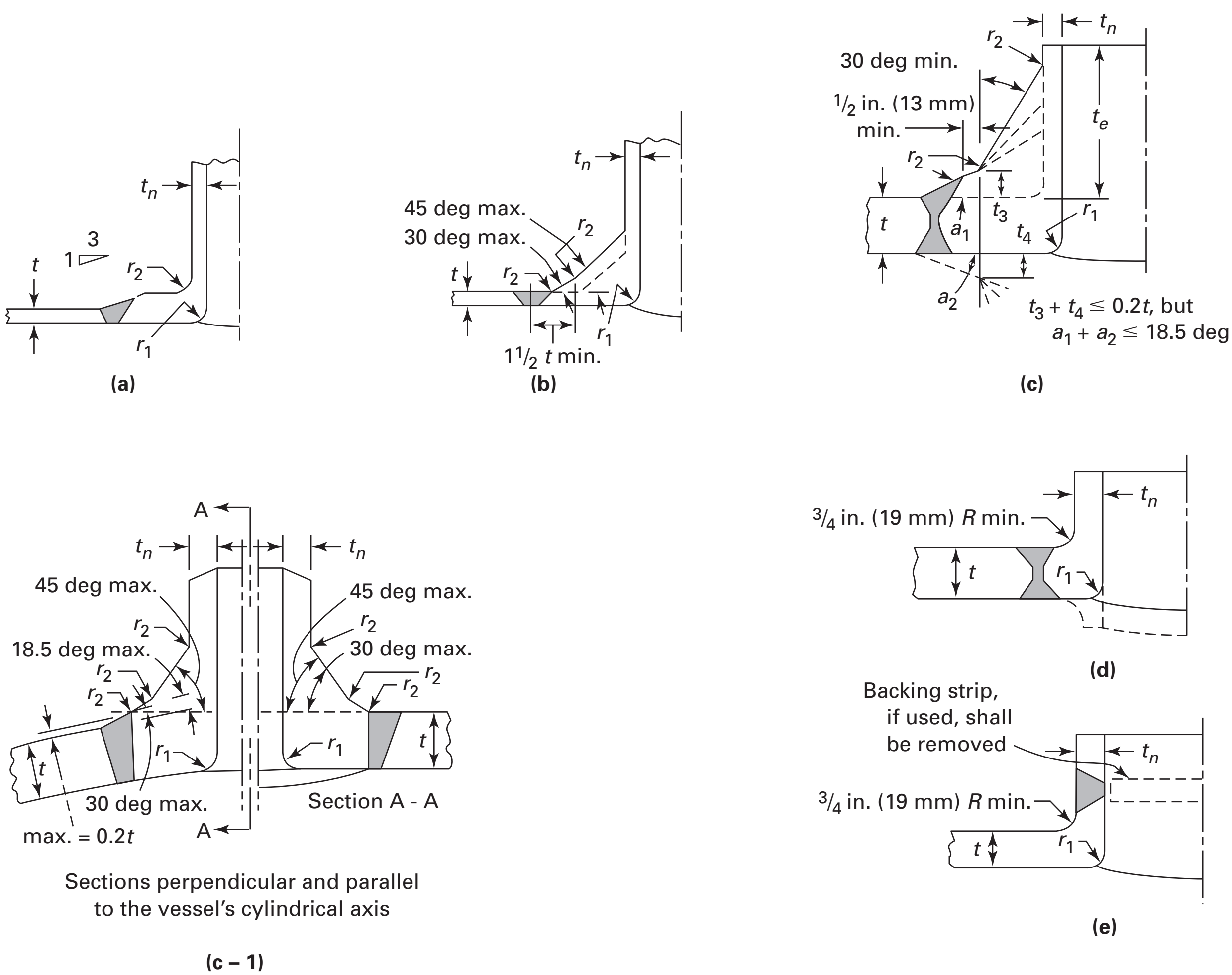
GENERAL NOTES:
(a) For definitions of nomenclature for illustrations (a) through (c), see NC-3358.3(e)(2).
(b) For definitions of nomenclature for illustrations (d) through (g), see NC-3358.3(e)(1).

Figure NC-4265-2
Acceptable Full Penetration Weld Details for Category C Joints



(15)

Figure NC-4266(a)-1
Nozzles Attached by Full Penetration Butt Welds



be used with welds deposited from only one side or when complete joint penetration cannot be verified by visual inspection. Backing strips, when used, shall be removed after welding.

(c) Pad and Screwed Fitting Types of Welded Nozzles

(1) Inserted Nozzle Necks With Added Reinforcement. Inserted type necks having added reinforcement in the form of one or more separate reinforcing plates shall be attached by welds at the outer edge of the reinforcement plate and at the nozzle neck periphery. The weld at the outer edge of the reinforcement shall be a fillet weld with a minimum throat dimension of the smaller of $0.7t_e$ or $0.7t$. The welds attaching the neck to the vessel wall and to the reinforcement shall be full penetration groove welds. Permissible types of weld attachments are shown in Figure NC-4266(c)-1 sketches (a), (b), and (c).

(2) Studded Connections

(-a) Studded connections, which may have externally imposed loads, shall have tapped holes complying with the requirements of NC-3262.4. The vessel or integral weld buildup shall have a flat surface machined on the shell to receive the connection. Drilled holes to be tapped shall not penetrate within one-fourth of the wall thickness from the inside surface of the vessel after deducting corrosion allowance unless at least the minimum thickness required as above is maintained by adding metal to the inside surface of the vessel.

(-b) Studded pad-type connections may be used for connections on which there are essentially no external mechanical loads, such as manways and handholes used only as inspection openings or thermowell connections, provided the requirements of NC-3237 are met. The pad shall be attached by a fillet weld along the outer edge and a single bevel weld along the inner edge. Permissible type of weld attachment is shown in Figure NC-4266(c)-1 sketch (d). The tapped holes for stud threads shall comply with NC-3262.4.

(3) Fittings With Internal Threads. Internally threaded fittings shall be limited to NPS 2 (DN 50). They shall be attached by means of full penetration groove welds as illustrated in Figure NC-4266(c)-1 sketches (e), (f), and (g), except pad type fittings, such as shown in sketch (h), which may be used if attached by means of fillet welds having a minimum throat dimension of the smaller of $0.7t_e$ or $0.7t$, as shown in sketch (h).

(d) Attachment of Nozzles Using Partial Penetration Welds. Partial penetration welds are limited by the restrictions of NC-3252.4(d). The weld size shall be such that the depth of penetration t_w will be at least $1\frac{1}{4}t_n$. Typical details are shown in Figure NC-4266(d)-1.

NC-4267 Types of Attachment Welds

Lugs, brackets, stiffeners, and other attachments shall be attached to the pressure-retaining parts by continuous welds. Fillet or partial penetration welds shall be continuous on all sides. Attachments are shown in Figure NC-4267-1.

NC-4300 WELDING QUALIFICATIONS

NC-4310 GENERAL REQUIREMENTS

NC-4311 Types of Processes Permitted

Only those welding processes which are capable of producing welds in accordance with the welding procedure qualification requirements of Section IX and this Subsection may be used for welding pressure-retaining material or attachments thereto. Any process used shall be such that the records required by NC-4320 can be prepared, except that records for stud welds shall be traceable to the welders and welding operators and not necessarily to each specific weld.

NC-4311.1 Stud Welding Restrictions. Stud welding is acceptable only for nonstructural and temporary attachments (NC-4435). Studs shall be limited to 1 in. (25 mm) maximum diameter for round studs and an equivalent cross-sectional area for studs of other shapes when welding in the flat position and $\frac{3}{4}$ in. (19 mm) diameter for all other welding positions. Postweld heat treatment shall comply with NC-4600, except that time at temperature need not exceed $\frac{1}{2}$ hr regardless of base material thickness. Welding procedure and performance qualification shall comply with the requirements of Section IX.

NC-4311.2 Capacitor Discharge Welding. Capacitor discharge welding may be used for welding temporary attachments and permanent nonstructural attachments provided:

(a) temporary attachments are removed in accordance with the provisions of NC-4435(b);

(b) the energy output for permanent nonstructural attachments such as strain gages and thermocouples is limited to 125 W-sec and the minimum thickness of the material to which the attachment is made is greater than 0.09 in. (2.5 mm); and

(c) a Welding Procedure Specification is prepared describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application; qualification of the welding procedure is not required.

NC-4311.4 Inertia and Continuous Drive Friction Welding.

(a) Inertia and continuous drive friction welding shall not be used for the fabrication of piping.

(b) The weld between the two members shall be a full penetration weld.

Figure NC-4266(b)-1 Full Penetration Corner Welded Attachments (15)

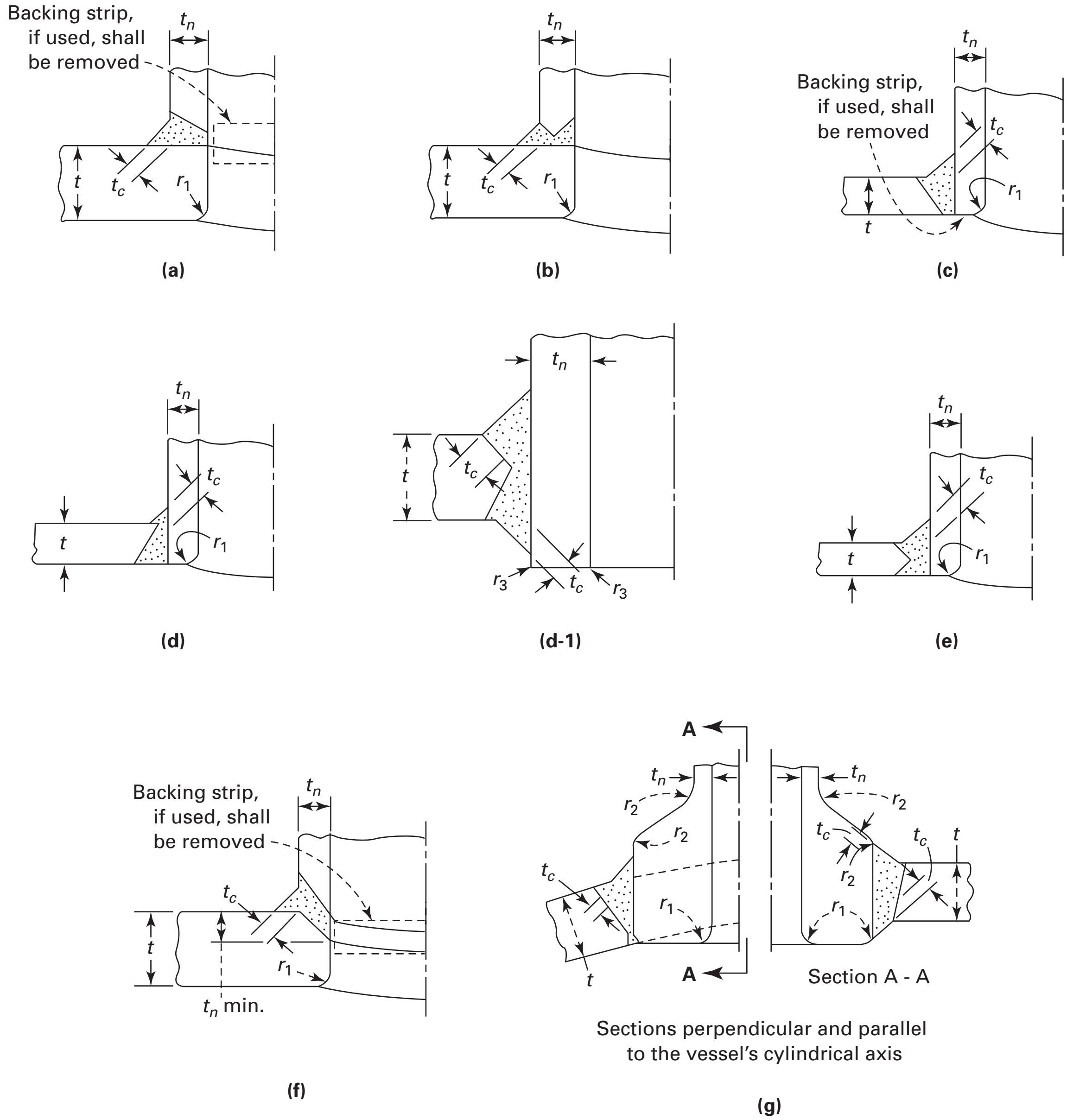


Figure NC-4266(c)-1
Pad and Screwed Fitting Types of Welded Nozzles and Other Connections to Shells, Drums, and Headers

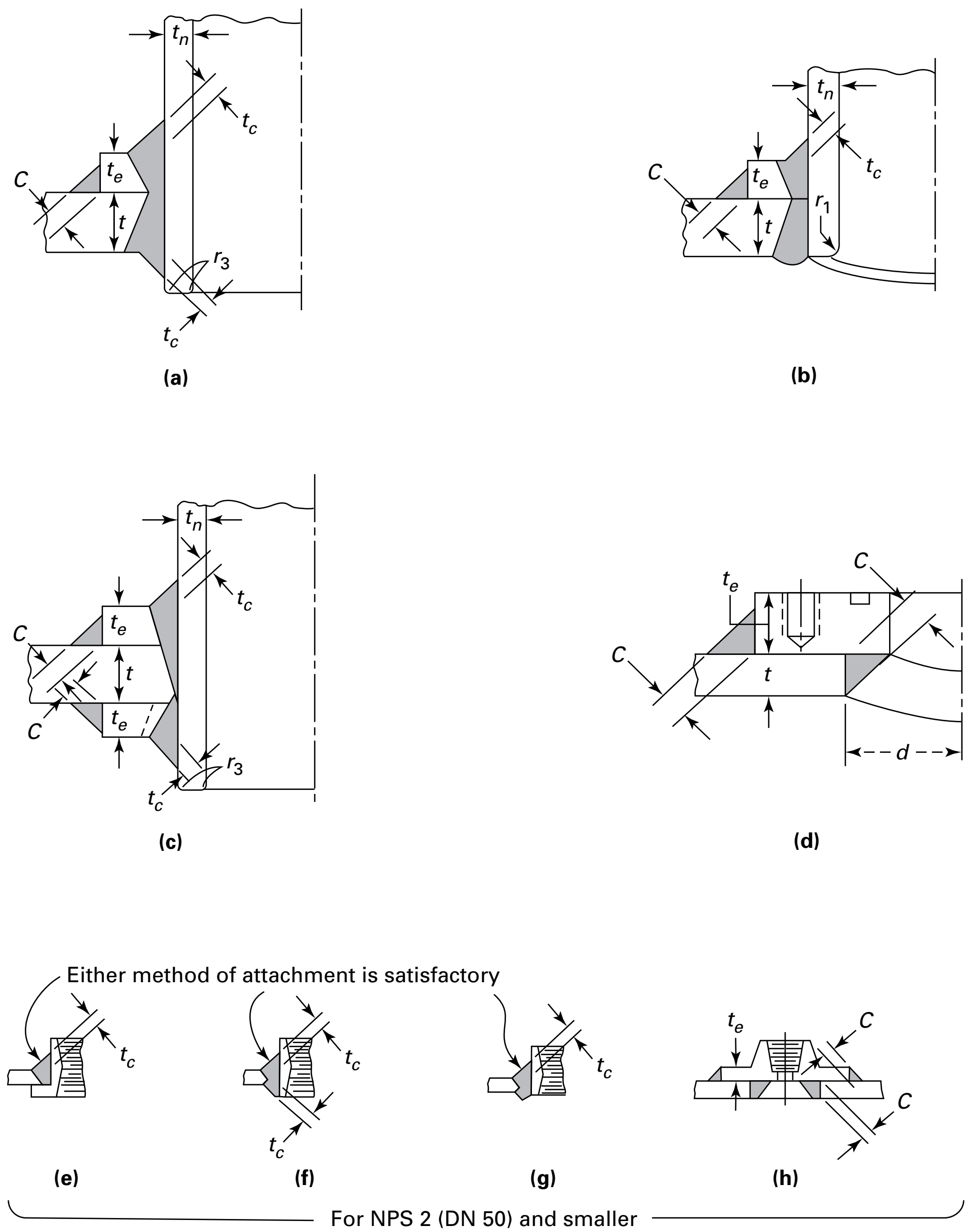
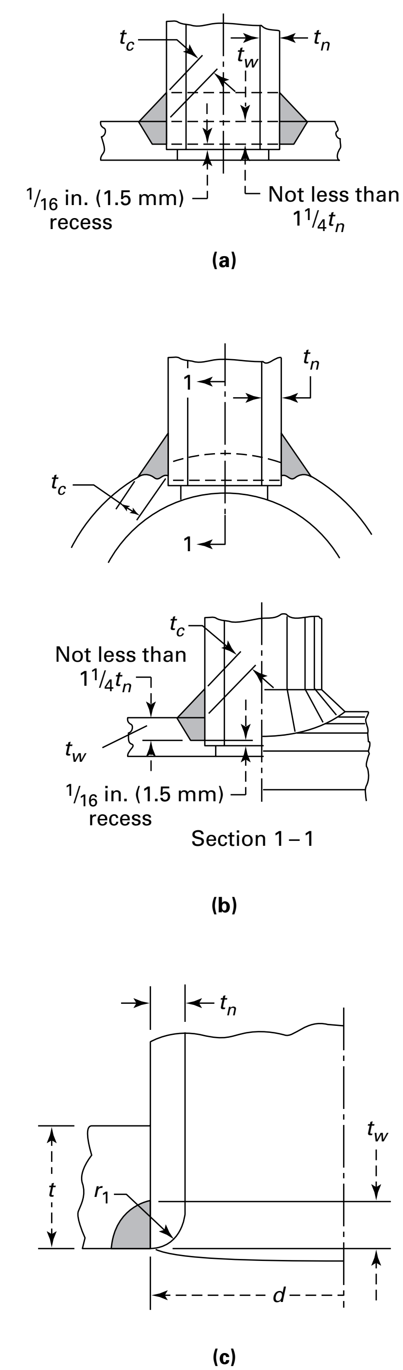


Figure NC-4266(d)-1
Partial Penetration Weld Connections



NC-4320 WELDING QUALIFICATIONS, RECORDS, AND IDENTIFYING STAMPS

NC-4321 Required Qualifications

(a) Each Certificate Holder is responsible for the welding done by his organization, and he shall establish the procedure and conduct the tests required by this Article and by Section IX in order to qualify both the welding procedures and the performance of welders and welding operators who apply these procedures.

(b) Procedures, welders, and welding operators used to join permanent or temporary attachments to pressure parts and to make permanent or temporary tack welds used in such welding shall also meet the qualification requirements of this Article.

(c) When making procedure test plates for butt welds, consideration shall be given to the effect of angular, lateral, and end restraint on the weldment. This applies particularly to material and weld metal of 80.0 ksi (550 MPa) tensile strength or higher and heavy sections of both low and high tensile strength material. The addition of restraint during welding may result in cracking difficulties that otherwise might not occur.

NC-4322 Maintenance and Certification of Records

The Certificate Holder shall maintain a record of the qualified welding procedures and of the welders and welding operators qualified by him, showing the date and results of tests and the identification mark assigned to each welder. These records shall be reviewed, verified, and certified by the Certificate Holder by signature or some other method of control in accordance with the Certificate Holder's Quality Assurance Program and shall be available to the Authorized Nuclear Inspector.

NC-4322.1 Identification of Joints by Welder or Welding Operator.

(a) Each welder or welding operator shall apply the identification mark assigned to him by the Certificate Holder on or adjacent to all permanent welded joints or series of joints on which he welds. The marking shall be at intervals of 3 ft (1 m) or less and shall be done with either blunt nose continuous or blunt nose interrupted dot die stamps. As an alternative, the Certificate Holder shall keep a record of permanent welded joints in each item and of the welders and welding operators used in making each of the joints.

(b) When a multiple number of permanent structural attachment welds, nonstructural welds, fillet welds, socket welds, welds of specially designed seals, weld metal cladding, hard surfacing and tube-to-tubesheet welds

(15)

Figure NC-4267-1 Attachments

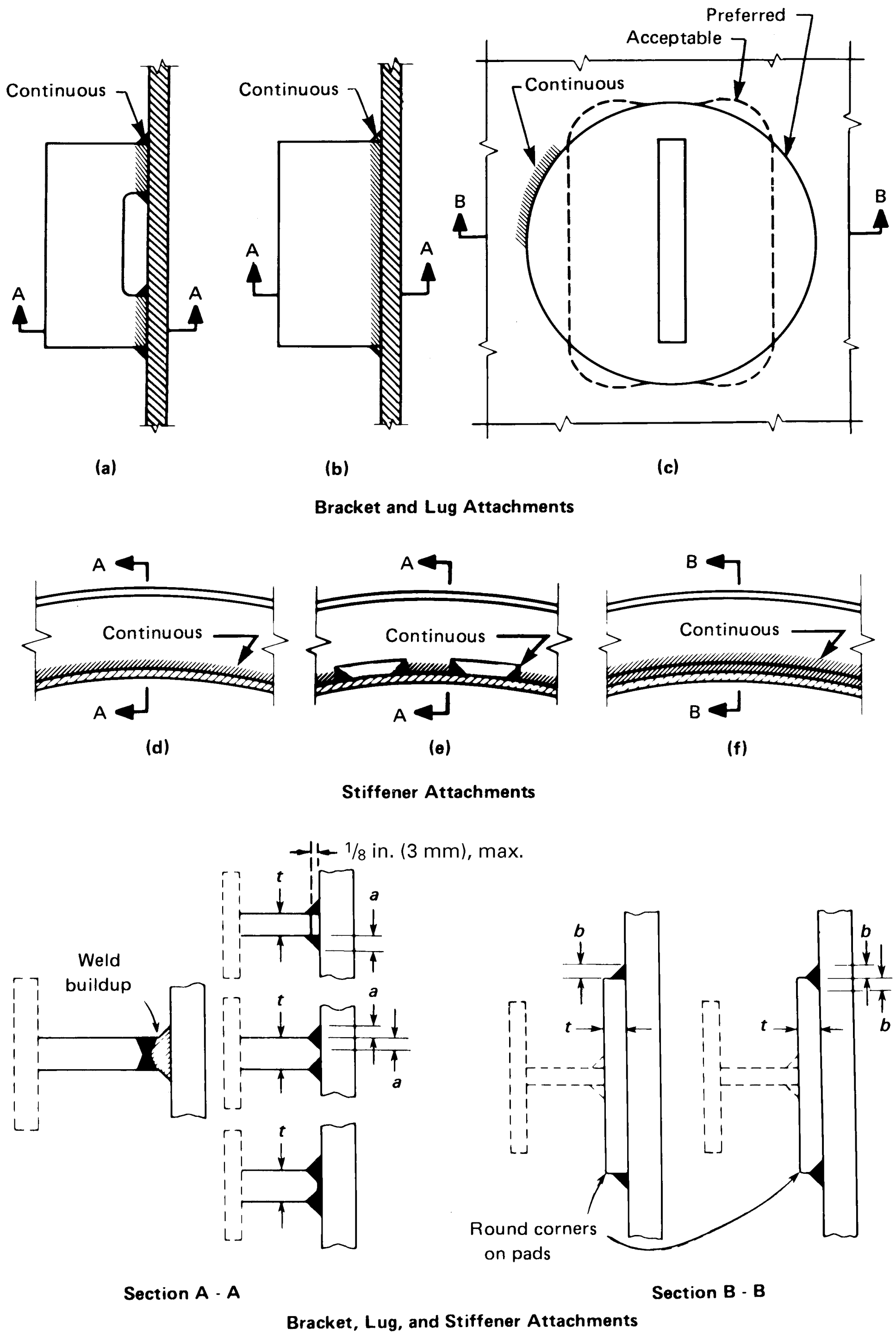
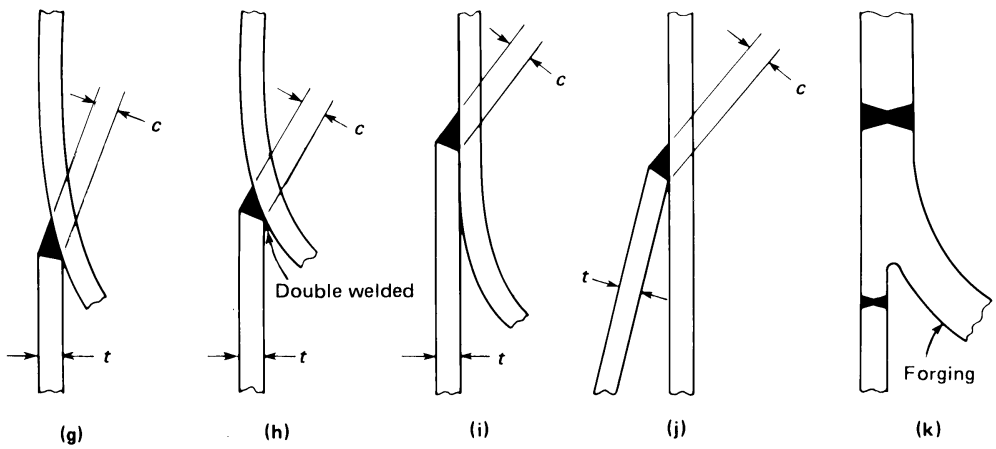


Figure NC-4267-1
Attachments (Cont'd)



GENERAL NOTES:
(a) See below.
$a \geq t/4$; $b \geq t/2$; $c \geq t$
c = minimum thickness of weld metal from the root to the face of the weld
t = thickness of attached member
(b) All welds continuous.

are made on an item, the Certificate Holder need not identify the welder or welding operator who welded each individual joint, provided:

(1) the Certificate Holder maintains a system that will identify the welders or welding operators who made such welds on each item so that the Inspector can verify that the welders or welding operators were all properly qualified;

(2) the welds in each category are all of the same type and configuration and are welded with the same Welding Procedure Specification.

(c) The identification of welder or welding operator is not required for tack welds.

NC-4323 Welding Prior to Qualifications

No welding shall be undertaken until after the welding procedures which are to be used have been qualified. Only welders and welding operators who are qualified in accordance with NC-4320 and Section IX shall be used.

(15)
NC-4324 Transferring Qualifications

The welding procedure qualifications and performance qualification tests for welders and welding operators conducted by one Certificate Holder shall not qualify welding procedures, and shall not qualify welders or welding operators to weld for any other Certificate Holder, except as provided in Section IX.

NC-4330 GENERAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION TESTS

NC-4331 Conformance to Section IX Requirements

All welding procedure qualification tests shall be in accordance with the requirements of Section IX as supplemented or modified by the requirements of this Article.

NC-4333 Heat Treatment of Qualification Welds for Ferritic Materials

Postweld heat treatment of procedure qualification welds shall conform to the applicable requirements of NC-4600 and Section IX. The postweld heat treatment time at temperature is to be at least 80% of the maximum time to be applied to the component weld material. The postweld heat treatment total time may be applied in one heating cycle.

NC-4334 Preparation of Test Coupons and Specimens

(a) Removal of test coupons from the test weld and the dimensions of specimens made from them shall conform to the requirements of Section IX, except that the removal of impact test coupons and the dimensions of impact test specimens shall be in accordance with (b) below.

(b) Weld deposit of each process in a multiple process weld shall, where possible, be included in the impact test specimens. When each process cannot be included in the full size impact test specimen at the $^1/_4t$ location required by this Section, additional full-size specimens shall be obtained from locations in the test weld that will ensure that at least a portion of each process has been included in full size test specimens. As an alternative, additional test welds can be made with each process so that full size specimens can be tested for each process.

NC-4334.1 Coupons Representing the Weld Deposits. Impact test specimens and testing methods shall conform to NC-2321. The impact specimen shall be located so that the longitudinal axis of the specimen is at least $^1/_4t$ and, where the thickness of the test assembly permits, not less than $^3/_8$ in. (10 mm) from the weld surface of the test assembly. In addition, when the postweld heat treatment temperature exceeds the maximum temperature specified in NC-4620, and the test assembly is cooled at an accelerated rate, the longitudinal axis of the specimen shall be a minimum of t from the edge of the test assembly. The specimen shall be transverse to the longitudinal axis of the weld with the area of the notch located in the weld. The length of the notch of the Charpy V-notch specimen shall be normal to the surface of the weld. Where drop weight specimens are required, the tension surface of the specimen shall be oriented parallel to the surface of the test assembly.

NC-4334.2 Coupons Representing the Heat Affected Zone. Where impact tests of the heat affected zone are required by NC-4335.2, specimens shall be taken from the welding procedure qualification test assemblies in accordance with (a) through (c) below.

(a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented either parallel to or perpendicular to the principal direction of rolling or forging.

(b) The heat affected zone impact test specimens and testing methods shall conform to the requirements of NC-2321.2. The specimens shall be removed from a location as near as practical to a depth midway between the surface and center thickness. The coupons for heat affected zone impact specimens shall be taken transverse to the axis of the weld and etched to define the heat affected zone. The notch of the Charpy V-notch specimen shall be cut approximately normal to the material surface in such a manner as to include as much heat affected zone as possible in the resulting fracture. Where the material thickness permits, the axis of a specimen may be inclined to allow the root of the notch to align parallel to the fusion line. When a grain refining heat treatment is not performed on welds made by the electroslag or electrogas welding process, the notch for the impact specimens shall be located in the grain coarsened region.

(c) For the comparison of heat affected zone values with base material values [NC-4335.2(b)], Charpy V-notch specimens shall be removed from the unaffected base material at approximately the same distance from the base material surface as the heat affected zone specimens. The axis of the unaffected base material specimens shall be parallel to the axis of the heat affected zone specimens, and the axis of the notch shall be normal to the surface of the base material. When required by NC-4335.2(b)(4), drop weight specimens shall be removed from a depth as near as practical to midway between the surface and center thickness of the unaffected base material and shall be tested in accordance with the requirements of NC-2321.1.

NC-4335 Impact Test Requirements

When materials are required to be impact tested per NC-2300, impact tests of the weld metal and heat affected zone shall be performed in accordance with the following subparagraphs. Exemption from impact testing under NC-2311(a)(8) does not apply to weld metal unless the specific weld metal used is included in Table NC-2311(a)-1. Exemption from impact testing of the heat affected zone of those base materials exempted by NC-2311(a)(8) is not permitted. The weld procedure qualification impact test specimens shall be prepared and tested in accordance with the applicable requirements of NC-2330 and NC-4334. Retests in accordance with the provisions of NC-2350 are permitted.

NC-4335.1 Impact Tests of Weld Metal.

(a) Impact tests of the weld metal shall be required for welding procedure qualification tests for production weld joints exceeding $^5/_8$ in. (16 mm) in thickness when the weld will be made on the surface or will penetrate the base material that requires impact testing in accordance with NC-2310. In addition, such testing of the weld metal is required for the welding procedure qualification tests for any weld repair to base material that requires impact testing in accordance with NC-2310, regardless of the depth of the repair. Exemption from impact testing under NC-2311(a)(8) does not apply to weld metal of welding procedure qualification tests for either production weld joints or base material repairs unless the specific weld metal used is included in Table NC-2311(a)-1.

(b) The impact test requirements and acceptance standards for welding procedure qualification weld metal shall be the same as specified in NC-2330 for the base material to be welded or repaired. Where two materials are to be joined by welding and have different fracture toughness requirements, the test requirements and acceptance standards of either material may be used for the weld metal, except where otherwise specified by NCA-1280 or other parts of this Section.

(c) A Welding Procedure Specification qualified to the impact testing requirements of Subsection NB or Subsection NE may be accepted as an alternative to the Welding Procedure Specification impact testing requirements of this Subsection.

NC-4335.2 Impact Tests of Heat Affected Zone.

(a) Charpy V-notch tests of the heat affected zone of the welding procedure qualification test assembly are required whenever the thickness of the weld exceeds $^5/_8$ in. (16 mm) and either of the base materials require impact testing in accordance with the rules of NC-2310. Exemption of base materials by NC-2311(a)(8) does not apply to the welding procedure qualification heat affected zone or unaffected base material for such materials. The only exceptions to the requirements are the following:

(1) the qualification for welds in P-Nos. 1 and 3 and SA-336 F12 materials that are postweld heat treated and are made by any process other than electroslag, electrogas, or thermit;

(2) the qualification for weld deposit cladding or hard-facing on any base material.

(3) that portion of the heat affected zone associated with GTAW root deposits with a maximum of two layers or $^3/_{16}$ in. (5 mm) thickness, whichever is less.

(b) Charpy V-notch testing shall be performed as specified in (1) through (6).

(1) Charpy V-notch test specimens representing both the heat affected zone and the unaffected base material shall be tested. The unaffected base material shall be tested at a temperature equal to or below the lowest service temperature.

(2) The Charpy V-notch tests of the unaffected base material shall meet the applicable requirements of Table NC-2332.1-1 or Table NC-2332.1-2, as applicable, or additional testing shall be performed at higher temperatures until either of the above requirements are met.

(3) The heat affected zone specimens shall be tested at the test temperature determined in (2). The average applicable toughness values of the heat affected zone specimens shall equal or exceed the average applicable toughness values of the unaffected base material specimens, or the adjustment given in (4) through (6) shall be made. Alternatively, another test coupon may be welded and tested.

(4) Additional Charpy V-notch tests shall be performed on either the heat affected zone or the unaffected base material, or both, at temperatures where the applicable toughness values of all three specimens tested is not less than that specified in (2). The applicable average toughness values for each test meeting this requirement shall be plotted on an applicable toughness value versus temperature graph. The difference in temperature T_{HAZ} and T_{UBM} where the heat affected zone and the unaffected base material applicable average toughness values are the same and not less than that specified in (2) shall be used to determine the adjustment temperature T_{ADJ} where:

$$T_{ADJ} = T_{HAZ} - T_{UBM}$$

If $T_{ADJ} \leq 0$, then $T_{ADJ} = 0$.

(5) As an alternative to (4), if the applicable toughness values of the heat affected zone specimens is no less than the values specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable, and the average of the heat affected zone specimens is not less than 7 ft-lb (10 N·m) or 5 mils (0.13 mm) below the average applicable toughness values of the unaffected base material, T_{ADJ} may be taken as 15°F (−9°C).

(6) As a second alternative to (4), if the applicable toughness values of the heat affected zone specimens are no less than the values specified in Table NC-2332.1-1 or Table NC-2332.1-2, as applicable, the difference between the average applicable toughness values of the heat affected zone and the unaffected base material shall be calculated and used as described in (c)(3).

(c) At least one of the following methods shall be used to compensate for the heat affected zone toughness decrease due to the welding procedure.

(1) The lowest service temperature specified in the Design Specification for all of the material to be welded in production welding procedure specifications (WPS) supported by this procedure qualification record (PQR) shall be increased by the adjustment temperature T_{ADJ}.

(2) The specified testing temperature for the production material may be reduced by T_{ADJ}.

(3) The materials to be welded may be welded using the WPS provided they exhibit toughness values that are no less than the minimum required toughness values required by NC-2300 plus the difference in the average toughness values established in (b)(6).

(d) The Charpy V-notch testing results shall be recorded on the PQR and any offsetting T_{ADJ} or increased toughness requirements on the production material on which welding is to be performed shall be noted on the PQR and WPS. More than one compensation method may be used on a par basis.

(e) A WPS qualified to the impact testing requirements of Subsection NB or NE may be accepted as an alternative to the WPS impact testing requirements of this Subsection.

NC-4336 Qualification Requirements for Built-Up Weld Deposits

Built-up weld deposits for base metal reinforcement shall be qualified in accordance with the requirements of NC-4331 through NC-4335, inclusive.

NC-4337 Welding of Instrument Tubing

Welding of P-No. 8 material instrument tubing may be performed without the prescribed radiographic examination of Article NC-5000 provided all of the additional rules of (a) through (j) are met.

(a) Nominal tube size shall not exceed $^1/_2$ in. (13 mm), and wall thickness shall not exceed 0.065 in. (1.6 mm).

(b) Automatic welding equipment shall be used.

(c) Welding shall be limited to the gas tungsten-arc welding process.

(d) The welding procedures and welding operators shall be qualified in accordance with Sections III and IX. In addition, one sample weld shall be prepared for each nominal tube size, nominal wall thickness, welding position, and welding machine model in accordance with the welding procedure specification, and the sample shall be tested in accordance with (f).

(e) Each production welding machine shall have the line voltage input corrected within ±10%.

(f) Prior to the start of production welding, two consecutive acceptable sample welds shall be prepared after equipment setup and prior to the start of production welding for each type of weld to be performed, i.e., welding procedure specification with welding machine, welding position, nominal tube size, and nominal wall thickness. Each sample shall be sectioned approximately $^1/_4$ in. (6 mm) from the weld so that the root of the weld is accessible for visual examination. Acceptance shall be based on complete root penetration.

(g) During production welding, voltage, current, and travel speed shall not vary more than ±10% from that used in (d).

(h) The production welding voltage, current, and travel speed shall be recorded on a chart recorder. The chart shall be verified to ensure each weld is acceptable. The chart shall be retained as part of the Lifetime Quality Assurance Records.

(i) Concavity on the outside surface of the weld shall not exceed 10% of the nominal wall thickness.

(j) Unacceptable concavity or indications in the weld resulting from the examination per NC-5222(c) shall be cause for the weld to be cut out and remade. No repairs are permitted.

NC-4350 SPECIAL QUALIFICATION REQUIREMENTS FOR TUBE-TO-TUBESHEET WELDS

The welding procedure for tube-to-tubesheet welds shall be qualified in accordance with ASME Section IX, QW-202.6 using a demonstration mockup in accordance with Section IX, QW-193. The weld throat (minimum leakage path) shall be not less than two-thirds of the specified tube wall thickness. Welders and welding operators shall be qualified by demonstration mockup in accordance with Section IX, QW-303.5.

NC-4360 QUALIFICATION REQUIREMENTS FOR WELDING SPECIALLY DESIGNED WELDED SEALS

NC-4361 General Requirements

(a) Specially designed welded seals are defined as the walls or membranes, such as an omega shaped seal membrane, which confine the fluid and where strength is provided by a separate device.

(b) The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the essential variables specified or listed in the following paragraphs are made in the procedure. Changes other than those given may be made in the procedure without the necessity for requalification, provided the procedure is amended to show these changes. In addition, the essential variables specified in Section IX shall apply for both procedure and performance qualification.

NC-4362 Essential Variables for Automatic, Machine, and Semiautomatic Welding

The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the changes listed in this paragraph or the applicable portions of Section IX are made:

(a) when preplaced filler metal is melted to form all or part of a weld, a change from one alloy type or classification to any other alloy type or classification of base material or filler metal, even though previously qualified base materials and filler metals are of the same P-Number or A-Number;

(b) a change of any dimension of the weld joint for automatic welding or a change of any dimension of the weld joint by more than 10% for semiautomatic or machine welding beyond that qualified;

(c) a change in the nominal size or shape of any filler metal added to the arc;

(d) for automatic welding, an increase or decrease in the length of the seal weld by more than 30%;

(e) for automatic welding, a change in the welding current greater than 50% of the difference between the maximum and minimum amperages used during qualification; only two test assemblies need to be welded for requalification;

(f) any change in the angular relationship or distance between the welding electrode and the work and the filler metal beyond the range qualified;

(g) the addition or deletion of the use of tack welds or locating fixtures to facilitate alignment or to maintain the root opening of the weld joint;

(h) the addition or deletion of consumable inserts.

NC-4363 Essential Variables for Manual Welding

The welding procedure shall be qualified as a new procedure specification and shall be completely requalified when any of the changes listed in (a) or (b) below are made in the procedure:

(a) a change of more than ±10% of any dimension, excluding angularity of the groove, of the weld joint cross section, except that base material thickness may vary from the minus 10% to 2.5 times the thickness qualified when welding parts of the same material thickness or the thin member may vary from minus 10% to two times the thickness qualified when welding a thin seal membrane to a thick member;

(b) when preplaced filler metal is melted to form all or a part of a weld, a change from one type or classification to any other type or classification of base material or filler metal, even though previously qualified base materials and filler metals are of the same P-Number or A-Number.

NC-4366 Test Assembly

The test assembly shall consist of a duplicate of the production weld, except that tolerances as stated in NC-4362(b) or NC-4363(a) are permitted. Except for automatic welding, the Certificate Holder may use a 12 in. (300 mm) length to qualify, if the length of the production weld is considered to be greater than necessary to qualify.

NC-4366.1 Automatic Welding. For automatic welding, at least six consecutive test assemblies representing the range of dimensions to be qualified shall be required to establish the reproducibility of the welding procedure. In addition, the Certificate Holder making the production welds shall verify this capability of making two consecutive test assemblies prior to production welding using the previously qualified procedure.

NC-4366.2 Manual, Machine, and Semiautomatic Welding. For manual, machine, and semiautomatic welding, two test assemblies shall be required.

NC-4367 Examination of Test Assembly

(a) Where 100% weld penetration is required, the test assembly shall be sectioned, if necessary, to permit examination of the entire underside weld surface.

(b) A minimum of four cross sections shall be taken from each test assembly. One cross section shall be made in a weld start-and-stop area and the others shall be taken at random. Each cross section shall be magnified to 10× to 15× in accordance with ASTM E883 for examination. All surfaces shall be free of cracks, incomplete penetration, incomplete melting of insert on consumable-type welds, and rounded indications or inclusions in excess of one rounded void with the maximum dimension not greater than 10% of the thickness of the weld. When doubt exists as to the acceptability of the weld after examination of four cross sections, the Inspector may require that additional metallographic cross sections be prepared for examination of the weld and adjacent base material.

NC-4368 Performance Qualification Test

The performance qualification test assembly shall meet the same requirements specified for the procedure qualification test assembly in NC-4366 and shall be examined in accordance with NC-4367. Furthermore, welding operators shall qualify using the same type and model of equipment, including the welding head, as the machine or machines that will be used to make production welds and shall be required to set up the machine with regard to adjustments and settings which affect the welding characteristics. One test assembly is required.

NC-4400 RULES GOVERNING MAKING, EXAMINING, AND REPAIRING WELDS

NC-4410 PRECAUTIONS TO BE TAKEN BEFORE WELDING

NC-4411 Identification, Storage, and Handling of Welding Materials

Each Certificate Holder is responsible for control of the welding electrodes and other materials which are used in the fabrication and installation of components (NC-4120). Suitable identification, storage, and handling of electrodes, flux, and other welding materials shall be maintained. Precautions shall be taken to minimize absorption of moisture by electrodes and flux.

NC-4412 Cleanliness and Protection of Welding Surfaces

The method used to prepare the base metal shall leave the weld preparation with reasonably smooth surfaces. The surfaces for welding shall be free of scale, rust, oil, grease, and other deleterious material. The work shall be protected from deleterious contamination and from rain, snow, and wind during welding. Welding shall not be performed on wet surfaces.

NC-4420 RULES FOR MAKING WELDED JOINTS

NC-4421 Backing Rings

Backing rings which remain in place may be used for piping in accordance with the requirements of NC-3661.2. The materials for backing rings shall be compatible with the base metal, but spacer pins shall not be incorporated into the weld.

NC-4422 Backup Plates, Backing Rings, and Compression Rings or Stiffeners for Storage Tanks

Backup plates and backing rings which remain in place and compression rings or stiffeners of storage tanks, such as angles, bars, and ring girders, may be used. The materials used for such backup plates, backing rings, and compression rings or stiffeners shall be compatible with the base metal, but spacer pins shall not be incorporated into the weld.

NC-4423 Double Welded Joints, Single-Welded Joints, and Peening

NC-4423.1 Double Welded Joints. Before applying weld metal on the second side to be welded, the root of full penetration double welded joints shall be prepared by suitable methods such as chipping, grinding, or thermal gouging, except for those processes of welding by which proper fusion and penetrations are otherwise obtained and demonstrated to be satisfactory by welding procedure qualifications.

NC-4423.2 Single-Welded Joints. Where single-welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

NC-4423.3 Peening. Controlled peening may be performed to minimize distortion. Peening shall not be used on the internal layer (root) of the weld metal nor on the final layers unless the weld is postweld heat treated.

(15) NC-4424 Surfaces of Welds

As-welded surfaces are permitted except for inertia and continuous drive friction welding where the flash shall be removed to sound metal. For piping, the appropriate stress indices given in Table NC-3673.2(b)-1 shall be applied. However, the surface of welds shall be sufficiently free from coarse ripples, grooves, overlaps, abrupt ridges, and valleys to meet the requirements of (a) through (e) below.

(a) The surface condition of the finished weld shall be suitable for the proper interpretation of radiographic and other required nondestructive examination of the weld. In those cases where there is a question regarding the surface condition on the interpretation of a radiographic film, the film shall be compared to the actual weld surface for interpretation and determination of acceptability.

(b) Reinforcements are permitted in accordance with NC-4426.1 for vessels, pumps, and valves, and NC-4426.2 for piping.

(c) Undercuts shall not exceed $^1/_{32}$ in. (0.8 mm) and shall not encroach on the required section thickness.

(d) Concavity on the root side of a single-welded circumferential butt weld is permitted when the resulting thickness of the weld meets the requirements of Article NC-3000.

(e) If the surface of the weld requires grinding to meet the above criteria, care shall be taken to avoid reducing the weld or base material below the required thickness.

(f) For inertia and continuous drive friction welding, the weld upset shall meet the specified amount within ±10%.

NC-4425 Welding Components of Different Diameters

When components of different diameters are welded together, there shall be a gradual transition between the two surfaces. The slope of the transition shall be such that the length–offset ratio shall not be less than 3:1 (Figures NC-3361-1 and NC-4233-1), unless greater slopes are shown to be acceptable by analysis for vessels designed to NC-3200. The length of the transition may include the weld.

NC-4426 Reinforcement of Welds

NC-4426.1 Thickness of Weld Reinforcement for Vessels, Pumps, and Valves. The surface of the reinforcement of all butt welded joints in vessels, pumps, and valves may be flush with the base material or may have uniform crowns. The height of reinforcement on each face of the weld shall not exceed the thicknesses in the following tabulation:

Nominal Thickness, in. (mm)	Maximum Reinforcement, in. (mm)
Up to 1 (25), incl.	$^3/_{32}$ (2.5)
Over 1 to 2 (25 to 50), incl.	$^1/_8$ (3)
Over 2 to 3 (50 to 75), incl.	$^5/_{32}$ (4)
Over 3 to 4 (75 to 100), incl.	$^7/_{32}$ (5.5)
Over 4 to 5 (100 to 125), incl.	$^1/_4$ (6)
Over 5 (125)	$^5/_{16}$ (8)

NC-4426.2 Thickness of Weld Reinforcement for Piping. For double welded butt joints, the limitation on the reinforcement given in Column 1 of the following tabulation shall apply separately to both inside and outside surfaces of the joint. For single-welded butt joints, the reinforcement given in Column 2 shall apply to the inside surface and the reinforcement given in Column 1 shall apply to the outside surface. The reinforcements shall be determined from the higher of the abutting surfaces involved.

Material Nominal Thickness, in. (mm)	Maximum Reinforcement Thickness, in. (mm)	
	Column 1	Column 2
Up to $^1/_8$ (3), incl.	$^3/_{32}$ (2.5)	$^3/_{32}$ (2.5)
Over $^1/_8$ to $^3/_{16}$ (3 to 5), incl.	$^1/_8$ (3)	$^3/_{32}$ (2.5)
Over $^3/_{16}$ to $^1/_2$ (5 to 13), incl.	$^5/_{32}$ (4.0)	$^1/_8$ (3)
Over $^1/_2$ to 1 (13 to 25), incl.	$^3/_{16}$ (5)	$^5/_{32}$ (4.0)
Over 1 to 2 (25 to 50), incl.	$^1/_4$ (6)	$^5/_{32}$ (4.0)
Over 2 (50)	Greater of $^1/_4$ in. (6 mm) or $^1/_8$ times the width of the weld, in in. (mm)	$^5/_{32}$ (4.0)

NC-4427 Shape and Size of Fillet Welds

(a) Fillet welds may vary from convex to concave. Except as permitted in (b) below, the shape and size of the weld shall be in accordance with the requirements of Figure NC-4427-1. A fillet weld in any single continuous weld may be less than the specified fillet weld dimension by not more than $^1/_{16}$ in. (1.5 mm), provided that the total undersize portion of the weld does not exceed 10% of the length of the weld. Individual undersize weld portions shall not exceed 2 in. (50 mm) in length. In making socket welds, a gap as shown in Figure NC-4427-1 shall be provided prior to welding. The gap need not be present nor be verified after welding. For sleeve type joints without internal shoulder, the gap shall be between the butting ends of the pipe or tube.

(b) Socket welds smaller than those specified in Figure NC-4427-1 may be used provided the requirements of Article NC-3000 are met.

NC-4428 Seal Welds of Threaded Joints

Where seal welding of threaded pipe joints is performed, the exposed threads shall be either removed entirely or covered with weld metal.

NC-4430 WELDING OF ATTACHMENTS

NC-4431 Materials for Attachments

Nonpressure-retaining attachments (NC-1132.1) welded to pressure-retaining components shall be of materials which meet the requirements of NC-2190. Materials for pressure-retaining attachments shall meet the requirements of NC-2120.

NC-4432 Welding of Structural Attachments

The rules of NC-4321 governing welding qualifications shall apply to the welding of structural attachments to pressure-retaining material.

NC-4433 Structural Attachments

Structural attachments shall conform reasonably to the curvature of the surface to which they are to be attached and shall be attached by full penetration, fillet, or partial penetration continuous or intermittent welds. Figure NC-4433-1 illustrates some of the typical details for attaching structural attachments to a component. Valve seats may be attached to the pressure boundary part by fillet or partial penetration welds, provided the valve seat is shouldered against the pressure boundary part.

NC-4434 Welding of Internal Structural Supports to Clad Components

Internal structural supports on clad components shall be welded to the base metal and not to the cladding except for weld overlay cladding.

NC-4435 Welding of Nonstructural Attachments and Their Removal

(a) Nonstructural attachments (NC-1132.1) welded to the pressure-retaining portion of the component need not comply with Article NC-2000 and may be welded with continuous or intermittent fillet or partial penetration welds, provided the requirements of (1) through (4) below are met.

(1) The welding procedure and the welders have been qualified in accordance with NC-4321.

(2) The material is identified and is compatible with the material to which it is attached.

(3) The welding material is identified and is compatible with the materials joined.

(4) The welds are postweld heat treated when required by NC-4620.

(b) Except for tanks or tank parts, removal of nonstructural temporary attachments shall be accomplished as follows.

(1) The immediate area around the temporary attachment is marked in a suitable manner so that after removal the area can be identified until after it has been examined in accordance with (3) below.

(2) The temporary attachment is completely removed in accordance with the procedures of NC-4211.

(3) After the temporary attachment has been removed, the marked area is examined by the liquid penetrant or magnetic particle method in accordance with the requirements of NC-5110 and meets the acceptance standards of NC-5340 or NC-5350, whichever is applicable.

(4) As an alternative to (a)(4) above, postweld heat treatment may be deferred until after removal of the attachment.

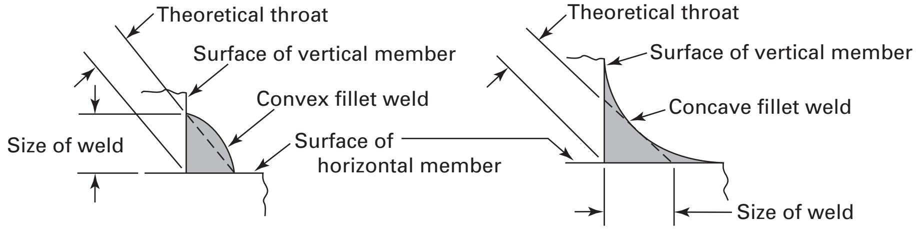
(c) For tanks and tank parts, removal of temporary attachments shall be in accordance with (b)(2) and (b)(4) above.

NC-4436 Installation of Attachments to Piping Systems After Testing

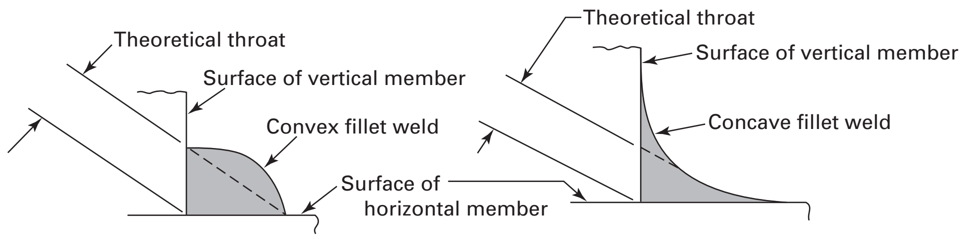
Attachments may be welded to the piping system after performance of the pressure test provided that:

(a) the welds do not require PWHT under NC-4622.7;

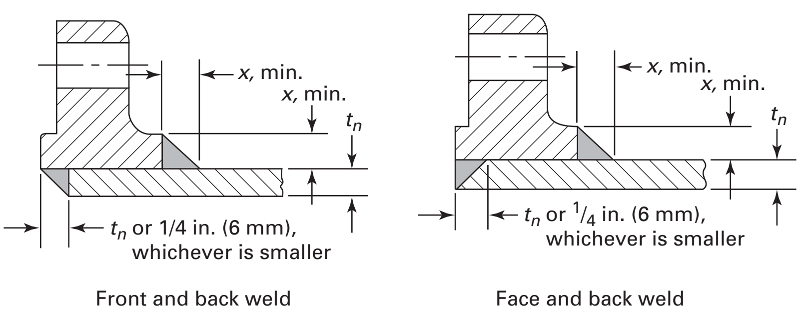
Figure NC-4427-1
Fillet and Socket Weld Details and Dimensions



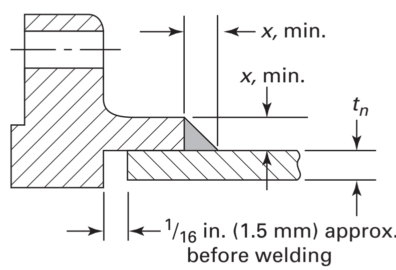
(a) Equal Leg Fillet Weld [Note (1)]



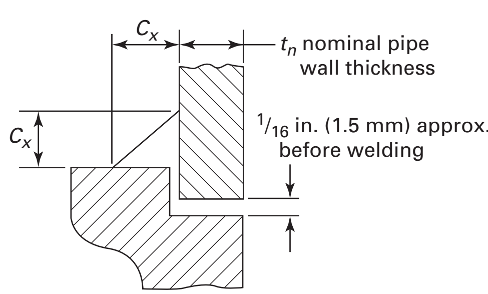
(b) Unequal Leg Fillet Weld [Note (2)]



(c-1) Slip-On Flange [Note (3)]



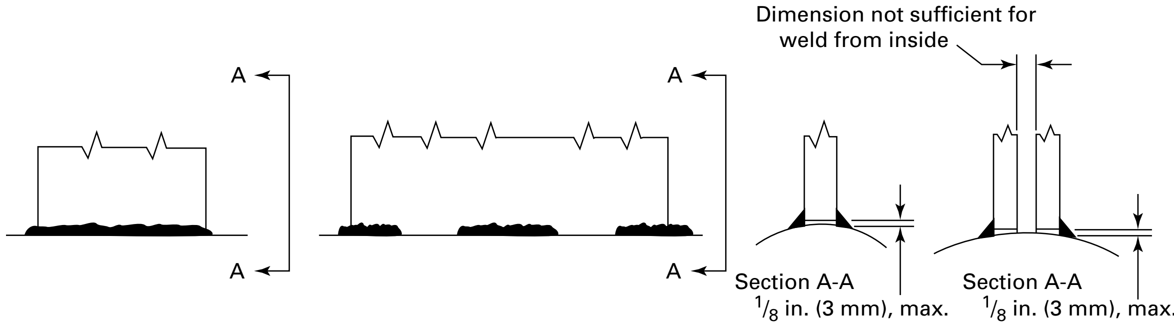
(c-2) Socket Welding Flange [Note (3)]



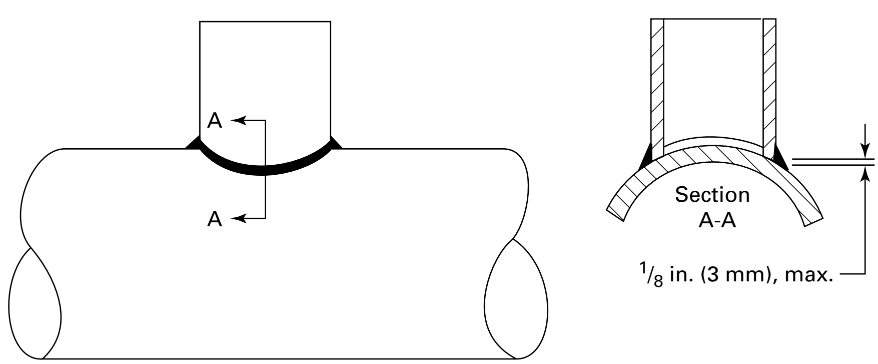
(c-3) Socket Welding Fittings [Note (4)]

NOTES:
(1) The size of an equal leg fillet weld is the leg length of the largest inscribed right isosceles triangle. Theoretical throat = 0.7 × size of weld.
(2) The size of an unequal leg fillet weld is the shorter leg length of the largest right triangle that can be inscribed within the fillet weld cross section.
(3) x, min. = $1.4t_n$ or the thickness of the hub, whichever is smaller, but not less than $^1/_8$ in. (3 mm), where t_n = nominal pipe wall thickness.
(4) C_x, min. = $1.09t_n$ where t_n = nominal pipe wall thickness.

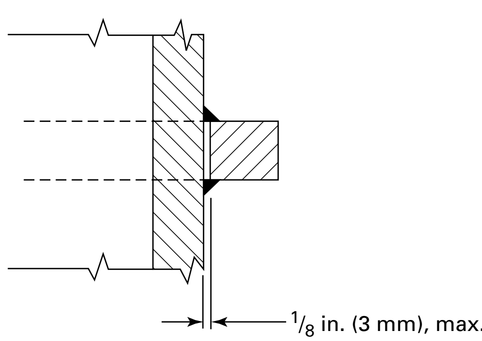
Figure NC-4433-1
Types of Attachment Welds



(a) Attachment of Lugs, Shoes, Pipe Saddles, and Brackets



(b) Attachment of Trunnions



(c) Attachment of Rings

GENERAL NOTE: The welds may be full penetration, partial penetration, or fillet welds.

(b) welds shall be restricted to fillet welds not exceeding $^3/_8$ in. (10 mm) throat thickness and to full penetration welds attaching materials not exceeding $^1/_2$ in. (13 mm) in thickness;

(c) welds shall not exceed a total length of 24 in. (600 mm) for fillet welds or 12 in. (300 mm) for full penetration welds; and

(d) welds shall be examined as required by Article NC-5000.

NC-4437 Attachment of Stiffener Rings

NC-4437.1 General Requirements. All permanent and temporary attachments of stiffener rings to shells, including tack welds, shall be made by qualified welders using qualified welding procedures.

NC-4437.2 Attachment of Stiffening Rings to Shell.

(a) Stiffening rings, when used, may be placed on the inside or outside of a vessel and shall be attached to the shell by welding or bolting. The ring shall be in contact with the shell.

(b) Stiffening rings may be attached to the shell by either continuous or intermittent welding. The total length of the intermittent welding on each side of the stiffening ring shall be:

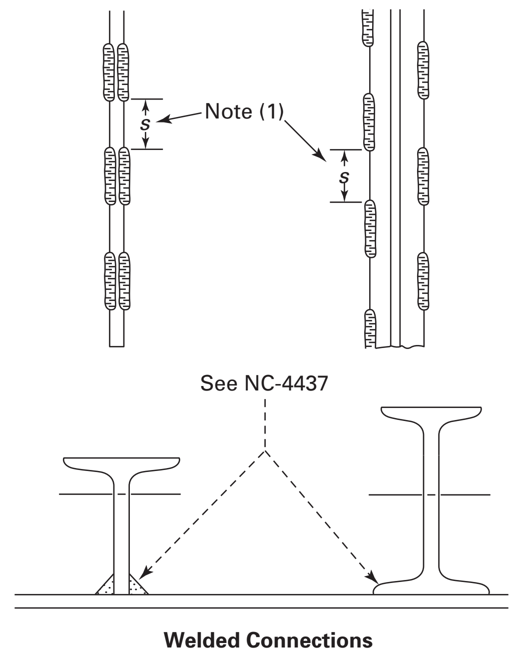
(1) not less than one-half the outside circumference of the component for rings on the outside; and

(2) not less than one-third the circumference of the vessel for rings on the inside.

Acceptable arrangements and spacings of intermittent welds are shown in Figure NC-4437.2(b)-1. Welds on opposite sides of the stiffener may be either staggered or in-line as indicated.

(c) All welding of stiffening rings shall comply with the requirements of this Subsection. In areas where a corrosion allowance is specified in the Design Specification, stiffening rings shall be attached to the shell with a continuous fillet weld, seal weld, or full penetration weld.

Figure NC-4437.2(b)-1 Some Acceptable Methods of Attaching Stiffening Rings to Shells of Cylindrical Vessels Subjected to External Pressure



NOTE:
(1) Maximum spacing, s: 8 × t for external rings 12 × t for internal rings

NC-4450 REPAIR OF WELD METAL DEFECTS

NC-4451 General Requirements

Defects in weld metal detected by the examinations required by Article NC-5000 or by the tests of Article NC-6000 shall be eliminated and repaired when necessary or the indication reduced to an acceptable limit.

NC-4452 Elimination of Surface Defects

Weld metal surface defects may be removed by grinding or machining and need not be repaired by welding, provided the requirements of (a), (b), and (c) below are met.

(a) The remaining thickness of the section is not reduced below that required by Article NC-3000.

(b) The depression, after defect elimination, is blended uniformly into the surrounding surface.

(c) The area is examined by a magnetic particle or liquid penetrant method in accordance with NC-5110 after blending and meets the acceptance standards of NC-5300 to ensure that the defect has been removed or the indication reduced to an acceptable limit. Defects detected by visual or volumetric method and located on an interior surface need only be reexamined by the method which initially detected the defect when the interior surface is inaccessible for surface examination.

NC-4453 Requirements for Making Repairs of Welds

Excavations in weld metal, when repaired by welding, shall meet the requirements of the following subparagraphs.

NC-4453.1 Defect Removal. Defects may be removed by mechanical means or by thermal gouging processes. The area prepared for repair shall be examined by a liquid penetrant or magnetic particle method in accordance with NC-5110 and meet the acceptance standards of NC-5340 or NC-5350. This examination is not required where defect elimination removes the full thickness of the weld and where the backside of the weld joint is not accessible for removal of examination materials.

NC-4453.2 Requirements for Welding Materials, Procedures, and Welders. The weld repair shall be made using welding materials, welders, and welding procedures qualified in accordance with NC-4125 and NC-4300.

NC-4453.3 Blending of Repaired Areas. After repair the surface shall be blended uniformly into the surrounding surface.

NC-4453.4 Examination of Repair Welds.

(a) The examination of a weld repair shall be repeated as required for the original weld, except that it need only be reexamined by the liquid penetrant or magnetic particle method when the unacceptable indication was originally detected by the liquid penetrant or magnetic particle method and when the repair cavity does not exceed the following:

(1) $^1/_3t$ for $t \leq {}^3/_4$ in. (19 mm)

(2) $^1/_4$ in. (6 mm) for $^3/_4$ in. (19 mm) $< t \leq 2^1/_2$ in. (64 mm)

(3) the lesser of $^3/_8$ in. (10 mm) or 10%t for $t > 2^1/_2$ in. (64 mm) where t equals the thickness of the weld.

(b) When repairs to welds joining P-No. 1 and P-No. 3 materials require examination by radiography as required in (a), but construction assembly prevents meaningful radiographic examination, ultrasonic examination may be substituted, provided that:

(1) the weld has been previously radiographed and met the applicable acceptance standards;

(2) the ultrasonic examination is performed using a procedure in accordance with Section V, Article V to the acceptance standards of NC-5330;

(3) the substitution is limited to Categories A and B welds in vessels and similar type welds in other items.

The absence of suitable radiographic equipment is not justification for the substitution.

NC-4453.5 Heat Treatment of Repaired Areas. The area shall be heat treated in accordance with NC-4620.

NC-4500 BRAZING

NC-4510 RULES FOR BRAZING

NC-4511 Where Brazing May Be Used

(a) Brazing is permitted for the attachment of tubes to tubesheets and as permitted for pipe joints in NC-3671.6. Appurtenances and piping with outside diameter equal to that of NPS 1 (DN 25) and less for all other materials may be fabricated using brazed joints in accordance with Figure NC-4511-1.

(b) Valves with inlet piping connections of NPS 4 (DN 100) and less may have seats brazed to the valve body or bonnet, provided the seat is shouldered against the pressure boundary part.

(c) Headers, NPS 4 (DN 100) and less, fabricated from copper, copper alloys, or copper–nickel alloys, which are an integral part of finned tubular heat exchangers, may utilize brazed joints fabricated in accordance with Figure NC-4511-1.

NC-4512 Brazing Material

Where brazing is permitted, the brazing filler material and fluxes shall conform to the rules covering identification in NC-2150 and to the requirements of (a), (b), and (c) below.

(a) The filler material used in brazing shall be a nonferrous metal or alloy with a solidus temperature above 800°F (425°C) and at least 500°F (275°C) above the highest temperature of the joint in service.

(b) The filler material shall melt and flow freely by capillary action within the desired temperature range, and in conjunction with a suitable flux or controlled atmosphere the filler material shall wet and adhere to the surfaces to be joined.

(c) Fluxes that are fluid and chemically active at the brazing temperature shall be used, when necessary, to prevent oxidation of the filler metal and the surfaces to be joined, and to promote free flowing of the filler material.

NC-4520 BRAZING QUALIFICATION REQUIREMENTS

NC-4521 Brazing Procedure and Performance Qualification

Qualification of the brazing procedure to be used and of the performance of brazers and brazing operators is required and shall comply with the requirements of Section IX, except as noted below.

NC-4522 Valve Seat Rings

Validation of the procedure qualification per Section IX, Table QB-451.5, Note (1) is not required for the furnace brazing of seat rings to bodies or bonnets of valves having inlet piping connections of NPS 4 (DN 100) and less.

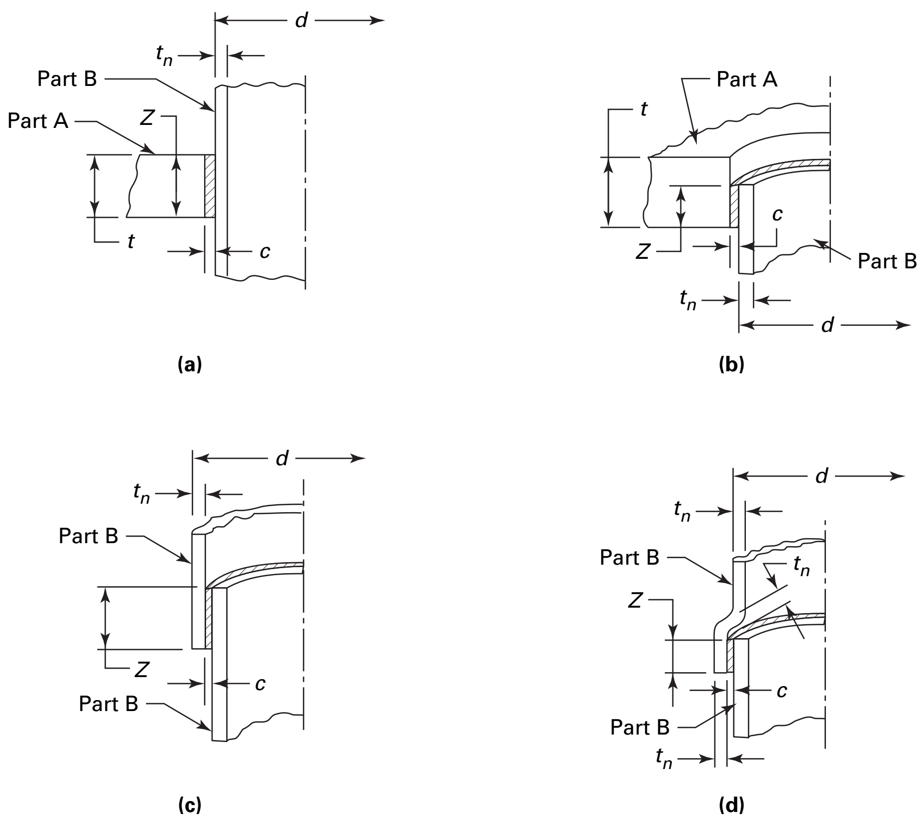
NC-4523 Reheated Joints

In addition to the requirements of Section IX, the brazing procedure shall be set up as a new procedure specification and shall be completely requalified when the construction of the brazed components includes reheating of any portion of the completed brazed joint to a temperature that is within 300°F (165°C) of the solidus temperature of the filler metal.

NC-4524 Maximum Temperature Limits

The design temperature shall not exceed the upper temperature shown in the third column of Table NC-4524-1. For design temperatures below the temperature shown in the second column of Table NC-4524-1, no further testing beyond that required by Section IX is

Figure NC-4511-1
Brazed Connections for Appurtenances and Piping



Legend:

c = clearance or interference between mating parts and shall be in accordance with the brazing procedure specification
d = outside diameter of Part B
t = thickness of part penetrated
t_n = nominal thickness of connecting part
z = depth of engagement and shall be the lesser of $3t_n$ or d, but in no case less than $^1/_4$ in. (6 mm)

GENERAL NOTES:
(a) Part A shall be attached to a component in accordance with the requirements for the component proper.
(b) Part B shall be attached either to Part A or to another Part B by the joints shown above, or in accordance with the requirements of the component proper.
(c) Grooves for preplaced filler metal are permitted, provided the reduction in cross-section due to the grooves is considered in the design.

required. For design temperatures in the range shown in the third column of Table NC-4524-1, tests in addition to those required by Section IX are required. These tests shall be considered a part of the procedure qualification. For such design temperatures, two tension tests on production-type joints are required, one at the design temperature and one at $1.05T$ [where T is the design temperature in °F (°C)]. Neither of these production-type joints shall fail in the braze metal.

NC-4530 FITTING AND ALIGNING OF PARTS TO BE BRAZED

Parts to be joined by brazing shall be fitted, and retained in position during the brazing operation within the tolerances specified in the brazing procedure specification. Brazed joints shall be assembled in a sequence which will permit the maximum number of joints to be visually examined on both sides of the joint after brazing.

NC-4540 EXAMINATION OF BRAZED JOINTS

The completed brazed joints shall be visually examined on all accessible surfaces in accordance with NC-5275.

Table NC-4524-1
Maximum Design Temperatures for Brazing Filler Metal, °F (°C)

Filler Metal Classification	Temperature Below Which Section IX Tests Only Are Required	Temperature Range Requiring Section IX Tests and Additional Tests
BCuP	300 (150)	300–350 (150–175)
BAg	400 (205)	400–500 (205–260)
BCuZn	400 (205)	400–500 (205–260)
BCu	400 (205)	400–650 (205–345)
BAlSi	300 (150)	300–350 (150–175)
BNi	800 (425)	...

GENERAL NOTE: Temperatures are based on AWS recommendations.

NC-4600 HEAT TREATMENT

NC-4610 WELDING PREHEAT REQUIREMENTS

NC-4611 When Preheat Is Necessary

The need for and temperature of preheat are dependent on a number of factors, such as the chemical analysis, degree of restraint of the parts being joined, elevated temperature, physical properties, and material thicknesses. Some practices used for preheating are given in Section III Appendices, Nonmandatory Appendix D as a general guide for the materials listed by P-Number of Section IX. It is cautioned that the preheating suggested in Section III Appendices, Nonmandatory Appendix D does not necessarily ensure satisfactory completion of the welded joint and that the preheating requirements for individual materials within the P-Number listing may be more or less restrictive. The welding procedure specification for the material being welded shall specify the minimum preheating requirements under the welding procedure qualification requirements of Section IX.

NC-4612 Preheating Methods

Preheat for welding or thermal cutting, when employed, may be applied by any method which does not harm the base material or any weld metal already applied or which does not introduce deleterious material into the welding area which is harmful to the weld.

NC-4613 Interpass Temperature

Consideration must be given to the limitations of interpass temperatures for quenched and tempered materials to avoid detrimental effects on the mechanical properties.

NC-4620 POSTWELD HEAT TREATMENT

NC-4621 Heating and Cooling Methods

Postweld heat treatment (PWHT) may be accomplished by any suitable methods of heating and cooling, provided the required heating and cooling rates, metal temperature, metal temperature uniformity, and temperature control are maintained.

NC-4622 PWHT Time and Temperature Requirements

NC-4622.1 General Requirements.[2] Except as otherwise permitted in NC-4622.7, all welds, including repair welds, shall be postweld heat treated. During postweld heat treatment, the metal temperature shall be maintained within the temperature ranges for the minimum holding time specified in Table NC-4622.1-1 except as otherwise permitted in NC-4622.4(c). P-Number groups in Table NC-4622.1-1 are in accordance with Section IX, QW-420. Except as provided in NC-4624.3, PWHT shall be performed in temperature-surveyed and -calibrated furnaces, or PWHT shall be performed with thermocouples in contact with the material or attached to blocks in contact with the material. In addition, the requirements of the following subparagraphs shall apply.

NC-4622.2 Time–Temperature Recordings. Time–temperature recordings of all postweld heat treatments shall be made available for review by the Authorized Inspector. Identification on the time–temperature recording shall be to the weld, part, or component. A summary of the time–temperature recording may be provided for permanent records in accordance with NCA-4134.17.

NC-4622.3 Definition of Nominal Thickness Governing PWHT. Nominal thickness in Table NC-4622.7(b)-1 is the thickness of the weld, the pressure-retaining material for structural attachment welds or the thinner of the pressure-retaining materials being joined, whichever is least. It is not intended that nominal thickness include material provided for forming allowance, thinning, or mill overrun when the excess material does not exceed $^1/_8$ in. (3 mm). For fillet welds the nominal thickness is the throat thickness, and for partial penetration and material repair welds the nominal thickness is the depth of the weld groove or preparation.

NC-4622.4 Holding Times at Temperature.

(a) The holding time at temperature as specified in Table NC-4622.1-1 shall be based on the nominal thickness of the weld. The holding time need not be continuous. It may be an accumulation of the times of multiple postweld heat-treat cycles.

(b) Holding time at temperature in excess of the minimum requirements of Table NC-4622.1-1 may be used, provided that specimens so heat treated are tested in accordance with NC-2200, NC-2400, and NC-4300.

Table NC-4622.1-1
Mandatory Requirements for Postweld Heat Treatment of Welds

P-No. (Sect. IX, QW-420)	Holding Temperature Range, °F (°C) [Note (1)]	Minimum Holding Time at Temperature for Weld Thickness (Nominal)			
		$^1/_2$ in. (13 mm) or less	Over $^1/_2$ in. to 2 in. (13 mm to 50 mm)	Over 2 in. to 5 in. (50 mm to 125 mm)	Over 5 in. (125 mm)
1,3	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)	2 hr plus 15 min each additional inch (2 h plus 0.5 min/mm) over 2 in. (50 mm)
4	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
5A, 5B, 5C, 6 except 6 Gr. 4	1,250–1,400 (675–760)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
6 Gr. 4	1,050–1,150 (565–620)				
7	1,300–1,400 (705–760)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9A Gr. 1	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
9B Gr. 1	1,100–1,175 (595–635)				
10C Gr. 1, 10F Gr. 1	1,100–1,250 (595–675)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
10I Gr. 1	1,300–1,400 (705–760)				
11A Gr. 4	1,000–1,050 (540–565)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)
15E Gr. 1	1,350–1,425 (730–775)	30 min	1 hr/in. (2 min/mm)	1 hr/in. (2 min/mm)	5 hr plus 15 min each additional inch (5 h plus 0.5 min/mm) over 5 in. (125 mm)
P-Nos. 8, 10H Gr. 1, 34, 42, 43, 45 and hard surfacing on P-No. 1base metal whose reported carbon content is not more than 0.30%	PWHT neither required nor prohibited				

GENERAL NOTE: Exemptions to the mandatory requirements of this Table are defined in NC-4622.7.

NOTE:
(1) All temperatures are metal temperatures.

(c) Alternatively, when it is impractical to postweld heat treat at the temperature range specified in Table NC-4622.1-1, it is permissible to perform the postweld heat treatment of certain materials at lower temperatures for longer periods of time in accordance with Table NC-4622.4(c)-1 and (1), (2), and (3) below.

(1) Except for P-No. 1 materials, when welds in the materials listed in Table NC-4622.4(c)-1 are to be postweld heat treated at the lower minimum temperatures, the impact test specimens for the welding procedure qualification required by NC-4300 shall be made using the same minimum temperatures and increased minimum holding time. Welding procedures, qualified at the temperature range and minimum holding time specified in Table NC-4622.1-1 and at the lower temperature and increased minimum holding time permitted by Table NC-4622.4(c)-1, are also qualified for any temperature in between. When such an in-between temperature is used, the minimum holding time shall be interpolated from Table NC-4622.1-1 and the alternative requirements from Table NC-4622.4(c)-1.

(2) Except for P-No. 1 materials, when welds in the materials listed in Table NC-4622.4(c)-1 are to be postweld heat treated at these lower minimum temperatures, the welding material certification required by NC-2400 shall be made using the same minimum temperature and increased minimum holding time. Welding material certified at the temperature range and minimum holding time specified in Table NC-4622.1-1 and at the lower minimum temperatures and increased minimum holding time permitted by Table NC-4622.4(c)-1 are also certified for any temperature in between.

(3) Base materials certified in accordance with NC-2200 may be postweld heat treated at these lower minimum temperatures and increased minimum holding times without recertification. Postweld heat treatment at these lower minimum temperatures and increased minimum holding times may also be the tempering operation, provided a higher tempering temperature is not required by the material specification.

NC-4622.5 PWHT Requirements When Different P-Number Materials Are Joined. When pressure-retaining materials of two different P-Number groups are joined by welding, the applicable postweld heat treatment shall be that specified in Table NC-4622.1-1 for the material requiring the higher PWHT temperature range.

NC-4622.6 PWHT Requirements for Nonpressure-Retaining Parts. When nonpressure-retaining materials are welded to pressure-retaining materials, the postweld heat treatment temperature range of the pressure-retaining materials shall control.

NC-4622.7 Exemptions to Mandatory Requirements. Postweld heat treatment in accordance with this subarticle is not required for (a) through (e) below:

(a) nonferrous materials;

(b) welds exempted in Table NC-4622.7(b)-1;

(c) welds subjected to temperatures above the PWHT temperature range specified in Table NC-4622.1-1, provided the Welding Procedure Specification is qualified in accordance with Section IX and the base material and the deposited weld material have been heat treated at the higher temperature;

(d) welds connecting nozzles to components or branch to run piping, provided the requirements in NC-4622.8 are met;

(e) weld repairs to P-No. 3 materials in vessels, provided the requirements of NC-4622.9 are met.

NC-4622.8 Requirements for Exempting PWHT of Nozzles to Component Welds and Branch-to-Run Piping Welds. Welds connecting nozzles or branch piping of P-No. 1 materials to components or run piping of P-No. 1 or P-No. 3 materials that are not exempted from PWHT in Table NC-4622.7(b)-1 need not be given a postweld heat treatment if the requirements of (a) are met for partial penetration and (b) are met for full penetration welds.

(a) The partial penetration welds are made with A-No. 8 or non-air-hardening nickel–chromium–iron weld metal after:

(1) the ferritic materials to be joined are buttered or built up with A-No. 8 or non-air-hardening nickel–chromium–iron weld metal having a minimum thickness of $^1/_4$ in. (6 mm); and

(2) the heat affected zones of the buttered or built-up ferritic materials are postweld heat treated in accordance with NC-4620, without the PWHT exemptions being applied, prior to making the final welds.

(b) The full penetration welds are made with A-No. 1 or A-No. 2 weld metal, provided that:

(1) the component or run pipe is built up or buttered in the area of the attachment with A-No. 1 or A-No. 2 metal having a minimum thickness of $^1/_4$ in. (6 mm);

(2) the A-No. 1 or A-No. 2 weld metal buildup or buttering is postweld heat treated in accordance with NC-4620 for P-No. 1 or P-No. 3 materials without the PWHT exemptions being applied;

(3) the welds do not penetrate through the component or run pipe thickness;

Table NC-4622.4(c)-1
Alternative Holding Temperatures and Times

Material P-Numbers	Alternative Minimum Holding Temperatures, °F (°C)	Alternative Minimum Holding Times
1, 3, 9A Gr. 1, and 9B Gr. 1	1,050 (565)	2 hr/in. (4 min/mm) thick
1, 3, 9A Gr. 1, and 9B Gr. 1	1,000 (540)	4 hr/in. (8 min/mm) thick

GENERAL NOTE: All other requirements of NC-4622 shall apply.

Table NC-4622.7(b)-1
Exemptions to Mandatory PWHT

P-No. (Section IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness, in. (mm) (NC-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Required, °F (°C)
1	All welds, where the materials being joined are 1½ in. (38 mm) and less	1¼ (32) and less	0.30 and less	...
		Over 1¼ to 1½ (32 to 38)	0.30 and less	200 (95)
		¾ (19) or less	Over 0.30	...
		Over ¾ to 1½ (19 to 38)	Over 0.30	200 (95)
	All welds in material over 1½ in. (38 mm)	¾ (19) or less	...	200 (95)
1 Gr. 1 or Gr. 2	Cladding or repair of cladding [Note (3)] with A-No. 8 or F-No. 43 filler metal in base material of: 1½ in. (38 mm) or less	...	0.30	100 (38)
	Over 1½ in. to 3 in. (38 mm to 75 mm)	...	0.30	200 (95) [Note (4)]
	Over 3 in. (75 mm)	...	0.30	250 (120) [Note (5)]
3	For vessel repair without required PWHT, see NC-4622.9	...	...	350 (175)
3 except Gr. 3	All welds, except repair welds in vessels, provided weld procedure qualification is made using equal or greater thickness base material than production weld [Note (6)]	⅝ (16) or less	0.25 or less	200 (95)
	Attachment welds joining nonpressure-retaining material to pressure-retaining material	½ (13) or less	0.25 or less	200 (95)
	Circumferential butt welds in pipe and tubes	½ (13) or less	0.25 or less	200 (95)
	Socket welds in pipe NPS 2 (DN 50) and less, and tubes with nominal O.D. 2⅜ in. (60 mm) or less	½ (13) or less	0.25 or less	200 (95)
4	All welds in pipe NPS 4 (DN 100) and less, and tubes with nominal O.D. 4.5 in. (114 mm) or less and attachment welds	½ (13) or less	0.15 or less	250 (120)
5A, 5B, and 5C	All welds in pipe NPS 4 (DN 100) and less, and tubes with maximum reported chromium 3.00% or less and nominal O.D. 4.5 in. (114 mm) or less and attachment welds	½ (13) or less	0.15 or less	300 (150)
6 (for Type 410S) or 7 Gr. 1 (for Type 405)	Type 405 and 410S welded with A-No. 8, A-No. 9, or F-No. 43 filler metal	⅜ (10) or less	0.08 or less	...
9A Gr. 1	All welds provided the procedure qualification is made using equal or greater thickness base material than the production weld [Note (6)]	⅜ (10) or less	...	200 (95)
	Attachment welds joining nonpressure-retaining material to pressure-retaining material over ⅝ in. (16 mm)	½ (13) or less	...	200 (95)
	Circumferential butt welds in pipe NPS 4 (DN 100) and less, and tubes with nominal O.D. 4.5 in. (114 mm) or less and attachment welds	½ (13) or less	0.15 or less	250 (120)
	Socket welds in pipe NPS 2 (DN 50) and less, and tubes with nominal O.D. 2⅜ in. (60 mm) or less	½ (13) or less	0.15 or less	250 (120)

Table NC-4622.7(b)-1
Exemptions to Mandatory PWHT (Cont'd)

P-No. (Section IX, QW-420)	Type of Weld [Note (1)]	Nominal Thickness, in. (mm) (NC-4622.3)	Max. Reported Carbon, % [Note (2)]	Min. Preheat Required, °F (°C)
9B Gr. 1	All welds provided the procedure qualification is made using equal or greater thickness base material than the production weld [Note (6)]	5/8 (16) or less	...	200 (95)
	Attachment welds joining nonpressure-retaining material to pressure-retaining material over 5/8 in. (16 mm)	1/2 (13) or less	...	200 (95)
	Circumferential butt welds in pipe NPS 4 (DN 100) and less, and tubes with nominal O.D. 4.5 in. (114 mm) or less and attachment welds	1/2 (13) or less	0.15 or less	250 (120)
	Socket welds in pipe NPS 2 (DN 50) and less, and tubes with nominal O.D. 2 3/8 in. (60 mm) or less	1/2 (13) or less	0.15 or less	250 (120)
10C Gr. 1	All welds, including repair welds, in material 1 1/2 in. (38 mm) and less	1 1/4 (32) and less	0.30 and less	...
		Over 1 1/4 to 1 1/2 (32 to 38)	0.30 and less	200 (95)
		3/4 (19) or less	Over 0.30	...
		Over 3/4 to 1 1/2 (19 to 38)	Over 0.30	200 (95)
	Fillet, partial penetration, and repair welds in material over 1 1/2 in. (38 mm)	3/4 (19) or less	...	200 (95)
10I Gr. 1	All welds in material 1/2 in. (13 mm) and less	1/2 (13) or less	...	...
11A Gr. 4	All welds in material 1/2 in. (13 mm) and less	1/2 (13) or less	...	250 (120)

GENERAL NOTE: The exemptions noted in this table do not apply to the following:
(1) electron beam welds in ferritic materials over 1/8 in. (3 mm) in thickness
(2) inertia and friction welds in material of any thickness of P-Nos. 3, 4, 5, 7 (except for Types 405 and 410 S), 10, and 11 materials

NOTES:
(1) Where the thickness of material is identified in the column Type of Weld, it is the thickness of the base material at the welded joint.
(2) Carbon level of the pressure-retaining materials being joined.
(3) The maximum resulting hardness of the heat affected zone in the procedure qualification test plate shall not exceed 35 Rc.
(4) Intermediate postweld soak at not less than 200°F (95°C) for 2-hr minimum.
(5) Intermediate postweld soak at not less than 300°F (150°C) for 2-hr minimum.
(6) Weld Procedure Qualification coupon need not exceed 1.5 in. (38 mm) in thickness.

(4) weld metal with A-No. 1 or A-No. 2 analysis is used to join the nozzle or branch pipe of P-No. 1 material to the weld buildup or buttering;

(5) the nominal thickness of the weld joining the nozzle or branch pipe to the component or run pipe does not exceed 1 1/2 in. (38 mm), and the maximum reported carbon content of the nozzle or branch piping connection does not exceed 0.30%;

(6) a 200°F (95°C) minimum preheat is maintained during welding whenever the nominal thickness of the weld exceeds:

(-a) 1 1/4 in. (32 mm) and the maximum reported carbon content of the material of the nozzle or branch pipe is 0.30% or less; or

(-b) 3/4 in. (19 mm) and the maximum reported carbon content of material of the nozzle or branch pipe connection exceeds 0.30%.

NC-4622.9 Weld Repair to Vessels. Limited weld repairs to vessels of P-No. 3 materials and A-No. 1, A-No. 2, A-No. 10, or A-No. 11 weld filler metal (Section IX, Table QW-442) may be made without PWHT or after the final PWHT, provided the requirements of the following subparagraphs are met:

(a) Examination of Area to Be Repaired. Before a repair is made, the area shall be examined by magnetic particle or liquid penetrant method in accordance with NC-5110 and shall meet the acceptance standards of NC-5340 or NC-5350, as appropriate.

(b) Maximum Extent of Repairs. A repair shall not exceed 10 in.^{2} (6 500 mm^2) in surface area and shall not be greater in depth than 50% of the base metal or weld thickness or 1/2 in. (13 mm), whichever is less.

(c) Repair Welding Procedure

(1) The repairs shall be made using one or more procedures and welders qualified in accordance with Section IX and the requirements of this Subsection using the shielded metal-arc process and low hydrogen covered electrodes.

(2) The largest electrode diameter shall be $^5/_{32}$ in. (4 mm), and the bead width shall not exceed four times the electrode diameter.

(3) The repair weld shall be made with a minimum of two layers of weld metal. The last layer shall be limited or ground off so that the weld surface does not extend above the base metal a greater distance than that allowed for reinforcement of butt welds.

(4) A preheat and interpass temperature of 300°F (150°C) minimum shall be used.

(d) Examination of Repair Welds. Following the repair and when the area has reached ambient temperature, the area shall again be examined by magnetic particle methods and accepted in accordance with (a) above.

NC-4623 PWHT Heating and Cooling Rate Requirements

Above 800°F (425°C), the rate of heating and cooling in any hourly interval shall not exceed 400°F (220°C) divided by the maximum thickness in inches (millimeters) of the material being heat treated, but shall not exceed 400°F (220°C) and need not be less than 100°F (56°C) in any hourly interval. During the heating and cooling period there shall not be a greater variation in temperature than 250°F (140°C) within any 15 ft (4.5 m) interval of weld length. The exceptions of (a) and (b) below are permitted.

(a) P-No. 6 materials may be cooled in air from the postweld heat treatment holding temperature specified in Table NC-4622.1-1.

(b) For P-No. 7 materials the cooling rate at temperatures above 1,200°F (650°C) shall not exceed 100°F/hr (56°C/h), after which the rate of cooling shall be sufficiently rapid to prevent embrittlement.

NC-4624 Methods of Postweld Heat Treatment

The postweld heat treatment shall be performed in accordance with the requirements of one of the following subparagraphs.

NC-4624.1 Furnace Heating — One Heat. Heating the component or item in a closed furnace in one heat is the preferred procedure and should be used whenever practical. The furnace atmosphere shall be controlled so as to avoid excessive oxidation, and direct impingement of flame on the component or item is prohibited.

NC-4624.2 Furnace Heating — More Than One Heat. The component or item may be heated in more than one heat in a furnace, provided the furnace atmosphere control requirements of NC-4624.1 apply and that overlap of the heated sections of the component or item is at least 5 ft (1.5 m). When this procedure is used, the portion of the component or item outside the furnace shall be shielded so that the temperature gradient is not harmful. The cross section where the component or item projects from the furnace shall not intersect a nozzle or other structural discontinuity.

NC-4624.3 Local Heating. Welds may be locally postweld heat treated when it is not practical to heat treat the entire component or item. Local postweld heat treatment shall consist of heating a circumferential band around the component or item at temperatures within the ranges specified in this subarticle. The minimum width of the controlled band at each side of the weld, on the face of the greatest weld width, shall be the thickness of the weld or 2 in. (50 mm), whichever is less. The temperature of the component or item from the edge of the controlled band outward shall be gradually diminished so as to avoid harmful thermal gradients. This procedure may also be used for postweld heat treatment after repairs.

NC-4624.4 Heating Components Internally. The component or item may be heated internally by any appropriate means and with adequate indicating and recording temperature devices to aid in the control and maintenance of a uniform distribution of temperature in the component or item. Previous to this operation, the component or item should be fully enclosed with insulating material.

NC-4630 HEAT TREATMENT OF WELDS OTHER THAN THE FINAL POSTWELD HEAT TREATMENT

The holding temperature, the time at temperature, the heating rate, and the cooling rate need not conform to the requirements of this Article for heat treatments other than the final postweld heat treatment.

NC-4650 HEAT TREATMENT AFTER BENDING OR FORMING FOR PIPE, PUMPS, AND VALVES

NC-4651 Conditions Requiring Heat Treatment After Bending or Forming

(a) Ferritic alloy steel pipe or formed portions of pumps or valves that have been heated for bending or other forming operations shall receive a heat treatment in accordance with NC-4620, a full anneal, a normalizing and tempering treatment, or a quenching and tempering treatment.

(b) Carbon steel pipe or formed portions of pumps or valves with a wall thickness greater than $^3/_4$ in. (19 mm) included in group P-No. 1 in Section IX that have been cold bent or formed shall receive heat treatment in accordance with NC-4620.

(c) Ferritic alloy pipe or formed portions of pumps or valves with an outside diameter greater than 4 in. (100 mm) and a wall thickness greater than $^1/_2$ in.

(13 mm) included in groups P-No. 3 through P-No. 5 in Section IX that have been cold bent or formed shall require a heat treatment in accordance with NC-4620.

NC-4652 Exemptions From Heat Treatment After Bending or Forming

If the conditions described in (a) through (d) are met, heat treatment after bending or forming is not required.

(a) Carbon steel pipe or portions of pumps and valves that have been bent or formed at a temperature of 1,650°F (900°C) or higher shall require no subsequent heat treatment, providing the requirements of NC-4213 have been met.

(b) Austenitic stainless steel pipe, or portions of pumps or valves that have been heated for bending or other forming operations, may be used in the as-bent condition, unless the Design Specifications require a heat treatment following bending or forming.

(c) Austenitic stainless steel pipe or portions of pumps or valves that have been cold bent or formed may be used in the as-bent condition, unless the Design Specifications require a heat treatment following bending or forming.

(d) Carbon steel and ferritic alloy-steel pipe or portions of pumps or valves with size and wall thicknesses less than specified in NC-4651(b) and NC-4651(c) may be cold bent or formed without a heat treatment following bending.

NC-4660 HEAT TREATMENT OF ELECTROSLAG WELDS

Electroslag welds in ferritic material over $1^1/_2$ in. (38 mm) in thickness at the joints shall be given a grain refining heat treatment.

NC-4700 MECHANICAL JOINTS

NC-4710 BOLTING AND THREADING

NC-4711 Thread Engagement

The threads of all bolts or studs shall be engaged in accordance with the design.

NC-4712 Thread Lubricants

Any lubricant or compound used in threaded joints shall be suitable for the service conditions and shall not react unfavorably with either the service fluid or any component material in the system.

NC-4713 Removal of Thread Lubricants

All threading lubricants or compounds shall be removed from surfaces which are to be seal welded.

NC-4720 BOLTING FLANGED JOINTS

In bolting gasketed flanged joints, the contact faces of the flanges shall bear uniformly on the gasket and the gasket shall be properly compressed in accordance with the design principles applicable to the type of gasket used. All flanged joints shall be made up with relatively uniform bolt stress.

NC-4730 ELECTRICAL AND MECHANICAL PENETRATION ASSEMBLIES

(a) Electrical and mechanical penetration assemblies, except those portions performing an electrical conducting or insulating function, shall be constructed in accordance with the rules for components.

(b) Tubes or pipes of NPS 2 (DN 50) and less may be joined to a penetration assembly in accordance with the rules of NC-4350.

(c) The closing seam for the penetration assembly may be made with a multipass single lap fillet weld as shown in Figure NC-4730-1, provided the requirements of (1) through (5) below are met.

(1) One of the heads on the penetration assembly shall meet the requirements of NC-3352.3.

(2) The penetration assembly shall not exceed 18 in. (450 mm) outside diameter.

(3) The Design Pressure of the penetration assembly shall not exceed 100 psi (700 kPa) and the Design Temperature shall not exceed 400°F (205°C).

(4) Examination of the fillet weld shall be by the liquid penetrant method in accordance with NC-5350.

(5) The fillet weld and closure head shall meet the requirements of NC-3720(b).

NC-4800 EXPANSION JOINTS

NC-4810 FABRICATION AND INSTALLATION RULES FOR BELLOWS EXPANSION JOINTS

For bellows type expansion joints, the requirements of (a) through (f) below shall be met.

(a) All welded joints shall comply with the requirements of Article NC-4000.

(b) The longitudinal seam welds in the bellows shall be a butt type full penetration weld.

(c) The bellows of the expansion joint shall be attached to the welding ends or flange by circumferential welds of a butt type having a full penetration through the thickness of the bellows portion, as shown in Figure NC-4810(c)-1.

(d) Other than the attachment welds, no circumferential welds are permitted in the bellows elements.

(e) Prior to installation of the expansion joint in the system, weld repairs shall not be permitted on parent material of the bellows.

(f) See NC-3649.2 for general requirements applicable to fabrication and installation.

Figure NC-4730-1
Penetration Assembly

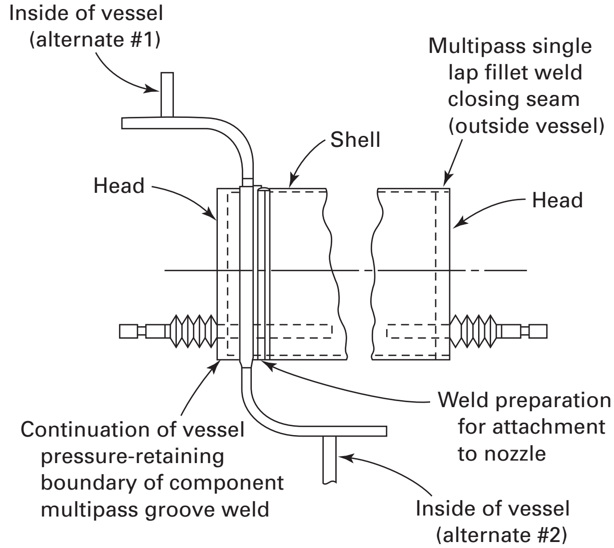
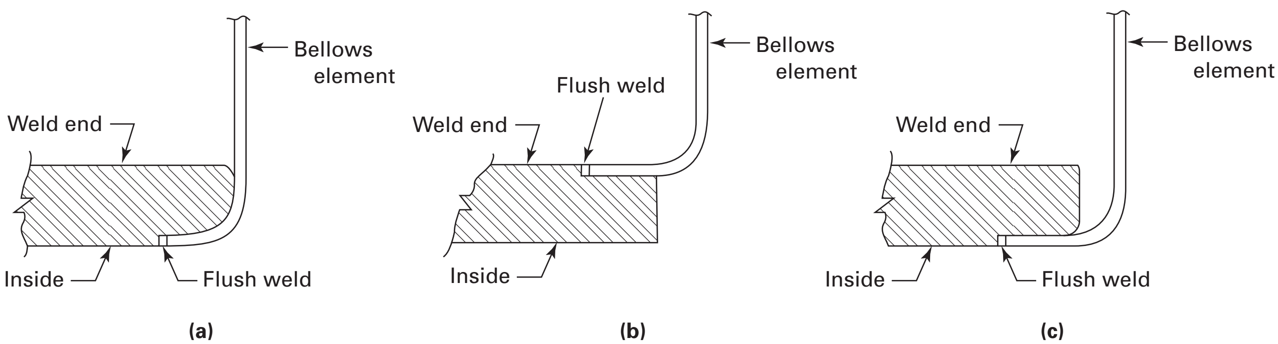


Figure NC-4810(c)-1
Permissible Attachment Welds for Bellows



ARTICLE NC-5000
EXAMINATION

NC-5100 GENERAL REQUIREMENTS FOR EXAMINATION

NC-5110 PROCEDURE, QUALIFICATION, AND EVALUATION

NC-5111 General Requirements

(a) Nondestructive examinations shall be conducted in accordance with the examination methods of Section V, except as they may be modified by the requirements of this Article. Radiographic examination shall be performed in accordance with Section V, Article 2, except that fluorescent screens are not permitted for film radiography, the geometric unsharpness shall not exceed the limits of Section V, Article 2, T-274.2, and the image quality indicators (IQIs) of Table NC-5111-1 shall be used in lieu of those shown in Section V, Article 2, Table T-276. The requirements for the retention of electronic and digital radiographic images are the same as that for radiographic film. Ultrasonic examination shall be in accordance with Section V, Article 4; magnetic particle examination shall be in accordance with Section V, Article 7; liquid penetrant examination shall be in accordance with Section V, Article 6; and leak testing shall be in accordance with Section V, Article 10.

(b) Class 2 pressure vessels designed to the requirements of NC-3200 shall meet the requirements of NC-5250 in lieu of NC-5210 through NC-5240.

(c) Nondestructive examination requirements for tanks are given in NC-5280.

(d) The examinations required by this Article, or by reference to this Article, shall be performed by personnel who have been qualified as required by this Article. The results of the examinations shall be evaluated in accordance with the acceptance standards of this Article.

NC-5112 Nondestructive Examination Procedures

All nondestructive examinations required by this Article shall be performed in accordance with detailed written procedures which have been proven by actual demonstration to the satisfaction of the Inspector. The procedure shall comply with the appropriate Article of Section V for the particular examination method. The digitization of radiographic film and radioscopic images shall meet the requirements of Section V, Article 2, Mandatory Appendix III, "Digital Image Acquisition, Display and Storage for Radiography and Radioscopy." Written procedures and records of demonstration of procedure capability and personnel qualification shall be made available to the Inspector on request. At least one copy of the procedure shall be readily available to all applicable nondestructive examination personnel for reference and use.

NC-5113 Post-Examination Cleaning

Following any nondestructive examination in which examination materials are applied to the piece, the piece shall be thoroughly cleaned in accordance with applicable materials or procedure specifications.

NC-5120 TIME OF EXAMINATION OF WELDS AND WELD METAL CLADDING

Acceptance examinations of welds and weld metal cladding required by NC-5200 shall be performed at the times stipulated in (a) through (d) below during fabrication and installation.

(a) Radiographic examination of welds shall be performed after an intermediate[60] or final postweld heat treatment, when required, except as provided in (1) and (2) below.

(1) Radiographic examination of welds in items fabricated of P-No. 1 materials may be performed prior to any required postweld heat treatment.

(2) Radiographic examination of welds in P-No. 3 materials may be performed prior to an intermediate or final postweld heat treatment provided the welds are ultrasonically examined after an intermediate or the final postweld heat treatment. The ultrasonic examination and acceptance standards shall be in accordance with this Article.

(b) Magnetic particle or liquid penetrant examinations of welds shall be performed after any required postweld heat treatment, except that welds in P-No. 1 materials may be examined either before or after postweld heat treatment.

(c) All dissimilar metal weld joints such as in austenitic or high nickel to ferritic material or using austenitic or high nickel alloy filler metal to join ferritic materials which penetrate the wall shall be examined after final postweld heat treatment.

(d) The magnetic particle or liquid penetrant examination of weld surfaces that are to be covered with weld metal cladding shall be performed before the weld metal cladding is deposited. The magnetic particle or liquid penetrant examination of weld surfaces that are not

Table NC-5111-1
Thickness, IQI Designations, and Essential Holes, and Wire Diameters

Single Wall Material Thickness Range, in. (mm)	IQI(s) — Hole or Wire Type [Note (1)] Source Side: Designation	Source Side: Hole Size, in. (mm)	Source Side: Essential Hole	Source Side: Required Wire Diameter — IQI, in. (mm)	Film Side: Designation	Film Side: Hole Size, in. (mm)	Film Side: Essential Hole	Film Side: Required Wire Diameter — IQI, in. (mm)
Up to $^1/_4$ (6), incl.	5	0.040 (1.02)	4*T*	0.006 (0.15)	5	0.040 (1.02)	4*T*	0.006 (0.15)
Over $^1/_4$ to $^3/_8$ (6 to 10)	7	0.040 (1.02)	4*T*	0.006 (0.15)	7	0.040 (1.02)	4*T*	0.006 (0.15)
Over $^3/_8$ to $^1/_2$ (10 to 13)	10	0.040 (1.02)	4*T*	0.010 (0.25)	10	0.040 (1.02)	4*T*	0.010 (0.25)
Over $^1/_2$ to $^5/_8$ (13 to 16)	12	0.050 (1.27)	4*T*	0.013 (0.33)	12	0.050 (1.27)	4*T*	0.013 (0.33)
Over $^5/_8$ to $^3/_4$ (16 to 19)	15	0.060 (1.52)	4*T*	0.016 (0.41)	12	0.050 (1.27)	4*T*	0.013 (0.33)
Over $^3/_4$ to 1 (19 to 25)	20	0.040 (1.02)	2*T*	0.016 (0.41)	17	0.035 (0.89)	2*T*	0.013 (0.33)
Over 1 to 1$^1/_4$ (25 to 32)	25	0.050 (1.27)	2*T*	0.020 (0.51)	17	0.035 (0.89)	2*T*	0.013 (0.33)
Over 1$^1/_4$ to 1$^1/_2$ (32 to 38)	30	0.060 (1.52)	2*T*	0.025 (0.64)	20	0.040 (1.02)	2*T*	0.016 (0.41)
Over 1$^1/_2$ to 2 (38 to 50)	35	0.070 (1.78)	2*T*	0.032 (0.81)	25	0.050 (1.27)	2*T*	0.020 (0.51)
Over 2 to 2$^1/_2$ (50 to 64)	40	0.080 (2.03)	2*T*	0.040 (1.02)	30	0.060 (1.52)	2*T*	0.025 (0.64)
Over 2$^1/_2$ to 3 (64 to 75)	45	0.090 (2.29)	2*T*	0.040 (1.02)	35	0.070 (1.78)	2*T*	0.032 (0.81)
Over 3 to 4 (75 to 100)	50	0.100 (2.54)	2*T*	0.050 (1.27)	40	0.080 (2.03)	2*T*	0.040 (1.02)
Over 4 to 6 (100 to 150)	60	0.120 (3.05)	2*T*	0.063 (1.60)	45	0.090 (2.29)	2*T*	0.040 (1.02)
Over 6 to 8 (150 to 200)	80	0.160 (4.06)	2*T*	0.100 (2.54)	50	0.100 (2.54)	2*T*	0.050 (1.27)
Over 8 to 10 (200 to 250)	100	0.200 (5.08)	2*T*	0.126 (3.20)	60	0.120 (3.05)	2*T*	0.063 (1.60)
Over 10 to 12 (250 to 300)	120	0.240 (6.10)	2*T*	0.160 (4.06)	80	0.160 (4.06)	2*T*	0.100 (2.54)
Over 12 to 16 (300 to 400)	160	0.320 (8.13)	2*T*	0.250 (6.35)	100	0.200 (5.08)	2*T*	0.126 (3.20)
Over 16 to 20 (400 to 500)	200	0.400 (10.16)	2*T*	0.320 (8.13)	120	0.240 (6.10)	2*T*	0.160 (4.06)

NOTE:
(1) Hole (plaque) type IQIs may be used on flat plates and on objects with geometries such that the IQI hole image is not distorted.

accessible after a postweld heat treatment shall be performed prior to the operation which caused this inaccessibility. These examinations may be performed before PWHT.

(e) Ultrasonic examination of electroslag welds in ferritic materials shall be performed after a grain refining heat treatment, when performed, or after final postweld heat treatment.

NC-5130 EXAMINATION OF WELD EDGE PREPARATION SURFACES

All full penetration weld edge preparation surfaces for joint Categories A, B, C, D, and similar joints in material 2 in. or more in thickness shall be examined by the magnetic particle or liquid penetrant method. Indications shall be evaluated in accordance with the acceptance standards of (a), (b), and (c) below.

(a) Only indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Laminar-type imperfections are acceptable without repair if they do not exceed 1 in. (25 mm) in length. The extent of all laminar-type imperfections exceeding 1 in. (25 mm) in length shall be determined by ultrasonic examination. Imperfections exceeding 1 in. (25 mm) in length shall be repaired by welding to a depth of $^3/_8$ in. (10 mm) or the depth of the imperfection, whichever is less, unless the ultrasonic examination reveals that additional depth of repair is required to meet the ultrasonic examination requirement for the product form.

(c) Indications of nonlaminar imperfections of (1) through (3) below are unacceptable:

(1) any linear indications greater than $^3/_{16}$ in. (5 mm) long;

(2) rounded indications with dimensions greater than $^3/_{16}$ in. (5 mm);

(3) four or more indications, in a line separated by $^1/_{16}$ in. (1.5 mm) or less, edge to edge.

(d) Weld repairs made to weld edge preparations for Categories A, B, C, D, and similar type welds shall be examined by the magnetic particle or liquid penetrant method before the surfaces become inaccessible. The examination may be performed before or after postweld heat treatment.

NC-5140 EXAMINATION OF OPENINGS CUT IN VESSELS DESIGNED TO NC-3200

For nozzle connections with necks abutting the vessel wall [Figure NC-4266(b)-1 sketches (a) and (b)], the radially disposed surfaces of the openings cut in the vessel walls shall be examined by either magnetic particle method or a liquid penetrant method in accordance with the requirements of this Article. Defects thus discovered shall be removed and repaired as required by the applicable Article.

NC-5200 EXAMINATION OF WELDS[61]

NC-5210 CATEGORY A VESSEL WELDED JOINTS AND LONGITUDINAL WELDED JOINTS IN PIPING, PUMPS, AND VALVES

NC-5211 Vessel Welded Joints

(a) Category A welded joints shall be fully radiographed when either of the members being joined exceeds $^3/_{16}$ in. (5 mm) thickness.

(b) Category A welded joint surfaces may be examined by either the magnetic particle or liquid penetrant method as an alternative to the radiographic examination when the thickness of each member being joined is $^3/_{16}$ in. (5 mm) or less.

NC-5212 Pipe, Pump, and Valve Welded Joints

Longitudinal butt welded joints, as defined in NC-3351.1, shall be radiographed.

NC-5220 CATEGORY B VESSEL WELDED JOINTS AND CIRCUMFERENTIAL WELDED JOINTS IN PIPING, PUMPS, AND VALVES

NC-5221 Vessel Welded Joints

(a) Category B welded joints shall be fully radiographed when either of the members being joined exceeds $^3/_{16}$ in. (5 mm) thickness.

(b) Category B welded joint surfaces may be examined by either the magnetic particle or liquid penetrant method as an alternative to the radiographic examination when the thickness of each member being joined is $^3/_{16}$ in. (5 mm) or less.

NC-5222 Piping, Pump, and Valve Welded Joints

(a) Butt welded joints shall be radiographed.

(b) Fillet and partial penetration welded joints shall be examined by either the magnetic particle or liquid penetrant method.

(c) Instrument tube butt welds qualified in accordance with NC-4337 shall be examined by the liquid penetrant method.

NC-5230 CATEGORY C VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN OTHER COMPONENTS

(a) Category C full penetration butt welded joints and similar welded joints in other components shall be fully radiographed when either of the members being joined exceeds $^3/_{16}$ in. (5 mm) of thickness.

(b) Category C full penetration corner welded joints and similar welded joints in other components shall be ultrasonically or radiographically examined when either of the members being joined exceeds $^3/_{16}$ in. (5 mm) of thickness.

(c) Category C welded joint surfaces and similar welded joints in other components may be examined by either the magnetic particle or liquid penetrant method as an alternative to the radiographic or ultrasonic examination when the thickness of each member being joined is $^3/_{16}$ in. (5 mm) or less.

(d) Category C partial penetration and fillet welded joints and similar welded joints in other components shall be examined by the magnetic particle or liquid penetrant method on all accessible surfaces.

NC-5240 CATEGORY D VESSEL WELDED JOINTS AND SIMILAR WELDED JOINTS IN OTHER COMPONENTS

NC-5241 Vessel Welded Joints

(a) Category D full penetration butt welded joints and similar welded joints in other components shall be fully radiographed when either of the members being joined exceeds $^3/_{16}$ in. (5 mm) of thickness.

(b) Category D full penetration corner welded joints and similar welded joints in other components shall be ultrasonically or radiographically examined when either of the members being joined exceeds $^3/_{16}$ in. (5 mm) of thickness.

(c) Category D welded joint surfaces and similar welded joints in other components may be examined by either the magnetic particle or liquid penetrant method as an alternative to the radiographic or ultrasonic examination when the thickness of each member being joined is $^3/_{16}$ in. (5 mm) or less.

(d) Category D partial penetration and fillet welded joints and similar welded joints in other components shall be examined by the magnetic particle or liquid penetrant method on all accessible surfaces.

NC-5242 Welded Branch Connections[62] and Nozzles in Piping, Pumps, and Valves

(a) Branch connections[62] and nozzles exceeding NPS 4 (DN 100) shall be examined by radiography.

(b) Branch connections[62] and nozzles NPS 4 (DN 100) and smaller shall have the external weld surface and the accessible internal weld surface examined by either the magnetic particle or liquid penetrant method.

NC-5250 EXAMINATION OF WELDS FOR VESSELS DESIGNED TO NC-3200

NC-5251 Category A Welded Joints

Category A welded joints shall be fully radiographed.

NC-5252 Category B Welded Joints

Category B welded joints shall be fully radiographed.

NC-5253 Category C Welded Joints

(a) Category C full penetration butt welded joints shall be fully radiographed.

(b) Category C full penetration corner welded joints shall be ultrasonically or radiographically examined.

(c) For corner joint constructions as illustrated in Figure NC-4265-1 sketches (b) and (c), except when dimension b is equal to or greater than t_s, the unstayed flat head, prior to welding, shall be 100% examined by the ultrasonic method in accordance with the requirements of SA-435, except that no lamination in the head is acceptable.

NC-5254 Category D Welded Joints

(a) Category D full penetration butt welded joints shall be fully radiographed.

(b) Category D full penetration corner welded joints shall be ultrasonically or radiographically examined.

(c) Category D partial penetration or fillet welded joints shall be examined by either the liquid penetrant or magnetic particle method on all accessible surfaces.

NC-5257 Other Welded Joints for Vessels Designed to NC-3200

The requirements of NC-5260, NC-5270, and NC-5410 also apply to vessels designed to NC-3200.

NC-5260 FILLET, PARTIAL PENETRATION, SOCKET, AND ATTACHMENT WELDS

NC-5261 Fillet, Partial Penetration, and Socket Welded Joints

Fillet and partial penetration welds, except for nonstructural attachments (NC-1132.1), and socket welds shall be examined by the magnetic particle or liquid penetrant method.

NC-5262 Structural Attachment Welded Joints

Structural attachment welded joints made to pressure-retaining material shall be examined by either the magnetic particle or liquid penetrant method.

NC-5270 SPECIAL WELDS

NC-5271 Welds of Specially Designed Seals

Welds of this type shall be examined by either the magnetic particle or liquid penetrant method.

NC-5272 Weld Metal Cladding

Weld metal cladding shall be examined by the liquid penetrant method.

NC-5273 Hard Surfacing

Hard surfacing shall be examined by the liquid penetrant method in accordance with NC-2546, and the acceptance standards applicable to materials less than $^5/_8$ in. (16 mm) thick shall apply. Penetrant examination is not required for hard surfacing on valves with inlet connections NPS 4 (DN 100) or less.

NC-5274 Tube-to-Tubesheet Welds

Tube-to-tubesheet welds shall be examined by the liquid penetrant method.

NC-5275 Brazed Joints

Flux and flux residue shall be removed from all surfaces prior to examination. Joints shall be visually examined on all accessible surfaces to determine whether there has been adequate flow of brazing metal through the joint. Optical aids may be employed for indirect visual examination of joints which cannot be directly examined.

NC-5276 Inertia and Continuous Drive Friction Welds

(a) When radiographic examination is required by this Article, inertia and continuous drive friction welds shall also be examined by the ultrasonic method to verify bonding over the entire area.

(b) The materials used shall be those assigned a P-Number by Section IX, but shall not include rimmed or semikilled steel.

(c) One of the two parts to be joined must be held in a fixed position and the other part rotated. The two faces to be joined must be symmetrical with respect to the axis of rotation.

(d) The weld between the two members shall be a full penetration weld.

NC-5278 Electroslag Welds

In addition to the requirements for the type of weld being examined, all complete penetration welds made by the electroslag welding process in ferritic materials shall be ultrasonically examined.

NC-5279 Special Exceptions

When the joint detail does not permit radiographic examination to be performed in accordance with this article, ultrasonic examination plus liquid penetrant or magnetic particle examination of the completed weld may be substituted for the radiographic examination. The absence of suitable radiographic equipment shall not be justification for such substitution. The substitution of ultrasonic examination can be made, provided the examination is performed using a detailed written procedure which has been proven by actual demonstration to the satisfaction of the Inspector as capable of detecting and locating defects described in this Subsection. The nondestructive examinations shall be in accordance with NC-5110 and meet the acceptance standards of NC-5300.

NC-5280 WELD JOINTS IN STORAGE TANKS

NC-5281 Examination Procedures

Nondestructive examinations of welds in storage tanks shall be in accordance with the examination procedures of Section V.

NC-5282 Atmospheric Storage Tanks

NC-5282.1 Sidewall Joints. Sidewall joints shall be fully radiographed.

NC-5282.2 Roof Joints and Roof-to-Sidewall Joints. Roof joints and roof-to-sidewall joints shall be examined visually.

NC-5282.3 Bottom Joints. Bottom joints shall be examined from the inside of the tank by applying soapsuds to the joints and pulling a partial vacuum of at least 3 psi (20 kPa) by means of a vacuum box with transparent top.

NC-5282.4 Bottom-to-Sidewall Joints. Bottom-to-sidewall joints shall be examined by the vacuum box method as detailed in NC-5282.3 and by a magnetic particle or liquid penetrant surface examination.

NC-5282.5 Nozzle-to-Tank Joints. Nozzle-to-sidewall or bottom joints shall be examined by either the magnetic particle or liquid penetrant method. Nozzle-to-roof joints shall be visually examined.

NC-5282.6 Joints in Nozzles. All joints in roof nozzles shall be visually examined. Butt joints in other nozzles shall be examined by the radiographic method; other types of nozzle joints shall be examined by the liquid penetrant or magnetic particle method.

NC-5282.7 Other Joints. Joints not specifically covered by NC-5282 shall be examined in the same manner as similar weld joints in vessels as required by this subarticle.

NC-5283 Weld Joints in 0 psi to 15 psi (0 kPa to 100 kPa) Storage Tanks

NC-5283.1 Sidewall Joints. Sidewall joints shall be fully radiographed.

NC-5283.2 Roof Joints. Roof joints shall be fully radiographed.

NC-5283.3 Roof-to-Sidewall Joints. Roof-to-sidewall joints shall be fully radiographed if the design permits. If not radiographed, these joints shall be examined by the magnetic particle or liquid penetrant method.

NC-5283.4 Bottom Joints. Joints in bottoms supported directly on grade shall be examined by the vacuum box method as detailed in NC-5282.3. Joints not supported directly on grade shall be fully radiographed.

NC-5283.5 Bottom-to-Sidewall Joints. Bottom-to-sidewall joints shall be examined by the vacuum box method as detailed in NC-5282.3 and by either the magnetic particle method or the liquid penetrant method.

NC-5283.6 Nozzle-to-Tank Joints. Nozzle-to-tank joints shall be examined by either the magnetic particle or liquid penetrant method.

NC-5283.7 Joints in Nozzles. Butt joints in nozzles shall be fully radiographed. Other joints shall be examined by magnetic particle or liquid penetrant methods.

NC-5283.8 Other Joints. Joints not specifically covered by NC-5283 shall be examined in the same manner as similar weld joints in vessels as required by this subarticle.

NC-5300 ACCEPTANCE STANDARDS

NC-5320 RADIOGRAPHIC ACCEPTANCE STANDARDS

Indications shown on the radiographs of welds and characterized as imperfections are unacceptable under the following conditions:

(a) any indication characterized as a crack or zone of incomplete fusion or penetration;

(b) any other elongated indication that has a length greater than:

(1) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm), inclusive

(2) $^1/_3t$ for t from $^3/_4$ in. to $2^1/_4$ in. (19 mm to 57 mm), inclusive

(3) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm)

where t is the thickness of the thinner portion of the weld.

(c) Internal root weld conditions are acceptable when the density change or image brightness difference as indicated in the radiograph is not abrupt; elongated indications on the radiograph at either edge of such conditions shall be unacceptable as provided in (b) above;

(d) any group of aligned indications having an aggregate length greater than t in a length of $12t$ unless the minimum distance between successive indications exceeds $6L$, in which case the aggregate length is unlimited, L being the length of the largest indication;

(e) rounded indications in excess of those shown as acceptable in Section III Appendices, Mandatory Appendix VI.

NC-5330 ULTRASONIC ACCEPTANCE STANDARDS

All imperfections that produce a response greater than 20% of the reference level shall be investigated to the extent that the operator can determine the shape, identity, and location of all such imperfections and evaluate them in terms of the acceptance rejection standards as given in (a) and (b) below.

(a) Imperfections are unacceptable if the indications exceed the reference level amplitude and have lengths exceeding:

(1) $^1/_4$ in. (6 mm) for t up to $^3/_4$ in. (19 mm), inclusive

(2) $^1/_3t$ for t from $^3/_4$ in. to $2^1/_4$ in. (19 mm to 57 mm), inclusive

(3) $^3/_4$ in. (19 mm) for t over $2^1/_4$ in. (57 mm) where t is the thickness of the weld being examined; if a weld joins two members having different thicknesses at the weld, t is the thinner of these two thicknesses.

(b) Indications characterized as cracks, lack of fusion, or incomplete penetration are unacceptable regardless of length.

NC-5340 MAGNETIC PARTICLE ACCEPTANCE STANDARDS

NC-5341 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by the retention of the examination medium. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined by the same or other nondestructive examination methods to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. After an indication has been verified to be nonrelevant, it is not necessary to reinvestigate repetitive nonrelevant indications of the same type. Nonrelevant indications which would mask defects are unacceptable.

(c) Relevant indications are those that result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

NC-5342 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $^3/_{16}$ in. (5 mm);

(3) four or more rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 in.^{2} (4 000 mm^2) of surface, with the major dimension of this area not to exceed 6 in. (150 mm), with the area taken in the most unfavorable location relative to the indications being evaluated.

NC-5350 LIQUID PENETRANT ACCEPTANCE STANDARDS

NC-5351 Evaluation of Indications

(a) Mechanical discontinuities at the surface are revealed by bleeding out of the penetrant; however, localized surface discontinuities such as may occur from machining marks, surface conditions, or an incomplete bond between base metal and cladding may produce similar indications that are nonrelevant.

(b) Any indication that is believed to be nonrelevant shall be reexamined to verify whether or not actual defects are present. Surface conditioning may precede the reexamination. Nonrelevant indications and broad areas of pigmentation that would mask defects are unacceptable.

(c) Relevant indications are those that result from imperfections. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications that are circular or elliptical with the length equal to or less than three times the width.

NC-5352 Acceptance Standards

(a) Only imperfections producing indications with major dimensions greater than $^1/_{16}$ in. (1.5 mm) shall be considered relevant imperfections.

(b) Imperfections producing the following indications are unacceptable:

(1) any cracks or linear indications;

(2) rounded indications with dimensions greater than $^3/_{16}$ in. (5 mm);

(3) four or more rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(4) ten or more rounded indications in any 6 in.^{2} (4 000 mm^2) of surface, with the major dimension of this area not to exceed 6 in. (150 mm), with the area taken in the most unfavorable location relative to the indications being evaluated.

NC-5360 VISUAL ACCEPTANCE STANDARDS FOR BRAZED JOINTS

Braze metal shall give evidence of having flowed uniformly through a joint by the appearance of an uninterrupted, narrow visible line of brazing alloy at the ends of the joint.

NC-5380 GAS AND BUBBLE FORMATION TESTING

For gas and bubble formation testing, the test procedure shall be in accordance with Section V, Article 10, T-1030. When vacuum box testing is used, the soak time shall be a minimum of 10 sec. Any indication of leaking, by the formation of bubbles or the breaking of the continuous soap film by leaks, shall be evidence of an unacceptable condition.

NC-5400 FINAL EXAMINATION OF COMPONENTS

NC-5410 EXAMINATION AFTER PRESSURE TESTING

After the required pressure test of a component constructed of ferritic materials with properties enhanced by quenching and tempering, all pressure-retaining welded joints shall be examined by the magnetic particle or liquid penetrant method on all accessible surfaces.

NC-5500 QUALIFICATIONS AND CERTIFICATION OF NONDESTRUCTIVE EXAMINATION PERSONNEL

NC-5510 GENERAL REQUIREMENTS

Organizations performing Code required nondestructive examinations shall use personnel competent and knowledgeable to the degree specified by NC-5520. When these services are subcontracted by the Certificate Holder or Quality System Certificate Holder, he shall verify the qualification of personnel to the requirements of NC-5520. All nondestructive examinations required by this Subsection shall be performed by and the results evaluated by qualified nondestructive examination personnel.

NC-5520 PERSONNEL QUALIFICATION, CERTIFICATION, AND VERIFICATION

(15) NC-5521 Qualification Procedure

(a) Personnel performing nondestructive examinations shall be qualified in accordance with the recommended guidelines of SNT-TC-1A.[63, 64] The ACCP Level II and III provisions for qualification and certification and the ASNT administered Level II certification provision for qualification and certification of NDE personnel shall not be used for Section III. The Employer's[65] written practice required by paragraph 5 of SNT-TC-1A shall identify his requirements relative to the recommended guidelines. The recommended guidelines of SNT-TC-1A shall be considered minimum requirements, except as modified in (1) through (5) below.

(1) Qualification of Level III nondestructive examination personnel shall be by examination.

(-a) The basic and method examinations, paragraphs 8.8.1 and 8.8.2 of SNT-TC-1A, may be prepared and administered by the Employer, ASNT, or an outside agency.

(-b) The specific examination, paragraph 8.8.3 of SNT-TC-1A, shall be prepared and administered by the Employer or an outside agency. The Employer or outside agency administering the specific examination shall identify the minimum grade requirement in the written program when the basic and method examinations have been administered by ASNT, which issues grades on a pass/fail basis. In this case, the minimum grade for the specific examination may not be less than 80%.

(2) The written practice identified in paragraph 5 of SNT-TC-1A and the procedures used for examination of personnel shall be referenced in the Employer's Quality Program.

(3) The number of hours of training and experience for nondestructive examination personnel who perform only one operation of a nondestructive examination method that consists of more than one operation, or perform nondestructive examination of limited scope, may be less than that recommended in Table 6.3.1 A of SNT-TC-1A. The training and experience times shall be described in the written practice, and any limitations or restrictions placed on the certification shall be described in the written practice and on the certificate.

The minimum classroom training times for visual examination personnel identified in Table 6.3.1 A of SNT-TC-1A for Level II certification may be reduced from 16 hr to 8 hr.

(4) For the near-vision acuity examination, the Jaeger Number 1 letters shall be used in lieu of the Jaeger Number 2 letters specified in paragraph 8.2.1 of SNT-TC-1A. The use of equivalent type and size letters is permitted.

(5) An NDE Level I individual shall be qualified to properly perform specific setups, specific calibrations, specific NDE, and specific evaluations for acceptance or rejection determinations according to written instructions and to record results. The NDE Level I individual shall receive the necessary instruction and supervision from a certified NDE Level II or Level III individual. A Level I individual may independently accept the results of nondestructive examinations when the specific acceptance criteria are defined in the written instructions.

(b) For nondestructive examination methods not covered by SNT-TC-1A documents, personnel shall be qualified to comparable levels of competency by subjection to comparable examinations on the particular method involved.

(c) The emphasis shall be on the individual's ability to perform the nondestructive examination in accordance with the applicable procedure for the intended application.

(d) For nondestructive examination methods that consist of more than one operation or type, it is permissible to use personnel qualified to perform one or more operations. As an example, one person may be used who is qualified to conduct radiographic examination and another may be used who is qualified to interpret and evaluate the radiographs.

NC-5522 Certification of Personnel

(a) The Employer retains responsibility for the adequacy of the program and is responsible for certification of Levels I, II, and III nondestructive examination personnel.

(b) When ASNT is the outside agency administering the Level III basic and method examinations [NC-5521(a)(2)], the Employer may use a letter from ASNT as evidence on which to base the certification.

(c) When an outside agency is the examining agent for Level III qualification of the Employer's personnel, the examination results shall be included with the Employer's record.

NC-5523 Verification of Nondestructive Examination Personnel Certification

The Certificate Holder has the responsibility to verify the qualification and certification of nondestructive examination personnel employed by Material Manufacturers and Material Suppliers qualified by them in accordance with NCA-3820 and subcontractors who provide nondestructive examination services to them.

NC-5530 RECORDS

Personnel qualification records identified in paragraph 9.4 of SNT-TC-1A shall be retained by the Employer.

NC-5700 EXAMINATION REQUIREMENTS FOR EXPANSION JOINTS

NC-5720 BELLOWS EXPANSION JOINTS

The examinations stipulated in (a) through (f) below are required to verify the integrity of bellows expansion joints for installation in components.

(a) The formed bellows shall be determined to be free of defects such as notches, crevices, material buildup or upsetting, weld spatter, etc., by visual examination. Suspect surface areas shall be further examined by liquid penetrant examination in accordance with NC-5110.

(b) The longitudinal seam welds in the bellows shall be examined by the liquid penetrant method in accordance with NC-5110. When the individual ply thickness exceeds $^1/_8$ in. (3 mm), the weld shall also be radiographed in accordance with NC-5110. These examinations may be performed either before or after the bellows is formed.

(c) The circumferential attachment welds between the bellows and pipe or flange shall be liquid penetrant examined in accordance with NC-5110 when the total bellows thickness is $^1/_4$ in. (6 mm) or less. When the total thickness exceeds this limit, the weld shall be radiographed in accordance with NC-5110 except where radiography is not meaningful, such as when the weld thickness constitutes less than 20% of the total thickness being radiographed, liquid penetrant examination may be substituted.

(d) In the case of liquid penetrant examination of bellows welds, imperfections producing the following indications are unacceptable:

(1) cracks or linear indications;

(2) four or more rounded indications in a line separated by $^1/_{16}$ in. (1.5 mm) or less edge to edge;

(3) five or more randomly distributed rounded indications in a weld length of 6 in. (150 mm);

(4) any rounded indication exceeding the lesser of one-half the bellows thickness or $^1/_{16}$ in. (1.5 mm) in diameter.

(e) The examination of all other welds in the expansion joint shall comply with Article NC-5000.

(f) The variation of the cylindrical end thickness of the formed bellows from the nominal or specified thickness shall not exceed the values given in Table 2 of SA-480. Thinning of the bellows material during forming shall be considered in the design and selection of material thickness, but need not be limited to the values specified in Table 2 of SA-480.

ARTICLE NC-6000 TESTING

NC-6100 GENERAL REQUIREMENTS

NC-6110 PRESSURE TESTING OF COMPONENTS, APPURTENANCES, AND SYSTEMS

NC-6111 Scope of Pressure Testing

All pressure-retaining components, appurtenances, and completed systems shall be pressure tested, except as specified in (a) through (d) below. Portions of piping systems which are exempt shall be identified in the Design Specification and the Data Report Form N-5 (see Section III Appendices, Mandatory Appendix V). The Design Specification shall be available to the Authorized Nuclear Inspector when the balance of the system is hydrostatically tested.

(a) Bolts, studs, nuts, washers, and gaskets are exempt.

(b) The following portions of piping systems whose only function is to transport fluids to and from spray ponds, lakes, reservoirs, or tanks which are open to the atmosphere are exempt:

(1) piping downstream of the last isolation valve preceding the pipe discharge to the spray pond, lake, reservoir, or tank; and

(2) piping upstream of the intake pump inlet isolation valve.

(c) Where systems discharge into Class 2 vessels, or the gaseous regions of MC containment vessels through spargers or spray nozzles, only that portion of the system external to the vessel is required to be pressure tested.

(d) The portion of a Class 2 safety and safety relief valve discharge piping that is submerged below the minimum Design Level in a containment pressure suppression pool of an MC or CC containment vessel is exempt. The minimum Design Level shall be specifically designated in the Design Specification.

NC-6112 Pneumatic Testing

A pneumatic test in accordance with NC-6300 may be substituted for the hydrostatic test when permitted by NC-6112.1(a).

NC-6112.1 Pneumatic Test Limitations.

(a) A pneumatic test may be used in lieu of a hydrostatic test only when any of the following conditions exist:

(1) when components, appurtenances, or systems are so designed or supported that they cannot be safely filled with liquid[66]

(2) when components, appurtenances, or systems which are not readily dried are to be used in services where traces of the testing medium cannot be tolerated.

(b) A pneumatic test at a pressure not to exceed 25% of the Design Pressure may be applied, prior to either a hydrostatic or a pneumatic test, as a means of locating leaks.

NC-6112.2 Precautions to Be Employed in Pneumatic Testing. Compressed gaseous fluid is hazardous when used as a testing medium. Therefore, it is recommended that special precautions for protection of personnel be taken when a gaseous fluid under pressure is used as a test medium.

NC-6113 Witnessing of Pressure Tests

Pressure testing required by this Article shall be performed in the presence of the Inspector, except that testing of each line valve and each pump having piping connections of NPS 4 (DN 100) and less need not be witnessed by the Inspector. For line valves and pumps NPS 4 (DN 100) and less, the Inspector's review and acceptance of the Certificate Holder's test records will be authorization to sign the Data Report Form, and takes precedence over NCA-5280.

NC-6114 Time of Pressure Testing

NC-6114.1 System Pressure Test. The installed system shall be pressure tested prior to initial operation.

The pressure test may be performed progressively on erected portions of the system.

NC-6114.2 Component and Appurtenance Pressure Test.

(a) Components and appurtenances shall be pressure tested prior to installation in a system, except as permitted in (b) below.

(b) The system pressure test may be substituted for a component or appurtenance pressure test, provided:

(1) the component can be repaired by welding in accordance with the rules of NC-4130 and NC-4450, if required, as a result of the system pressure test;

(2) the component repair weld can be postweld heat treated in accordance with NC-4620, if required, and nondestructively examined in accordance with the rules of NC-4130 and NC-4450, as applicable; and

(3) the component is resubjected to the required system pressure test following the completion of repair and examination if the repair is required to be radiographed by NC-4453.4.

(c) Valves require pressure testing prior to installation in a system in accordance with NC-3500.

(d) Items which, when assembled, form a completed pump or valve may be tested in the form of subassemblies, provided:

(1) the test pressure is in accordance with the requirements of NC-6221;

(2) the pressure test is performed in a manner which, in the subassembly under test, will simulate the loadings present when the completed pump or valve is assembled and pressurized;

(3) the component Certificate Holder approves any pressure test of component subassemblies;

(4) the component Certificate Holder specifies the pressure test requirements and test pressure to be used;

(5) each subassembly pressure test is performed by a Certificate Holder and is performed in the presence of the Authorized Nuclear Inspector;

(6) each subassembly pressure tested by other than the component Certificate Holder is stamped with the Certification Mark with NPT Designator, except as provided in NCA-8330; the test pressure shall be identified on the Partial Data Report Form;

(7) each subassembly pressure tested by other than the component Certificate Holder is listed on the Code Data Report Form;

(8) the pressure tested subassemblies of pumps or valves are subsequently assembled by mechanical methods only;

(9) welds examined during the subassembly pressure test need not be reexamined during the system pressure test.

NC-6114.3 Material Pressure Test. The component or appurtenance pressure test may be used in lieu of any such test required by the material specification for a part or material used in the component or appurtenance, provided:

(a) nondestructive examinations, if required by the material specification, can be performed subsequent to the component or appurtenance pressure test;

(b) the material can be repaired by welding in accordance with the rules of NC-4130 if required as a result of the pressure test; and

(c) postweld heat treatment, when required after repairs, can be performed in accordance with NC-4620.

NC-6115 Machining After Pressure Test

An additional amount of material, not to exceed 10% of the wall thickness or $^3/_8$ in. (10 mm), whichever is less, is permitted on the completed component during pressure testing where machining to critical dimensions and tolerances is required.

NC-6120 PREPARATION FOR TESTING

NC-6121 Exposure of Joints

All joints, including welded joints, shall be left uninsulated and exposed for examination during the test.

NC-6122 Addition of Temporary Supports

Components designed to contain vapor or gas may be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

NC-6123 Restraint or Isolation of Expansion Joints

Expansion joints shall be provided with temporary restraints, if required, for the additional pressure load under test.

NC-6124 Isolation of Equipment Not Subjected to Pressure Test

Equipment that is not to be subjected to the pressure test shall be either disconnected from the component or system or isolated during the test by a blind flange or similar means. Valves may be used if the valves with their closures are suitable for the proposed test pressure.

NC-6125 Treatment of Flanged Joints Containing Blanks

Flanged joints at which blanks are inserted to isolate other equipment during the test need not be retested.

NC-6126 Precautions Against Test Medium Expansion

If a pressure test is to be maintained for a period of time and the test medium in the system is subject to thermal expansion, precautions shall be taken to avoid excessive pressure.

NC-6127 Check of Test Equipment Before Applying Pressure

The test equipment shall be examined before pressure is applied to ensure that it is tight and that all low pressure filling lines and other items that should not be subjected to the test have been disconnected or isolated.

NC-6200 HYDROSTATIC TESTS

The requirements of this paragraph apply to all components except tanks, for which NC-6500 applies.

NC-6210 HYDROSTATIC TEST PROCEDURE

NC-6211 Venting During Fill Operation

The component or system in which the test is to be conducted shall be vented during the filling operation to minimize air pocketing.

NC-6212 Test Medium and Test Temperature

(a) Water or an alternative liquid, as permitted by the Design Specification, shall be used for the hydrostatic test.

(b) It is recommended that the test be made at a temperature that will minimize the possibility of brittle fracture. The test pressure shall not be applied until the component, appurtenance, or system and the pressurizing fluid are at approximately the same temperature.

NC-6220 HYDROSTATIC TEST PRESSURE REQUIREMENTS

NC-6221 Minimum Hydrostatic Test Pressure

(a) The installed system shall be hydrostatically tested at not less than 1.25 times the lowest Design Pressure of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of Article NC-7000.

(b) Vessels designed in accordance with NC-3200 shall be hydrostatically tested at not less than 1.25 times the Design Pressure.

(c) Valves shall be hydrostatically tested in accordance with the rules of NC-3500.

(d) Other components shall be hydrostatically tested at not less than 1.25 times their Design Pressure.

(e) As an alternative to (a) above, piping between the discharge side of a centrifugal pump and the first shutoff valve may be hydrostatically tested at the shutoff head of the pump. The pressure shall be maintained for a sufficient time to permit examination of all joints, connections, and regions of high stress.

NC-6222 Maximum Permissible Pressure

(a) If the minimum test pressure of NC-6221(a) or NC-6221(d) is to be exceeded by 6% at any location, the upper limit shall be established by analysis using all loadings that may exist during the test.

(b) For vessels designed to NC-3200, the stress limits of NC-3218 shall be used in determining the maximum permissible pressure.

(c) When testing a system, the test pressure shall not exceed the maximum permissible test pressure of any component in the system.

NC-6223 Hydrostatic Test Pressure Holding Time

The hydrostatic test pressure shall be maintained a minimum of 10 min prior to initiation of the examination for leakage required by NC-6224.

NC-6224 Examination for Leakage After Application of Pressure

Following the application of the hydrostatic test pressure for the required time (NC-6223), all joints, connections, and regions of high stress such as regions around openings and thickness transition sections shall be examined for leakage. Except in the case of pumps and valves, which shall be examined while at test pressure, this examination shall be made at a pressure equal to the greater of the Design Pressure or three-fourths of the test pressure, and it shall be witnessed by the Inspector. Leakage of temporary gaskets and seals, installed for the purpose of conducting the hydrostatic test, and which will be replaced later, may be permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time. Other leaks, such as from permanent seals, seats, and gasketed joints in components, may be permitted when specifically allowed by the Design Specifications. Leakage from temporary seals or leakage permitted by the Design Specification shall be directed away from the surface of the component to avoid masking leaks from other joints.

NC-6230 BELLOWS EXPANSION JOINTS

The hydrostatic test requirements for bellows expansion joints shall be as required in (a) through (c) below.

(a) The completed expansion joint shall be subjected to a hydrostatic test in accordance with the applicable provisions of this Article as supplemented by the Design Specifications.

(b) This test may be performed with the bellows fixed in the straight position, at its neutral length, when the design has been shown to comply with NC-3649.4(e)(1) or NC-3649.4(e)(2). If the design is to comply with NC-3649.4(e)(3), this test shall be performed with the bellows fixed at the maximum design rotation angle or offset movement.

(c) In addition to inspecting the expansion joint for leaks and general structural integrity during the test, the Inspector shall also visually inspect the bellows for evidence of meridional yielding as defined in NC-3649.4(b) and for evidence of squirm as defined in NC-3649.4(c). If the design is to comply with NC-3649.4(e)(3), actual measurements shall be made before, during, and after the pressure test in accordance with NC-3649.4(b) and NC-3649.4(c).

NC-6240 PROVISION FOR EMBEDDED OR INACCESSIBLE WELDED JOINTS IN PIPING

When welded joints in piping subassemblies or piping systems will be embedded or are otherwise inaccessible for inspection at the time of the system hydrostatic test, either of the following alternatives may be employed. Alternative (b) does not apply to brazed joints.

(a) The piping subassembly, or portion of the piping system which is to be embedded, or will be otherwise inaccessible, shall be hydrostatically tested at some point in the fabrication or installation prior to embedment or inaccessibility.

(b) Radiography shall be performed on all circumferential butt welds, and either magnetic particle or liquid penetrant examination shall be performed on all fillet or socket welds in accordance with the requirements of

Article NC-5000. The longitudinal butt welds shall meet the requirements of Article NC-2000. The hydrostatic test may then be performed after embedment, using maintenance of pressure as the acceptance criterion for those welds only. The system shall be pressurized to the hydrostatic test pressure and then isolated from the pressurizing source for a period of 1 hr/in. (2 min/mm) of wall thickness but not less than 1 hr. During the test period, there shall be no drop in pressure.[67]

NC-6300 PNEUMATIC TESTS

NC-6310 PNEUMATIC TESTING PROCEDURES

NC-6311 General Requirements

When a pneumatic test is performed, it shall be conducted in accordance with the requirements of NC-6100 and this subarticle.

NC-6312 Test Medium and Test Temperature

(a) The gas used as the test medium shall be nonflammable.

(b) Testing temperature shall be in accordance with NC-6212(b).

NC-6313 Procedure for Applying Pressure

The pressure in the system shall be gradually increased to not more than one-half of the test pressure, after which the pressure shall be increased in steps of approximately one-tenth of the test pressure until the required test pressure has been reached.

NC-6320 PNEUMATIC TEST PRESSURE REQUIREMENTS

NC-6321 Minimum Required Pneumatic Test Pressure

(a) The installed system shall be pneumatically tested at not less than 1.1 times the lowest Design Pressure of any component within the boundary protected by the overpressure protection devices which satisfy the requirements of Article NC-7000.

(b) Valves shall be pneumatically tested in accordance with the rules of NC-3500.

(c) Components shall be pneumatically tested at not less than 1.1 times their Design Pressure.

NC-6322 Maximum Permissible Test Pressure

The maximum test pressure shall be limited as defined in NC-6222.

NC-6323 Test Pressure Holding Time

The test pressure of NC-6321 shall be maintained for a minimum total time of 10 min.

NC-6324 Examination for Leakage After Application of Pressure

Following the application of pressure for the time specified in NC-6323, the test pressure shall be reduced to a value equal to the greater of the Design Pressure or three-fourths of the test pressure, and held for a sufficient time to permit examination as defined in NC-6224.

NC-6330 BELLOWS EXPANSION JOINTS

When a pneumatic test is performed on a bellows expansion joint in lieu of a hydrostatic test, the requirements of NC-6230 shall be met.

NC-6400 PRESSURE TEST GAGES

NC-6410 REQUIREMENTS FOR PRESSURE TEST GAGES

NC-6411 Types of Gages to Be Used and Their Location

Pressure test gages used in pressure testing shall be indicating pressure gages and shall be connected directly to the component. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. For systems with a large volumetric content, it is recommended that a recording gage be used in addition to the indicating gage.

NC-6412 Range of Indicating Pressure Gages

(a) Analog-type indicating pressure gages used in testing shall be graduated over a range not less than $1\frac{1}{2}$ times nor more than 4 times the test pressure.

(b) Digital-type pressure gages may be used without range restriction provided the combined error due to calibration and readability does not exceed 1% of the test pressure.

NC-6413 Calibration of Pressure Test Gages

All test gages shall be calibrated against a standard dead-weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests, using the same pressure test gage or gages, which are conducted within a period not exceeding 2 weeks.

NC-6500 ATMOSPHERIC AND 0 psi TO 15 psi (0 kPa TO 100 kPa) STORAGE TANKS

NC-6510 TESTING OF ATMOSPHERIC STORAGE TANKS

NC-6511 Testing of Reinforcement Pads

Following the examination specified in NC-5282.5 and before filling the tank with test water, the reinforcement pads shall be tested by applying up to 15 psi (100 kPa) pneumatic pressure between the tank shell and the reinforcement plate on each opening, using the telltale hole; and while each such space is subject to such pressure, soapsuds, linseed oil, or other suitable material for detection of leaks shall be applied to all attachment welding around reinforcement, both inside and outside the tank.

NC-6512 Preparation for Testing

Preparation for testing of storage tanks shall conform to the requirements of NC-6120, as applicable. Flat bottoms supported directly on grade need not comply with NC-6121.

NC-6513 Hydrostatic Testing of Tank Shell

Upon completion of the tank, the shell shall be tested. For tanks with supported cone, self-supported cone, self-supported dome, and self-supported umbrella roofs, the tank shall be filled with water and inspected frequently during the filling operation. The filling height shall be 2 in. (50 mm) above the top leg of the angle. For tanks with flat roofs, the filling height shall be the liquid level for which the tank was designed or the bottom of any overflow which limits the filling height.

NC-6520 TESTING OF 0 psi TO 15 psi (0 kPa TO 100 kPa) STORAGE TANKS

NC-6521 Testing of Reinforcement Pads

Following the examination specified in NC-5283.6 and before performing the preliminary pneumatic testing, the reinforcement pads shall be tested by using the same procedure as given in NC-6511.

NC-6522 Preparation for Testing

Preparation for testing of storage tanks shall conform to the requirements of NC-6120, as applicable. Flat bottoms supported directly on grade need not comply with NC-6121.

NC-6523 Preliminary Pneumatic Testing

Prior to the application of the hydrostatic or combination hydrostatic pneumatic test, the tank shall be filled with air to a pressure of 2 psi (15 kPa) or one-half the pressure P_G for which the vapor space at the top of the tank is designed, whichever pressure is the smaller. Soapsuds shall be applied to all joints in the tank wall above the high liquid design level. If any leaks appear, the defective condition shall be corrected and the applicable preliminary tightness test shall be repeated. In the case of a tank whose bottom rests directly on the tank grade without having anchor bolts provided near the boundary of contact to hold it down, if the bottom at this boundary rises slightly off the foundation during the tightness test with air pressure in the tank, sand shall be tamped firmly under the bottom, while the tank is under pressure, to fill the gap so formed.

NC-6524 Combination Hydrostatic Pneumatic Tests

The following requirements apply to tanks which have not been designed to be filled with liquid to a test level higher than their specified capacity level.

NC-6524.1 Pressurizing. After the preliminary tests specified in NC-6523 have been completed, the pressure relief valve or valves shall be blanked off. With the top of the tank vented to atmosphere to prevent accumulation of pressure, the tank shall be filled with water to its high liquid level. The vents at the top of the tank shall then be closed, and air shall be injected slowly into the top of the tank until the pressure in the vapor space is about one-half the pressure P_G for which this space is designed. Thereafter, the test pressure shall be increased in steps of approximately 2 psi (15 kPa) or one-fourth of the intended test pressure, whichever is the smaller, until the pressure in the vapor space is 1.25 times the pressure P_G for which this space is designed. Means shall be provided so that the required test pressure will not be exceeded.

NC-6524.2 Time at Pressure. The pressure in the tank shall be held stationary for a reasonable time after the application of each increment of pressure as specified so as to provide an opportunity to examine the tank carefully for signs of distress. The maximum test pressure of 1.25 times the vapor space design pressure shall be held for at least 1 hr, after which the pressure shall be reduced slowly to the vapor space design pressure.

NC-6524.3 Soap Bubble Test. The vapor space design pressure shall be held for a sufficient time to permit a close visual examination of all joints in the walls of the tank and of all welding around manways, nozzles, and other connections. In this examination, soapsuds shall be applied to all weld joints located above the high liquid design level for which the tank is designed, including the roof-to-sidewall joint. This examination is not required for welds subject to radiography.

NC-6524.4 Precautions to Be Employed in Pneumatic Testing. An air test, as specified in NC-6523 and in NC-6524, introduces some hazard. In view of the large amount of air which will be present during such a test, it is recommended that no one be permitted to go near the tank while the pressure is being applied for the first time in this test. While the pressure in the tank exceeds the pressure for which the vapor space is designed, the inspections should be made from a reasonable distance from the tank using optical aids, if necessary, for observations of particular areas.

NC-6525 Hydrostatic Test

The following requirements apply to tanks which have been designed and constructed to be filled with liquid to the top of the roof.

NC-6525.1 Filling. Following the preliminary tests specified in NC-6523, the pressure relief valve or valves shall be blanked off. With the top of the tank vented to atmosphere, the tank shall be filled with water to the top of the roof, while allowing all air to escape in order to prevent accumulation of pressure. The vents on the tank shall be closed, and the pressure in the tank shall be increased slowly until the hydrostatic pressure under the topmost point in the roof is 1.25 times the pressure P_G for which the vapor space is designed to withstand when in operation with the tank filled to its specified high liquid level.

NC-6525.2 Pressurizing. Test pressure may be developed by (a) or (b) below:

(a) pumping water into the tank with all vents closed;

(b) superimposing a vertical pipe, not less than NPS 6 (DN 150), above the top of the tank with an overflow located at such a height as to give the desired test pressure by static head alone and then filling the pipe to the level of said overflow.

NC-6525.3 Time at Pressure. Test pressure shall be held for at least 1 hr. The hydrostatic pressure under the roof shall then be reduced to the Design Pressure and shall be held at this level for a sufficient time to permit close visual examination of all joints in the walls of the tank and of all welding around manways, nozzles, and other connections.

NC-6526 Partial Vacuum Testing Procedure

NC-6526.1 Development of Partial Vacuum for Which Tank Was Designed. Following the tests specified in NC-6524 or in NC-6525, the pressure in the tank shall be released and a manometer shall be connected to the vapor space. The ability of that part of the tank to withstand the partial vacuum for which it is designed shall then be checked by withdrawing water from the tank or by air evacuation, with all vents closed, until the design partial vacuum is developed. Careful observations shall be made under the above condition of loading to determine whether any appreciable changes occur in the shape of the tank.

NC-6530 TEST GAGES

NC-6531 Indicating Gage and Its Location

An indicating gage shall be connected directly to the topmost part of the roof on the tank under test, except that, in the case of a tank which is designed for storage of gases or vapors alone and is to be tested only with air, this gage may be connected to the tank at some lower level. If the indicating gage is not readily visible to the operator controlling the pressure applied, an additional indicating gage shall be provided where it will be visible to the operator throughout the duration of the test. Means shall be provided so that the required test pressure will not be exceeded.

NC-6532 Recording Gage and Its Location

A recording gage shall also be used on each tank, and a record shall be kept of the pressures during all stages of the tests. This gage shall be connected either to the piping leading to the indicating gage or directly to the tank at a point near the indicating gage connection.

NC-6533 Accumulation of Static Head on Gages

In all cases in which a gage is mounted at a level lower than its connection to the tank or lower than some part of the piping leading to the gage, suitable precautions shall be taken to prevent accumulation of any static head of condensed moisture or water from other sources in the piping leads above the level of the gage.

NC-6534 Calibration of Pressure Test Gages

All test gages shall be calibrated against a standard dead weight tester or a calibrated master gage. The test gages shall be calibrated before each test or series of tests. A series of tests is that group of tests, using the same pressure test gage or gages, which are conducted within a period not exceeding two weeks.

NC-6600 SPECIAL TEST PRESSURE SITUATIONS

NC-6610 COMPONENTS DESIGNED FOR EXTERNAL PRESSURE

Components designed for external pressure only shall be subjected to an internal or external test pressure at 1.25 times the design external pressure. The pressure shall be under proper control so that the required test pressure is never exceeded by more than 6%.

NC-6620 PRESSURE TESTING OF COMBINATION UNITS

NC-6621 Pressure Chambers Designed to Operate Independently

Pressure chambers of combination units that have been designed to operate independently shall be pressure tested as separate vessels, that is, each chamber shall be tested without pressure in the adjacent chamber.

NC-6622 Common Elements Designed for a Maximum Differential Pressure

(a) When pressure chambers of combination units have their common elements designed for the maximum differential pressure that can occur during startup, operation, and shutdown, and the differential pressure is less than the higher of the Design Pressures of the adjacent chambers, the common elements shall be subjected to a pressure test of at least 1.25 times the maximum differential pressure.

(b) Following the test of the common elements, as required by (a) and their inspection, the adjacent chambers shall be pressure tested (NC-6221). Care must be taken to limit the differential pressure between the chambers to the pressure used when testing the common elements.

NC-6900 PROOF TESTS TO ESTABLISH DESIGN PRESSURE

NC-6910 GENERAL REQUIREMENTS

NC-6911 Establishment by Test of Design Pressure

The Design Pressure for components, except those designed to NC-3200, and piping or component parts for which the strength cannot be computed with a satisfactory assurance of accuracy, shall be established in accordance with the requirements of this subarticle, using one of the test procedures applicable to the type of loading and to the material used in construction.

NC-6911.1 Types of Proof Tests. Provision is made in these rules for two types of tests to determine the internal Design Pressure:

(a) tests based on yielding of the part to be tested (these tests are limited to materials with a ratio of specified minimum yield to specified minimum ultimate strength of 0.625 or less);

(b) tests based on bursting of the part.

NC-6911.2 Purpose for Which Proof Tests May Be Used. The tests in this subarticle may be used only for the purpose of establishing the Design Pressure of those elements or component parts for which the thickness cannot be determined by means of the design rules given in this Subsection. The Design Pressure of all other elements or component parts shall not be greater than that determined by means of the applicable design rules.

NC-6911.3 Permissible Previous Pressurization of Component or Part. The component or component part for which the Design Pressure is to be established shall not previously have been subjected to a pressure greater than $1\frac{1}{2}$ times the desired or anticipated Design Pressure, adjusted for Design Temperature as provided in NC-6911.9.

NC-6911.4 Test Requirements for Duplicate Components or Parts. When the Design Pressure of a component or component part has been established by a proof test, duplicate parts of the same materials, design, and construction need not be proof tested but shall be given a hydrostatic test in accordance with NC-6200 or a pneumatic test in accordance with NC-6300. The dimensions and minimum thickness of the structure to be tested shall not vary materially from those actually used. A geometrically similar part may be qualified by a series of tests covering the complete size range of the pressure part.

NC-6911.5 Application of Pressure. In the procedures given in NC-6921, NC-6923, and NC-6924, the hydrostatic pressure in the component or component part shall be increased gradually until approximately one-half the anticipated Design Pressure is reached. Thereafter, the test pressure shall be increased in steps of approximately one-tenth or less of the anticipated Design Pressure until the pressure required by the test procedure is reached. The pressure shall be held stationary at the end of each increment for a sufficient time to allow the observations required by the test procedure to be made and shall be released to zero to permit determination of any permanent strain after any pressure increment that indicates an increase in strain or displacement over the previous equal pressure increment.

NC-6911.6 Check of Measurements. As a check that the measurements are being taken on the most critical areas, the Inspector may require a lime wash or other brittle coating to be applied on all areas of probable high stress concentrations in the test procedures given in NC-6923 and NC-6924. The surfaces shall be suitably cleaned before the coating is applied in order to obtain satisfactory adhesion. The technique shall be suited to the coating material.

NC-6911.7 Determination of Design Pressure for Components or Parts Having Corrosion Allowance. The test procedures in this subarticle give the Design Pressure for the thickness of material tested. When the thickness as tested includes extra thickness as provided in NC-3121, the Design Pressure at which the component shall be permitted to operate shall be determined by multiplying the Design Pressure obtained from the test by the ratio

$$\left(t - c\right) / t$$

where

c = allowance added for corrosion, erosion, and abrasion
t = nominal thickness of the material at the weakest point

NC-6911.8 Determination of Yield Strength and Tensile Strength

(a) For proof tests based on yielding (NC-6921, NC-6923, or NC-6924), the yield strength (or yield point, for those materials which exhibit that type of yield behavior indicated by a "sharp-kneed" portion of the stress-strain diagram) of the material in the part tested shall be determined in accordance with the method prescribed in the applicable material specification and as described in ASTM E8. For proof tests based on bursting, NC-6922, the tensile strength instead of the yield strength of the material in the part tested shall be similarly determined.

(b) Yield or tensile strength so determined shall be the average from three or four specimens cut from the part tested after the test is completed. The specimens shall be cut from a location where the stress during the test has not exceeded the yield strength. The specimens shall not be flame cut because this might affect the strength of material. If yield or tensile strength is not determined by test specimens from the pressure part tested, alternative methods are given in NC-6921, NC-6922, NC-6923, and NC-6924 for evaluation of proof test results to establish the Design Pressure.

(c) When excess stock from the same piece of wrought material is available and has been given the same stress relieving heat treatment as the pressure part, the test specimens may be cut from this excess stock. The specimens shall not be removed by flame cutting or any other method involving sufficient heat to affect the properties of the specimen.

NC-6911.9 Design Pressure at Higher Temperatures. The Design Pressure for components and component parts that are to operate at temperatures at which the allowable stress value of the material is less than at the test temperature shall be determined by the following equation:

$$P_o = Pt\left(\frac{S_o}{S_t}\right)$$

where

P_o = Design Pressure at the Design Temperature, psig (MPa gage)
P_t = Design Pressure at test temperature, psig (MPa gage)
S_o = maximum allowable stress value at the Design Temperature, psi (MPa)
S_t = maximum allowable stress value at test temperature, psi (MPa)

NC-6912 Retests

A retest shall be allowed on a duplicate component or component part if errors or irregularities are obvious in the test results.

NC-6913 Witnessing of Tests by Inspector

Tests to establish the Design Pressure of components or component parts shall be witnessed and approved by the Inspector.

NC-6914 Safety Precautions

Safety of testing personnel should be given serious consideration when conducting proof tests, and particular care should be taken during bursting tests in NC-6922.

NC-6920 PROCEDURES

NC-6921 Brittle Coating Test Procedure

(a) Subject to the limitations of NC-6911.1(a), this procedure may be used only for components and component parts under internal pressure, constructed of materials having a definitely determinable yield point. The component parts that require proof testing shall be coated with a lime wash or other brittle coating in accordance with NC-6911.6. Pressure shall be applied in accordance with NC-6911.5. The parts being proof tested shall be examined between pressure increments for signs of yielding as evidenced by flaking of the brittle coating or by the appearance of strain lines. The application of pressure shall be stopped at the first sign of yielding or, if desired, at some lower pressure.

(b) The Design Pressure P at test temperature for components or component parts tested under NC-6921 shall be computed as stipulated in (1) through (4) below:

(1) if the average yield strength is determined in accordance with NC-6911.8:

$$P = 0.5H\left(\frac{Y_s}{Y_a}\right)$$

(2) to eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, one of the following equations may be used to determine the Design Pressure:

(-a) for carbon steel meeting an acceptable Specification in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 with a specified minimum tensile strength of not over 70.0 ksi (480 MPa):

(U.S. Customary Units)

$$P = 0.5H\left(\frac{S}{S + 5{,}000}\right) \quad (1)$$

(SI Units)

$$P = 0.5H\left(\frac{S}{S + 34.5}\right)$$

(-b) for any other acceptable material listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3:

$$P = 0.4H \quad (2)$$

where

H = hydrostatic test pressure at which the test was stopped
S = specified minimum tensile strength
Y_a = actual average yield strength from test specimens
Y_s = specified minimum yield strength

(3) when eq. (2)(-a)(1) or eq. (2)(-b)(2) is used, the material in the pressure part shall have no appreciable cold working or other treatment that would tend to raise the yield strength above the normal value;

(4) the Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

(15) NC-6922 Bursting Test Procedure

(a) This procedure may be used for components or component parts under internal pressure when constructed of any material permitted to be used under the rules of this Subsection. The Design Pressure of any component part proof tested by this method shall be established by a hydrostatic test to failure by rupture of a full size sample of such pressure part. The hydrostatic pressure at which rupture occurs shall be determined.

(b) The Design Pressure P at test temperature for parts tested under NC-6922 shall be computed as stipulated in (1) through (3) below:

(1) parts constructed of materials other than cast materials:

$$P = \frac{B}{5} \times \frac{S}{S_{ave}}$$

or

$$P = \frac{B}{5} \times \frac{S}{S_{max}} \quad (3)$$

(2) parts constructed of cast materials, except cast iron and cast nodular iron which are not permitted:

$$P = \frac{Bf}{5} \times \frac{S}{S_{ave}}$$

or

$$P = \frac{Bf}{5} \times \frac{S}{S_{max}} \quad (4)$$

where

B = bursting test pressure
f = casting quality factor
S = specified minimum tensile strength
S_{ave} = average actual tensile strength of test specimens
S_{max} = maximum tensile strength of range of specification

(3) the Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

NC-6923 Strain Measurement Test Procedure

(a) Subject to limitations of NC-6911.1(a), this procedure may be used for components or component parts under internal pressure, constructed of any material permitted to be used under the rules of this Subsection. Strains shall be measured in the direction of the maximum stress at the most highly stressed parts (see NC-6911.6) by means of strain gages of any type capable of indicating strains to 0.00005 in./in. (0.00005 mm/mm) (0.005%). Pressure shall be applied as provided in NC-6911.5.

(b) After each increment of pressure has been applied, readings of the strain gages and the hydrostatic pressure shall be taken and recorded. The pressure shall be released and any permanent strain at each gage shall be determined after any pressure increment that indicates an increase in strain for this increment over the previous equal pressure increment. Only one application of each increment of pressure is required.

(c) Two curves of strain against test pressure shall be plotted for each gage line as the test progresses, one showing the strain under pressure and one showing the permanent strain when the pressure is removed. The test may be discontinued when the test pressure reaches the value H which will, by the equation, justify the desired Design Pressure but shall not exceed the pressure at which the plotted points for the most highly strained gage line reach the value given below for the material used:

(1) 0.2% permanent strain for aluminum-base and nickel-base alloys;

(2) 0.2% permanent strain for carbon low alloy and high alloy steels;

(3) 0.5% strain under pressure for copper-base alloys.

(d) The Design Pressure P in psig (kPa gage) at test temperature for parts tested under this paragraph, shall be computed as stipulated in (1) through (3) below:

(1) if the average yield strength is determined in accordance with NC-6911.8:

$$P = 0.5H\left(\frac{Y_s}{Y_a}\right) \quad (5)$$

(2) if the actual average yield strength is not determined by test specimens:

$$P = 0.4H \quad (6)$$

where

H = hydrostatic test pressure at which the test was stopped in accordance with (c) above, psig (MPa gage)
Y_a = actual average yield strength from test specimens, psi (MPa)
Y_s = specified minimum yield strength, psi (MPa)

(3) the Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

NC-6924 Displacement Measurement Test Procedure

(a) Subject to the limitations of NC-6911.1(a), this procedure may be used only for components and component parts under internal pressure, constructed of materials having a definitely determinable yield point. Displacement shall be measured at the most highly stressed parts (NC-6911.6) by means of measuring devices of any type capable of measuring to 0.001 in. (0.02 mm). The displacement may be measured between two diametrically opposed reference points in a symmetrical structure or between a reference point and a fixed base point. Pressure shall be applied as provided in NC-6911.5.

(b) After each increment of pressure has been applied, readings of the displacement and hydrostatic test pressure shall be taken and recorded. The pressure shall be released and any permanent displacement shall be determined after any pressure increment that indicates an increase in measured displacement for this increment over the previous equal pressure increment. Only one application of each increment is required. Care must be taken to ensure that the readings represent only displacements of the parts on which measurements are being made and do not include any slip of the measuring devices or any movement of the fixed base points or of the pressure part as a whole.

(c) Two curves of displacement against test pressure shall be plotted for each reference point as the test progresses, one showing the displacement under pressure and one showing the permanent displacement when the pressure is removed. The application of pressure shall be stopped when it is evident that the curve through the points representing displacement under pressure has deviated from a straight line.

(d) The pressure coincident with the proportional limit of the material shall be determined by noting the pressure at which the curve representing displacement under pressure deviates from a straight line. The pressure at the proportional limit may be checked from the curve of permanent displacement by locating the point where the permanent displacement begins to increase regularly with further increases in pressure. Permanent deformation at the beginning of the curve that results from the equalization of stresses and irregularities in the material may be disregarded.

(e) The Design Pressure P in psig (MPa gage) at test temperature for parts tested under this paragraph shall be computed as stipulated in (1) through (4) below:

(1) if the average yield strength is determined in accordance with NC-6911.8:

$$P = 0.5H\left(\frac{Y_s}{Y_a}\right) \quad (7)$$

(2) to eliminate the necessity of cutting tensile specimens and determining the actual yield strength of the material under test, eq. (-a)(8) or (-b)(9) may be used to determine the Design Pressure:

(-a) for carbon steel, meeting an acceptable specification in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3 with a specified minimum tensile strength of not over 70.0 ksi (480 MPa):

(U.S. Customary Units)

$$P = 0.5H\left(\frac{S}{S + 5{,}000}\right) \quad (8)$$

(SI Units)

$$P = 0.5H\left(\frac{S}{S + 34.5}\right)$$

(-b) for any other acceptable material listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3:

$$P = 0.4H \quad (9)$$

where

H = hydrostatic test pressure coincident with the proportional limit of the weakest element of the component part test
S = specified minimum tensile strength
Y_a = actual average yield strength from test specimens
Y_s = specified minimum yield strength

(3) when eq. (2)(-a)(8) or (2)(-b)(9) is used, the material in the pressure part shall have had no appreciable cold working or other treatment that would tend to raise the yield strength above the normal value;

(4) the Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

NC-6930 PROCEDURE FOR COMPONENTS HAVING CHAMBERS OF SPECIAL SHAPE SUBJECT TO COLLAPSE

(a) Pressure chambers of components, portions of which have a shape other than that of a complete circular cylinder or formed head, and, also, jackets of cylindrical vessels which extend over only a portion of the circumference, which are not fully staybolted as required by NC-3133 and NC-3329, shall withstand without excessive deformation a hydrostatic test of not less than 3 times the desired Design Pressure.

(b) The Design Pressure at other temperatures shall be determined as provided in NC-6911.9.

ARTICLE NC-7000 OVERPRESSURE PROTECTION

NC-7100 GENERAL REQUIREMENTS

NC-7110 SCOPE

(a) A system[68] shall be protected from the consequences arising from the application of conditions of pressure and coincident temperature that would cause either the Design Pressure or the Service Limits specified in the Design Specification to be exceeded.

(b) Pressure relief devices[69] are required when the operating conditions considered in the Overpressure Protection Report would cause the Service Limits specified in the Design Specification to be exceeded.

(c) Protection of components in the system from the effects of pressure increases of extremely short duration, such as water hammer resulting from the rapid closing of a valve, is beyond the scope of this Article. These effects shall be included in the Design Specification.

(15) NC-7111 Definitions

(a) Overpressure, as used in this Article, can consist of either one of the following pressure changes:

(1) an increase in system fluid pressure resulting from thermal imbalances, excess pump flow, and other similar phenomena, capable of causing a system pressure increase of a sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices listed in this Article; or

(2) changes in differential pressure resulting from thermal imbalances, vapor condensation, and other similar phenomena, capable of causing an internal or external pressure increase of sufficient duration to be compatible with the dynamic response characteristics of the pressure relief devices listed in this Article.

(b) The basic definitions of pressure relief devices as specified in this Article are in accordance with ASME PTC 25, Pressure Relief Devices.

(c) Primary pressure is the pressure of the fluid at the inlet of the pressure relief device.

(d) Secondary pressure is that value of pressure existing in the passage between the actual discharge area and the outlet for which the discharge system of the pressure relief devices shall be designed.

NC-7120 INTEGRATED OVERPRESSURE PROTECTION

Overpressure protection of the system shall be provided by any of the following methods as an integrated overpressure protection:

(a) the use of pressure relief devices and associated pressure-sensing elements;

(b) a design without pressure relief devices that does not exceed the Service Limits specified in the Design Specifications [NC-7110(b)].

NC-7130 VERIFICATION OF THE OPERATION OF RECLOSING PRESSURE RELIEF DEVICES

NC-7131 Construction

(a) Reclosing pressure relief devices shall be constructed so that potential impairment of the overpressure protection function from service exposure to fluids can be determined by test or examination.

(b) Reclosing pressure relief devices and their associated pressure-sensing elements shall be so constructed that their correct operation can be demonstrated under service or test conditions, as may be required by regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

NC-7140 INSTALLATION

NC-7141 Pressure Relief Devices

(a) Pressure relief devices shall be as close as practicable to the major source of overpressure anticipated to arise within the system under the conditions summarized in the Overpressure Protection Report (NC-7200).

(b) The connection between a system and its pressure relief device shall have a minimum inside diameter equal to or greater than nominal inside diameter of the pressure relief device inlet. The opening in the connection shall be designed to provide direct and unobstructed flow between the system and the pressure relief device.

(c) The connection between a system and its safety valve shall be not longer than the face-to-face dimension of the corresponding tee fitting of the same dimension and pressure rating listed in ASME B16.5, ASME B16.9, or ASME B16.11. Alternatively, the connection shall not result in accumulative line losses greater than 2% of the relieving pressure.

(d) The connection between a system and its safety relief valve or relief valve shall not result in accumulated line losses greater than 3% of the relieving pressure.

(e) Safety, safety relief, and relief valves shall be installed in an upright position.

(f) The flow area of the discharge piping connected to a pressure relief device shall not be less than the flow area of the device outlets. If two or more pressure relief valves discharge into common piping, the area of the common piping shall not be less than the combined outlet area of the valves discharging into it. Back pressure that may exist or develop shall not reduce the relieving capacity of the relieving device(s) below that required to protect the system; potential for flashing shall be considered.

(g) Valve installation not in accordance with (c), (d), (e), and (f) above may be used provided:

(1) the NV Certificate Holder confirms that the valve design is satisfactory for the intended installation and satisfies the requirements of the valve Design Specification;

(2) the valves are adjusted for acceptable performance and in conformance with the requirements of the valve Design Specification;

(3) technical justification for the adequacy of the installation is provided in the Overpressure Protection Report, including verification that the requirements of (1) and (2) have been met.

NC-7142 Stop Valves

(a) No stop valve or other device shall be placed in such a location, relative to a pressure relief device, that it could reduce the overpressure protection below that required by the rules of this Article, unless such stop valves are constructed and installed with controls and interlocks so that the relieving capacity requirements of NC-7300 are met under all conditions of operation of both the system and the stop valves.

(b) Simple administrative control of stop valve position is not acceptable.

(c) Stop valves shall have independent and diverse interlocks to prevent valves from being closed during all conditions of system operation when the pressure relief device is needed to meet the requirements of NC-7300.

(d) Stop valves shall have independent and diverse interlocks to assure that the valves will automatically open and remain open during all conditions of system operation when the pressure relief device is needed to meet the requirements of NC-7300.

(e) Means shall be provided to permit verification of the operation of controls and interlocks.

NC-7143 Draining of Pressure Relief Devices

(a) A pressure relief device installation shall be fitted with a drain at its lowest point where liquid or residue can collect if such liquid or residue could interfere with proper relieving operation.

(b) If the design of a pressure relief device permits liquid or residue to collect on the discharge side of the disk and could interfere with proper relieving operation, the device shall be fitted with a drain to minimize the collection of liquid or residue.

NC-7150 ACCEPTABLE PRESSURE RELIEF DEVICES

NC-7151 Pressure Relief Valves[70]

Pressure relief valves may be used in accordance with NC-7170 and NC-7500.

NC-7152 Vacuum Relief Valves

Vacuum relief valves may be used in accordance with NC-7170 and NC-7500.

NC-7153 Nonreclosing Pressure Relief Devices[71]

Nonreclosing pressure relief devices may be used in accordance with NC-7170 and NC-7600.

NC-7160 UNACCEPTABLE PRESSURE RELIEF DEVICES

NC-7161 Deadweight Pressure Relief Valves

Deadweight valves shall not be used.

NC-7170 PERMITTED USE OF PRESSURE RELIEF DEVICES

NC-7171 Safety Valves[72]

Safety valves, meeting the requirements of NC-7510, may be used for:

(a) steam service;

(b) air and gas service.

NC-7172 Safety Relief Valves[73]

Safety relief valves, meeting the requirements of NC-7510, may be used for:

(a) steam service;

(b) air and gas service;

(c) liquid service.

NC-7173 Relief Valves[74]

Relief valves, meeting the requirements of NC-7510, may be used for liquid service.

NC-7174 Pilot-Operated Pressure Relief Valves[75]

Pilot-operated pressure relief valves, meeting the requirements of NC-7520, may be used for:

(a) steam service;

(b) air and gas service, provided that the design is such that the main valve will open automatically at not over the set pressure and will not discharge its full rated capacity if some essential part of the actuator should fail;

(c) liquid service.

NC-7175 Power-Actuated Pressure Relief Valves[76]

Power-actuated pressure relief valves, meeting the requirements of NC-7530, may be used for:

(a) steam service;

(b) air and gas service, provided that the design is such that the main valve will open automatically at not over the set pressure and will not discharge its full rated capacity if some essential part of the pilot should fail;

(c) liquid service.

NC-7176 Safety Valves With Auxiliary Actuating Devices

Safety valves with auxiliary actuating devices, meeting the requirements of NC-7540, may be used for steam service.

NC-7177 Vacuum Relief Valves[77]

Vacuum relief valves, meeting the requirements of NC-7550, may be used for air and gas service.

NC-7178 Nonreclosing Devices

Rupture disk devices[78] may be used on air, gas, or steam service, except for main steam service, in accordance with NC-7600.

NC-7200 OVERPRESSURE PROTECTION REPORT

NC-7210 RESPONSIBILITY FOR REPORT

The provisions intended to meet the requirements of this Article shall be the subject of an Overpressure Protection Report prepared by the Owner or his Designee.

NC-7220 CONTENT OF REPORT

The Overpressure Protection Report shall define the protected systems and the integrated overpressure protection provided. As a minimum, the report shall include the following:

(a) identification of specific ASME Section III, Article NC-7000, Edition and Addenda and applicable Code Cases used in the design of the overpressure protection system;

(b) drawings showing arrangement of protected systems including the pressure relief devices;

(c) the analysis of the effect of the range of operating conditions, including the effect of discharge piping back pressure;

(d) an analysis of the conditions that give rise to the maximum pressure or vacuum relieving requirements, except when the basis for establishing relieving capacity is the loss of the heat sink of the protected system when the thermal input to the system is at a maximum;

(e) the relief capacity required to prevent a pressure or vacuum rise in any component from exceeding the limitations of NC-7300;

(f) the operating controls or safety controls of the protected system upon which the anticipated required relief capacity of (d) and the maximum pressure, vacuum, and temperature of (c) are predicted;

(g) the redundancy and independence of the pressure relief devices and their associated pressure or vacuum sensors and controls employed to preclude a loss of overpressure protection in the event of a failure of any pressure relief device, sensing element, associated control, or external power sources;

(h) the extent that an individual component can be isolated from the overall system overpressure protection and the analysis of the conditions under which additional individual overpressure protection is necessary;

(i) the design secondary pressure including a justification of the value identified in the Design Specification for pressure relief devices;

(j) the analysis of pressure transient conditions, including those associated with the response time of pressure or vacuum relief valves, taking into account the effect of liquid and two-phase flow;

(k) consideration of set pressure and blowdown limitations, taking into account opening pressure tolerances and overpressure of the pressure relief device;

(l) consideration of burst pressure tolerance and manufacturing design range of the rupture disk device;

(m) verification that pressure relief devices are not required, if applicable. Verification shall include reference to each component's Design Report and applicable requirements in Article NC-3000 that demonstrate the calculated stress levels do not exceed the Service Limits specified in the component Design Specification for all system service loadings.

NC-7230 CERTIFICATION OF REPORT

The Report, after it has been reconciled with the requirements of this Article, shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Section III Appendices, Mandatory Appendix XXIII.

NC-7240 REVIEW OF REPORT AFTER INSTALLATION

(a) Any modification of the installation from that used for the preparation of the Overpressure Protection Report shall be reconciled with the Overpressure Protection Report.

(b) Modifications shall be documented in an addendum to the Overpressure Protection Report. The addendum shall contain a copy of the as-built drawing and shall include either:

(1) a statement that the as-built system meets the requirements of the Overpressure Protection Report; or

(2) a revision to the Overpressure Protection Report to make it agree with the as-built system; or

(3) a description of the changes made to the as-built system to make it comply with the Overpressure Protection Report.

(c) The addendum shall be certified by one or more Registered Professional Engineers competent in the applicable field of design and qualified in accordance with the requirements of Section III Appendices, Mandatory Appendix XXIII.

NC-7250 FILING OF REPORT

A copy of the Overpressure Protection Report shall be filed at the nuclear power plant site prior to the Inspector signing the Owner's Data Report. The report shall be made available to the Authorized Inspector and the regulatory and enforcement authorities having jurisdiction at the nuclear power plant site.

NC-7300 RELIEVING CAPACITY REQUIREMENTS

NC-7310 EXPECTED SYSTEM PRESSURE TRANSIENT CONDITIONS[79]

NC-7311 Relieving Capacity of Pressure Relief Devices

(a) The total relieving capacity of the pressure relief devices (certified in accordance with NC-7700, intended for overpressure protection within the scope of this Subsection, and credited in conformance with NC-7500 or NC-7600) shall take into account any losses due to fluid flow through piping and other components.

(b) The total relieving capacity shall be sufficient to prevent a rise in pressure of more than 10% or 3 psi (20 kPa), whichever is greater, above the Design Pressure of any component within the pressure-retaining boundary of the protected system under any expected system pressure transient conditions as summarized in the Overpressure Protection Report (NC-7200).

(c) The rated capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification and in the Overpressure Protection Report.

NC-7312 Relieving Capacity of Pressure Relief Devices Used With Pressure Reducing Devices

When using pressure reducing devices, the combined relieving capacity of the pressure relief devices shall be sufficient to meet the requirements of NC-7311 when:

(a) pressure reducing devices and their bypass valves are fully open; and

(b) all discharge paths are blocked on the low pressure side of the pressure reducing device.

NC-7313 Required Number and Capacity of Pressure Relief Devices

(a) The required relieving capacity for main steam and feedwater systems within the scope of this Subsection shall be provided by the use of at least two pressure relief devices.

(b) Other systems or components requiring individual protection may be served by one or more devices except when power-actuated pressure relief valves are used, in which case at least two valves shall be used to contribute to the required relieving capacity.

(c) When more than one device is used, no device shall have a capacity less than 50% of the device with the largest capacity.

NC-7314 Required Number and Capacity of Pressure Relief Devices for Isolatable Components Requiring Overpressure Protection

The required relieving capacity for overpressure protection of an isolatable component shall be provided by the use of at least one pressure relief device meeting the requirements of NC-7500 or NC-7600. Alternatively, pressure relief devices are not required if the design of the component, when isolated, is in compliance with NC-7120(b).

NC-7315 Relieving Capacity of Vacuum Relief Valves

(a) The capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification.

(b) At least two independent vacuum relief valves shall be provided on each system. The capacity of each vacuum relief valve shall not be less than that required to protect the system.

(c) Systems designed to withstand the maximum differential pressure do not require vacuum relief valves.

NC-7320 UNEXPECTED SYSTEM EXCESS PRESSURE TRANSIENT CONDITIONS[80]

NC-7321 Relieving Capacity of Pressure Relief Devices

(a) The total relieving capacity of the pressure relief devices (certified in accordance with NC-7700, intended for overpressure protection within the scope of this Subsection, and credited in conformance with NC-7500 or NC-7600) shall take into account any losses due to fluid flow through piping and other components.

(b) The total relieving capacity shall be sufficient to prevent a rise in pressure of more than 10% or 3 psi (20 kPa), whichever is greater, above the Design Pressure of any component within the pressure-retaining boundary of the protected system under each of the unexpected system excess pressure transient conditions specified in the Overpressure Protection Report.

NC-7322 Relieving Capacity of Vacuum Relief Valves

(a) The capacity of each vacuum relief valve shall not be less than that required to prevent a differential pressure in excess of the value specified in the Design Specification of the system being protected.

(b) At least two independent vacuum relief valves shall be provided on each system. The capacity of each vacuum relief valve shall not be less than that required to protect the system.

(c) Systems designed to withstand the maximum differential pressure do not require vacuum relief valves.

NC-7330 SYSTEM FAULTED CONDITIONS

This Article does not provide rules for overpressure protection of system faulted conditions.

NC-7400 SET PRESSURES OF PRESSURE RELIEF DEVICES

NC-7410 SET PRESSURE LIMITATIONS FOR EXPECTED SYSTEM PRESSURE TRANSIENT CONDITIONS

The stamped set pressure of at least one of the pressure relief devices connected to the system shall not be greater than the Design Pressure of any component within the pressure-retaining boundary of the protected system. Additional pressure relief devices may have higher stamped set pressure settings, but in no case shall these set pressures be such that the total system pressure exceeds the system limitations specified in NC-7310.

NC-7420 SET PRESSURE LIMITATION FOR UNEXPECTED SYSTEM EXCESS PRESSURE TRANSIENT CONDITIONS

The establishment of the stamped set pressure shall take into account the requirements of NC-7320.

NC-7500 OPERATING AND DESIGN REQUIREMENTS FOR PRESSURE AND VACUUM RELIEF VALVES

NC-7510 SAFETY, SAFETY RELIEF, AND RELIEF VALVES

NC-7511 General Requirements

NC-7511.1 Spring Loaded Valves. Valves shall open automatically by direct action of the fluid pressure as a result of forces acting against a spring.

NC-7511.2 Balanced Valves. Balanced valves, whose operation is independent of back pressure, may be used if means are provided to verify the integrity of the balancing device.

NC-7511.3 Antisimmer-Type Valves. Valves that are fitted with antisimmer devices that serve to raise the set pressure of the valve during normal operation of the system may be used, provided:

(a) the design is such that the valve opens automatically and discharges its certified capacity at 10% or 3 psi (20 kPa), whichever is greater, of the system design pressure in the event any item of the auxiliary loading device should fail;

(b) the operating signal and energy source provisions are such that the valve reverts to its normal set pressure in the event of any failure of signal or loss of energy source;

(c) the auxiliary loading force imposed on such valves does not raise the set pressure of the valve by more than 10% or 3 psi (20 kPa), whichever is greater;

(d) the auxiliary loading force which augments the force exerted by the valve spring is automatically unloaded at a pressure not greater than the set pressure of the valve.

NC-7511.4 Restricted Lift Valves. The capacity of a Certification Mark with NV Designator stamped valve may be reduced by the valve manufacturer provided the following limitations have been met.

(a) The valve size shall be NPS $^3/_4$ (DN 20) or larger.

(b) The valve design shall be tested, and the capacity shall be certified in accordance with the rules specified in NC-7731 and NC-7734.

(c) No changes shall be made in the design of the valve except to change the valve lift by use of the lift restraining device.

(d) The restriction of valve capacity is permitted only by the use of a lift restraining device, which shall limit valve lift and shall not otherwise interfere with flow through the valve.

(e) The lift restraining device is designed so that, if adjustable, the adjustable feature shall be sealed. Seals shall be installed in accordance with NC-7515.

(f) For main steam service for Class 2 construction, the safety or safety relief valve is not used in combination with a rupture disk and shall not have their lift restricted to a value less than 70%.

(g) For air and gas service and for Classes 2 and 3 steam service other than main steam service, if a valve design has been tested in combination with a rupture disk in accordance with the requirements of Article NC-7000, restricted lift valves of this design may be used in combination without further testing. Valves shall not have their lift restricted to a value less than 30% of the full rated lift, nor less than 0.080 in. (2.0 mm).

(h) During production testing, the manufacturer shall assure that the set pressure, blowdown, and valve performance meet the applicable requirements of this Article and the valve design specification.

Valves beyond the capability of the production test facility, because of size or flow rate, may be adjusted for blowdown and performance based on test or experience data, or other adequate technical justification, to meet the requirements of this Article and the valve design specification. The basis for the manufacturer's adjusting ring settings shall be documented in the Overpressure Protection Report.

(i) When sizing and selecting valves, the restricted lift capacity shall be determined by multiplying the capacity restricted lift to the full rated lift.

(j) Valves shall be marked in accordance with the relevant nameplate stamping provisions of NC-7800 modified as follows:

(1) Replace "capacity" with "restricted lift capacity."

(2) Add "restricted lift ____ in. (mm)"

NC-7512 Safety Valve Operating Requirements

NC-7512.1 Antichattering and Lift Requirements.

(a) Safety valves shall be constructed to operate without chattering and to attain rated lift at a pressure which does not exceed the set pressure by more than 3% or 2 psi (15 kPa), whichever is greater.

(b) For valves used for main steam service, conformance with (a) above shall be established for each production valve by testing on steam at the stamped set pressure. The test shall take into account valve discharge piping back pressure as specified in the valve Design Specification.

NC-7512.2 Set Pressure Tolerance.

(a) The set pressure tolerance plus or minus shall not exceed the following: 2 psi (15 kPa) for pressures up to and including 70 psi (500 kPa), 3% for pressures over 70 psi (500 kPa) up to and including 300 psi (2 000 kPa), 10 psi (70 kPa) for pressures over 300 psi (2 000 kPa) up to and including 1,000 psi (7 000 kPa), and 1% for pressures over 1,000 psi (7 000 kPa). The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (NC-7200) and in the safety valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) shall be established for each production valve by test. Steam valves shall be tested on steam. Alternative fluids may be used as the test media if the requirements of NC-7560 have been met.

NC-7512.3 Blowdown.

(a) Safety valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (NC-7200).

(b) For valves used for main steam service, conformance with (a) shall be established for each production valve by testing on steam at the stamped set pressure. The test shall take into account valve discharge piping back pressure as specified in the valve Design Specification (NCA-3250).

(c) For valves used for other than main steam service, the adjustment shall be determined by test or proration from the Certificate Holder's blowdown test data. Alternative fluids may be used as the test media if the requirements of NC-7560 have been met.

NC-7513 Safety Relief and Relief Valve Operating Requirements

Safety relief and relief valves shall be constructed to attain rated lift at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20 kPa), whichever is greater.

NC-7513.1 Set Pressure Tolerance.

(a) The set pressure tolerance plus or minus from the set pressure of safety relief and relief valves shall not exceed 2 psi (15 kPa) for pressures up to and including 70 psi (500 kPa) and 3% for pressures above 70 psi (500 kPa).

The set pressure tolerance shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (NC-7200) and in the valve Design Specification (NCA-3250).

(b) Conformance with the requirements of (a) shall be established for each production valve by test. Steam valves shall be tested on steam, air or gas valves on air or gas, and liquid valves on liquid. Alternative fluids may be used as the test media if the requirements of NC-7560 have been met.

NC-7513.2 Blowdown. Safety relief and relief valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting shall be covered in the Overpressure Protection Report (NC-7200). The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data. Alternative fluids may be used as the test media if the requirements of NC-7560 have been met.

NC-7514 Credited Relieving Capacity

The credited relieving capacity of safety, safety relief, and relief valves shall be based on the certified relieving capacity. In addition, the capacity can be prorated as permitted by NC-7700.

NC-7515 Sealing of Adjustments

Means shall be provided in the design of all valves for sealing all adjustments or access to adjustments which can be made without disassembly of the valve. For a pilot-operated pressure relief valve, an additional seal shall be provided to seal the pilot and main valve together. Seals shall be installed by the Certificate Holder at the time of initial adjustment. Seals shall be installed in a manner to prevent changing the adjustment or disassembly of the valve without breaking the seal. The seal shall serve as a means of identifying the Certificate Holder making the initial adjustment.

NC-7520 PILOT-OPERATED PRESSURE RELIEF VALVES

NC-7521 General Requirements

Pilot-operated pressure relief valves shall operate independently of any external energy source.

NC-7522 Operating Requirements

NC-7522.1 Actuation. The pilot control device shall be actuated directly by the fluid pressure of the protected system.

NC-7522.2 Response Time. The Overpressure Protection Report (NC-7200) shall include the effects of divergence between opening (set) and closing (blowdown) pressures of the pilot valve and the pressures at which the main valve attains rated lift and closes. These divergences are caused by the inherent time delay (e.g., response time) between the operation of the pilot and the main valve, and the rate of the system pressure change. The limits for response time shall be specified in the Design Specification (NCA-3250).

NC-7522.3 Main Valve Operation. The main valve shall operate in direct response to the pilot control device. The valve shall be constructed to attain rated lift under stable conditions at pressures which do not exceed the set pressure by more than 3% or 2 psi (15 kPa), whichever is greater, for steam, and 10% or 3 psi (20 kPa), whichever is greater, for air, gas, or liquid service.

NC-7522.4 Sensing Mechanism Integrity. For other than spring loaded direct acting pilot control devices, means shall be provided to detect failure of the pressure-sensing element, such as bellows, when operation of the pilot control device is dependent upon the integrity of a pressure-sensing element.

NC-7522.5 Set Pressure Tolerance.

(a) The set pressure tolerance shall apply only to the pilot valve.

(b) The set pressure tolerance plus or minus shall not exceed the following:

(1) 2 psi (15 kPa) for pressures up to and including 70 psi (500 kPa);

(2) 3% for pressures over 70 psi (500 kPa) up to and including 300 psi (2 000 kPa);

(3) 10 psi (70 kPa) for pressures over 300 psi (2 000 kPa) up to and including 1,000 psi (7 000 kPa); and

(4) 1% for pressures over 1,000 psi (7 000 kPa) for steam, air, and gas valves.

The set pressure tolerance as stated shall apply unless a greater tolerance is established as permissible in the Overpressure Protection Report (NC-7200) and the valve Design Specification.

(c) Conformance with the requirements of (b) above shall be established for each production valve by test. Steam valves shall be tested on steam, air or gas valves on air or gas, and liquid valves on liquid. Alternative fluids may be used as the test media if the requirements of NC-7560 have been met.

NC-7522.6 Blowdown.

(a) The blowdown requirements shall only apply to the pilot valve.

(b) Pilot valves shall be adjusted to close after blowing down to a pressure not lower than that specified in the valve Design Specification (NCA-3250) and the basis for the setting is covered in the Overpressure Protection Report (NC-7200).

(c) The adjustment shall be determined by test or by proration from the Certificate Holder's blowdown test data. Alternative fluids may be used as the test media if the requirements of NC-7560 have been met.

NC-7523 Credited Relieving Capacity

Except as required in NC-7523.1 and NC-7523.2, the credited relieving capacity of pilot-operated pressure relief valves shall be based on the certified relieving capacity. In addition, the capacity may be prorated as permitted in NC-7700.

NC-7523.1 System Upset Conditions. For system upset conditions in main steam service, the relieving capacity with which these values are credited shall be not more than:

(a) the stamped relieving capacity of the smaller one when two valves are installed;

(b) the stamped relieving capacity of the smaller two where three valves are installed;

(c) three-fourths of the total stamped relieving capacity where more than three valves are installed.

NC-7523.2 System Emergency Conditions. For system emergency conditions in main steam service, the relieving capacity with which these valves are credited shall be not more than:

(a) the relieving capacity of the valve with smaller stamped capacity where two valves are installed;

(b) the relieving capacity of all except the valve with the largest stamped capacity where more than two valves are installed.

NC-7524 Sealing of Adjustments

The sealing requirements of NC-7515 shall apply.

NC-7530 POWER-ACTUATED PRESSURE RELIEF VALVES

NC-7531 General Requirements

Power-actuated pressure relief valves, which depend upon an external energy source such as electrical, pneumatic, or hydraulic systems and which respond to signals from pressure or temperature sensing devices, may be used, provided the requirements of this subsubarticle are met.

NC-7532 Operating Requirements

NC-7532.1 Response Time. In systems protected by power operated pressure relief valves, consideration shall be given to the time lapse between the signal to open and achieving the fully opened position, and the time lapse between the signal to close and achieving the fully closed position.

NC-7532.2 Sensors, Controls, and External Energy Sources.

(a) The sensors, controls, and external energy sources for valve operation shall have redundance and independence at least equal to that required for the control and safety protection systems associated with the system.

(b) The relief valve and its auxiliary devices treated as a combination shall comply with the following requirements.

(1) The valve opening pressure shall be controlled within a tolerance of ±1% of the set pressure when the automatic control is in use.

(2) The valve blowdown shall be controlled to a pressure not lower than that specified in the valve Design Specification (NCA-3250).

NC-7533 Certified Relieving Capacity

The power-actuated pressure relief valve certified relieving capacity and the proration of capacity shall be as determined by NC-7700.

NC-7534 Credited Relieving Capacity

NC-7534.1 Expected System Pressure Transient Conditions. For expected system pressure transient conditions, the relieving capacity with which these valves are credited shall be not more than:

(a) the certified relieving capacity of the smaller one when two valves are installed;

(b) one-half of the total certified relieving capacity when three or more valves are installed.

NC-7534.2 Unexpected System Excess Pressure Transient Conditions. For unexpected system excess pressure transient conditions, the relieving capacity with which these valves are credited shall not be more than:

(a) the relieving capacity of the valve with the smaller stamped capacity where two valves are installed;

(b) the relieving capacity of all except the valve with the largest certified capacity for valves where three through ten valves are installed;

(c) the relieving capacity of all except two valves of the largest certified capacity where more than ten valves are installed.

NC-7540 SAFETY VALVES WITH AUXILIARY ACTUATING DEVICES

NC-7541 General Requirements

Safety valves with auxiliary actuating devices which operate independently of the spring loading of the valve may be used, provided the requirements of NC-7510 are met except as modified by this subsubarticle.

NC-7542 Construction

(a) The construction shall be such that the valve opens automatically by direct action of the fluid at a pressure not higher than the safety valve set pressure and relieves at the relieving capacity in the event of failure of any essential part of the valve's auxiliary devices.

(b) The construction of the auxiliary actuating device shall be such that the safety valve will not be prevented from operating as defined in NC-7510 when the auxiliary actuating device is deenergized.

NC-7543 Expected System Pressure Transient Conditions

For expected system pressure transient conditions, credit for capacity (NC-7546) can be taken for valves opening at the setpoint of the auxiliary actuating device in accordance with (a) and (b) below.

(a) When two valves are installed, the valve of the smaller certified capacity is credited with opening at the setpoint of the auxiliary actuating device. The valve with the larger certified capacity is credited with opening at the safety valve set pressure.

(b) For groups of more than two valves all of the same certified capacity, half the valves in a group containing an even number of valves, or the number of valves in the group minus one and divided by two for a group containing an odd number of valves, are credited with opening at the setpoint of the auxiliary actuating device.

NC-7544 Unexpected System Excess Pressure Transient Conditions

For unexpected system excess pressure transient conditions, credit for capacity may be taken for valves opening at the setpoint of the auxiliary actuating device in accordance with the following.

(a) When two valves are installed, the valve with the smaller certified capacity may be credited with opening at the setpoint of the auxiliary actuating device. The valve with the larger certified capacity shall be credited with opening at the safety valve set pressure.

(b) When three through ten valves are installed, credit may be given for opening at the setpoint of the auxiliary actuating device for all valves except the one with the largest certified capacity. The valve assumed not to open at the setpoint of the auxiliary actuating device shall be credited with opening at the safety valve set pressure.

(c) When more than ten valves are installed, credit may be given for opening at the setpoint of the auxiliary actuating device for all valves except for two of the largest certified capacity. The two valves assumed not to open at the setpoint of the auxiliary actuating device shall be credited with opening at the safety valve set pressure.

NC-7545 Auxiliary Device Sensors and Controls

The sensors, controls, and external energy sources for the auxiliary actuating device shall comply with the requirements of NC-7530.

NC-7546 Certified Relieving Capacity

The certified relieving capacity and proration of capacity for safety valves with auxiliary actuating devices shall be determined by NC-7700.

NC-7547 Credited Relieving Capacity

The relieving capacities with which these valves are credited shall be:

(a) for valves credited with opening at the auxiliary actuating device setpoint, the capacity at the lower relieving pressure as determined by the rules of NC-7700 (this shall specifically include the 90% of average tested capacity inherent in the Code Certification procedure);

(b) for valves credited with opening at the safety valve set pressure, the stamped capacity as determined by the rules of NC-7700.

NC-7548 Response Time

For valves credited with opening at the auxiliary actuating device setpoint, consideration shall be given to the time delay between the signal to open and achieving the fully opened position and the time delay between the signal to close and achieving the fully closed position.

NC-7550 VACUUM RELIEF VALVES

NC-7551 General Requirements

Vacuum relief valves shall meet the construction requirements applicable to Class 2 valves and the additional requirements of this Article.

NC-7552 Types Permitted

(a) Balanced self-actuating horizontally installed swinging disk valves are permitted.

(b) Vertically installed vacuum disk or pallet-type valves are permitted.

(c) All vacuum relief valves shall have provisions for adjustment of the differential pressure.

NC-7553 Operating Requirements

Vacuum relief valves, which are operated by indirect means depending on an external energy source, such as electrical, pneumatic, or hydraulic systems, are not acceptable unless at least two independent external power-operated valves and control systems are employed so that the required relieving capacity is obtained if any one of the valves or systems should fail to operate.

NC-7560 ALTERNATIVE TEST MEDIA

NC-7561 General Requirements

Pressure relief devices may be subjected to set-pressure tests using a test medium of a fluid type or temperature other than that for which they are designed, provided the testing complies with NC-7562 through NC-7564. Valves designed for compressible fluid (other than steam) shall be tested with a compressible fluid, and valves designed for non-compressible fluids shall be tested with a non-compressible fluid. Valves designed for steam service shall be tested with steam.

NC-7562 Correlation

Correlation of pressure relief device operation with respect to the parameters under test shall be established for the specified alternative test medium, as compared with the conditions of the operating medium.

NC-7563 Verification of Correlation Procedure

The certificate holder shall ensure that the correlation established in accordance with the procedure will be of suffcient accuracy such that the pressure relief device tested or adjusted, or both, using the alternative media, will comply with the operating requirements. Results of the tests performed to verify the adequacy of the alternative test media correlation shall be documented.

NC-7564 Procedure

A written procedure shall be prepared by the certificate holder in accordance with the requirements of NC-7563. The procedure shall specify all the test parameters that affect correlation and shall include at least the following:

(a) specific description of test setup;

(b) specific requirements for instrumentation;

(c) specific requirements for assist equipment (if any); and

(d) specific requirements for testing conditions, i.e., device temperature, ambient temperature, ambient pressure, etc.

Test parameters shall be listed, i.e., time between openings, number of tests, etc.

NC-7600 NONRECLOSING PRESSURE RELIEF DEVICES

NC-7610 RUPTURE DISK DEVICES

NC-7611 General Requirements

Rupture disk devices certified in accordance with NC-7720 and NC-7750 are subject to the following:

(a) rupture disk devices may be used as the sole pressure relief devices, except for main steam or liquid service (NC-7625);

(b) rupture disk devices may be used on the inlet side of pressure relief valves only when such valves are of the full bore[81] type (NC-7623);

(c) rupture disk devices may be used in conjunction with pressure relief valves on the outlet side (NC-7624).

NC-7612 Burst Pressure Tolerance

The burst pressure tolerance at the specified disk temperature[82] shall not exceed ±2 psi (15 kPa) for stamped burst pressure up to and including 40 psi (300 kPa) and ±5% for stamped burst pressure above 40 psi (300 kPa) as established by the rules of NC-7613, unless other values have been established in the Design Specification and are covered in the Overpressure Protection Report.

NC-7613 Tests to Establish Stamped Burst Pressure

(a) Every rupture disk shall have a stamped burst pressure established by rules of NC-7612 within a manufacturing design range,[83] at a specified disk temperature, and shall be stamped with a lot number.

(b) Each lot of rupture disks[84] shall be tested in accordance with one of the following methods. All tests of disks for a given lot shall be made in a holder of the same form and pressure area dimensions as that being used in service.

(1) At least two sample rupture disks from each lot of rupture disks shall be burst at the specified disk temperature. The stamped burst pressure shall be determined so that the sample rupture disk burst pressures are within the tolerance specified by NC-7612.

(2) At least four sample rupture disks, but not less than 5% from each lot of rupture disks, shall be burst at four different temperatures distributed over the applicable temperature range for which the disks will be used. These data shall be used to establish a smooth curve of burst pressure vs. temperature for the lot of disks. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in NC-7612.

The value for the stamped burst pressure shall be established from the curve for a specified disk temperature.

(3) For prebulged solid metal disks or graphite disks only, at least four sample rupture disks using one size of disk from each lot of material shall be burst at four different temperatures, distributed over the applicable temperature range for which this material will be used. These data shall be used to establish a smooth curve of burst pressure vs. temperature for the lot of material. The burst pressure for each data point shall not deviate from the curve more than the burst pressure tolerance specified in NC-7612.

At least two disks from each lot of disks, made from this lot of material and of the same size as those to be used, shall be burst at the ambient temperature to establish the room rating of the lot of disks. The curve shall be used to establish the stamped rating at the specified disk temperature for the lot of disks.

NC-7614 Burst Pressure in Relation to Pressure Relief Valve Set Pressure

The burst pressure of a rupture disk may be either lower or higher than the set pressure of the associated pressure relief valve, but in no case shall the rupture disk burst pressure and valve set pressure be such that the total accumulated pressure during full capacity relief exceeds the permitted limit (NC-7400).

NC-7620 INSTALLATION REQUIREMENTS

NC-7621 Provisions for Venting or Draining

When a rupture disk is used in conjunction with a pressure relief valve, the space between the rupture disk and the associated pressure relief valve shall be vented and/or drained. This space shall be provided with means to monitor its internal pressure during service periods.

NC-7622 System Obstructions

When the release of rupture disk material may occur,-piping and other components downstream of the rupture disk shall be constructed such that no obstruction can be caused nor the function of a pressure relief valve impaired.

NC-7623 Rupture Disk Devices at the Inlet Side of Pressure Relief Valves

A rupture disk device may be installed at the inlet side of a pressure relief valve if the following provisions are met:

(a) the combination of the pressure relief valve and the rupture disk device capacity shall meet the requirements of NC-7300;

(b) the stamped burst pressure at the specified disk temperature of the rupture disk does not exceed the limits of NC-7400;

(c) the opening provided through the rupture disk after burst is sufficient to permit a flow equal to the capacity of the valve, and there is no chance of interference with proper functioning of the valve; but in no case shall this area be less than the area of the inlet of the valve unless

the capacity and functioning of the specific combination of rupture disk and valve have been established by test in accordance with NC-7700.

NC-7624 Rupture Disk Devices at the Outlet Side of Pressure Relief Valves

A rupture disk device may be installed at the outlet side of pressure relief valves if the following provisions are met:

(a) the set pressure of the valve is independent of back pressure; or for unbalanced valves the set pressure of the valve plus the stamped burst pressure of the rupture disk plus any pressure in the outlet piping does not exceed the limits of NC-7400.

(b) the relieving capacity meets the requirements of NC-7300.

(c) the stamped burst pressure of the rupture disk at the specified disk temperature plus any pressure in the outlet piping from the rupture disk device shall not exceed the secondary Design Pressure of the pressure relief valve and the Design Pressure of any pipe or fittings between the valve and the rupture disk device. However, in no case shall the stamped burst pressure of the rupture disk at the operating temperature plus any pressure in the outlet piping from the rupture disk device exceed the limits of NC-7400.

(d) the opening provided through the rupture disk device after burst is sufficient for the pressure relief valve to flow its certified capacity.

NC-7625 Rupture Disk Devices Used as Sole Pressure Relief Device

Rupture disk devices may be used as the sole pressure relief device if the following provisions are met:

(a) at least two rupture disk devices are used in series as the sole pressure relief device for services where release of the contents of the protected system is acceptable to the enforcement authorities having jurisdiction at the nuclear power plant site;

(b) the rupture disk device is sized to meet the requirements of NC-7300;

(c) the stamped burst pressure at the specified temperature of the rupture disk does not exceed the limits of NC-7400;

(d) the space between the two rupture disk devices is monitored for pressure buildup, and a means of draining and/or venting is provided to check for rupture disk leakage or burst;[85]

(e) the distance between the rupture disks is designed so that the first disk will not contact the second disk at rupture.

NC-7700 CERTIFICATION

NC-7710 RESPONSIBILITY FOR CERTIFICATION OF PRESSURE AND VACUUM RELIEF VALVES

(a) The Certificate Holder shall be responsible for having the relieving capacity of his valves certified as prescribed in this subarticle.

(b) Capacity certification which is obtained in compliance with other Subsections and which complies with this Subsection may be considered as qualified for capacity certification under the rules of this Subsection, and the valve may be stamped with the appropriate symbol of this Subsection.

NC-7720 RESPONSIBILITY FOR CERTIFICATION OF NONRECLOSING PRESSURE RELIEF DEVICES

When rupture disk devices are used at the inlet of pressure relief valves, the manufacturer of the rupture disk devices or Certificate Holder shall be responsible for having the relieving capacity of the combination determined.

NC-7730 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES — COMPRESSIBLE FLUIDS

NC-7731 General Requirements

NC-7731.1 Capacity Certification. Capacity certification procedures shall be as required in NC-7732 through NC-7737.

NC-7731.2 Test Media.

(a) Capacity certification tests of pressure relief valves for steam service shall be conducted with dry saturated steam. For test purposes, the limits of 98% minimum quality and 20°F (10°C) maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

(b) Capacity certification tests for pressure relief valves for air and gas service shall be conducted with air, gas, or dry saturated steam.

NC-7731.3 Test Pressure.

(a) Capacity certification tests of pressure relief valves for main steam service shall be conducted at a pressure which does not exceed the set pressure by more than 3% or 2 psi (15 kPa), whichever is greater.

(b) Capacity certification tests of pressure relief valves with set pressures of 15 psig and higher for air, gas, or steam service other than main steam service shall be conducted at a pressure which does not exceed the set pressure by more than 10% or 3 psi (20 kPa), whichever is greater.

(c) Capacity certification tests for air or gas service with set pressures of 3 psig (20 kPa gage) up to but not including 15 psig (100 kPa gage) shall be conducted in accordance with the requirements of NC-7731 through

NC-7734. When tests are performed in accordance with NC-7734, the capacity shall be determined at no more than 2 psi (13.8 kPa) above the actual set pressure.

NC-7731.4 Blowdown.

(a) Valves set at or above 15 psig (100 kPa gage), having an adjustable blowdown construction, shall be adjusted prior to capacity certification testing so that the blowdown does not exceed 5% of the set pressure.

(b) Valves set below 15 psig (100 kPa gage), having adjustable blowdown construction, shall be adjusted prior to capacity certification testing so that blowdown does not exceed 3 psi (20 kPa) and shall not be less than 0.5 psi (4 kPa).

NC-7731.5 Drawings. Prior to capacity certification tests, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and all test results to the ASME designated organization for review and acceptance.

NC-7731.6 Design Changes. When changes are made in the design of a pressure relief valve which affect the flow path, lift, or performance characteristics, new tests shall be performed in accordance with this subarticle.

NC-7731.7 Restricted Lift Valves.

(a) The design of the lift restraining device shall be subject to review by an ASME designated organization.

(b) For main steam service under Subsection NC, all valves shall be capacity tested at each pressure and lift at a flow rating pressure not exceeding 103% of the valve set pressure as required in the applicable NC paragraphs.

(c) For air or gas service and for steam service other than in (a) above, all valves shall be capacity tested at each pressure and lift at a flow rating pressure not exceeding 110% of the set pressure as required in the applicable Code paragraph.

(d) For each valve tested, it shall be verified that actual measured capacity at restricted lift will equal or exceed the ASME rated capacity at full rated lift multiplied by the ratio of measured restricted lift to full rated lift.

NC-7732 Flow Model Test Method — Pilot or Power Operated Valves

NC-7732.1 Flow Capacity. When test facility limitations make it impossible to perform capacity tests of the full-scale pressure relief valves, flow models of three different sizes may be utilized as a basis for capacity certification. Such flow models shall be sized consistent with the capabilities of the accepted test laboratory where the tests will be conducted and shall accurately model those features, such as orifice size, valve lift, and internal flow configuration, which affect flow capacity. The test models need not be functional pressure relief valves, provided that other tests are conducted to demonstrate proper function of the valve design as prescribed in NC-7732.2. The relieving capacity of valve designs certified by use of flow models shall be established by the coefficient of discharge method similar to that outlined in NC-7734. The certified relieving capacity of all sizes and pressures of a given design for which the value of K has been established, based on flow model tests in accordance with the method of NC-7734, shall not exceed the value calculated by the appropriate equation in NC-7734.2 multiplied by the coefficient K.

NC-7732.2 Demonstration of Function. The function of three valves of the design to be certified shall be demonstrated by tests. Such tests may be performed in conjunction with the capacity certification tests outlined above or as separate tests using production valves. The purpose of these tests is to demonstrate to the satisfaction of a representative from an ASME designated organization that the valve will open at set pressure within the required opening pressure tolerance, will achieve full lift, and will reclose within required blowdown. If required by test facility limitations, these tests may be conducted at reduced flow capabilities. Measurement of valve blowdown may not be possible.

NC-7733 Slope Method

(a) For pressure relief valves of a specific design, four valves of each combination inlet size and orifice size shall be tested. These four valves shall be set at pressures that will cover the appropriate range of pressures for which the valves are to be used or within the range of the authorized test facility.

(b) The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as follows.

(1) For valves with set pressures of 15 psig (100 kPa gage) and greater, slope is defined as the measured capacity divided by the absolute inlet pressure.

(2) For valves with set pressures of 3 psig (20 kPa gage) up to but not including 15 psig (100 kPa gage), slope is defined as the measured capacity divided by the quantity,

$$\left[(P)(P - P_o)\right]^{1/2}$$

where

$$F = \sqrt{\left(\frac{k}{k-1}\right)\left(r^{2/k}\right)\left[\frac{1-(r)^{\frac{k-1}{k}}}{1-r}\right]}$$

k = ratio of specific heats, C_v/C_p
P = inlet pressure, psi (kPa)
P_o = discharge pressure, psi (kPa)
r = pressure ratio, P_o/P

(c) If any of the experimentally determined slopes fall outside of a range of ±5% of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these

valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the ±5% range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design.

(d) For valves with set pressures of 15 psig (100 kPa gage) and greater, the certified capacity shall be 90% of the average slope multiplied by the flow rating pressure, psia.

(e) For valves with set pressures of 3 psig (20 kPa gage) up to but not including 15 psig (100 kPa gage), the certified capacity shall be 90% of the average slope multiplied by the quantity,

$$F\left[(P)(P - P_o)\right]^{1/2}$$

(f) In addition, demonstration of function tests shall be conducted as prescribed in NC-7732.2.

NC-7734 Coefficient of Discharge Method

A coefficient K may be established for a specific pressure relief valve design according to the procedure given in the following subparagraphs.

NC-7734.1 Number of Valves to Be Tested. For each design, at least three valves for each of three different sizes shall be submitted for test. Each valve of a given size shall be set at a different pressure.

For restricted lift valves, each size valve shall be tested for capacity at its full rated lift, at the minimum lift for which certification is required, and at an intermediate lift point approximately halfway between the full rated lift and minimum lift certification points. Each of the three test valves shall be set at a different pressure.

NC-7734.2 Establishment of Coefficient of Discharge.

(a) Tests shall be made on each pressure relief valve to determine its lift, opening and blowdown pressures, and capacity in terms of the fluid used in the test. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{actual flow}}{\text{theoretical flow}} = \text{coefficient of discharge}$$

where Actual Flow is determined quantitatively by test, and Theoretical Flow is calculated by the following equation.

(1) For valves with set pressures of 15 psig (100 kPa gage) and greater. For test with dry saturated steam:

$$W_T = 51.5AP$$

For pressures over 1,500 psig (10.9 MPa) and up to 3,200 psig (22.1 MPa), the value of W_T, calculated by the above equation, shall be corrected by being multiplied by the following factor, which shall be used only if it is 1.0 or greater:

(U.S. Customary Units)

$$\frac{(0.1906P - 1{,}000)}{(0.2292P - 1{,}061)}$$

(SI Units)

$$\frac{(27.6P - 1000)}{(33.2P - 1061)}$$

For test with air:

$$W_T = 356AP\sqrt{M/T}$$

For test with gas:

$$W_T = CAP\sqrt{M/ZT}$$

where

A = actual discharge area through the valve at developed lift

C = constant for gas or vapor which is a function of the ratio of specific heats, k

k = C_p/C_v, ratio of specific heats (see Section III Appendices, Mandatory Appendix XVIII, Figure XVIII-1110-1)

M = molecular weight

P = (set pressure × 1.03) plus atmospheric pressure, psia (kPa abs), or set pressure plus 2 psi (15 kPa) plus atmospheric pressure, whichever is greater, for test pressures determined by NC-7731.3(a)

= (set pressure × 1.10) plus atmospheric pressure, psia (kPa abs), or set pressure plus 3 psi (20 kPa) plus atmospheric pressure, whichever is greater, for test pressures determined by NC-7731.3(b)

T = absolute temperature at inlet (K), +460°F (+273°C)

W_T = Theoretical Flow

Z = compressibility factor corresponding to P and T

The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90, and their product shall be taken as the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9 × 0.975).

(2) For valves with set pressures of 3 psig (20 kPa gage) up to but not including 15 psig (100 kPa gage). The following equation may be used for other than saturated steam flow:

(U.S. Customary Units)

$$W = 735FA\left[\frac{MP(P - P_o)}{T}\right]^{1/2}$$

(SI Units)

$$W = 55.8FA\left[\frac{MP(P - P_o)}{T}\right]^{1/2}$$

(U.S. Customary Units)

$$Q = 279{,}000FA\left[\frac{P(P - P_o)}{MT}\right]^{1/2}$$

(SI Units)

$$Q = 1320FA\left[\frac{MP(P - P_o)}{MT}\right]^{1/2}$$

where

$$F = \sqrt{\left(\frac{k}{k - 1}\right)\left(r^{2/k}\right)\left[\frac{1 - (r)^{\frac{k-1}{k}}}{1 - r}\right]}$$

or is obtained from Figure NC-7734.2(a)-1.

A = flow area
k = ratio of specific heats, c_v/c_p
M = molecular weight
P = inlet pressure
P_o = discharge pressure
T = temperature, deg Rankine (deg K)
r = pressure ratio, P_o/P
Q = ft^3/hr at 14.7 psi and 60°F (m^3/h at 0.101 MPa and 20°C)
W = flow

The average of the coefficients of discharge K_d of the tests required shall be multiplied by 0.90 and their product shall be the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.90 × 0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of ±5% of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the ±5% range, then the test shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design.

NC-7734.3 Calculation of Certified Capacity.

(a) The certified capacity of all sizes and pressures of a given design, for which the value of K has been established under the provisions of NC-7734.2 and which are manufactured subsequently, shall not exceed the value calculated by the appropriate equation multiplied by the coefficient K.

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d, for valves of the extreme ends of a larger range is within ±5% of the average coeffiecient, K. For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

NC-7734.4 Demonstration of Function. Tests shall be conducted as prescribed in NC-7732.2.

NC-7735 Single Valve Method

NC-7735.1 Valve Capacity Within Test Facility Limits.

(a) When a single valve is to be capacity tested, the certified capacity may be based on three separate tests associated with each set pressure for which capacity certification is required.

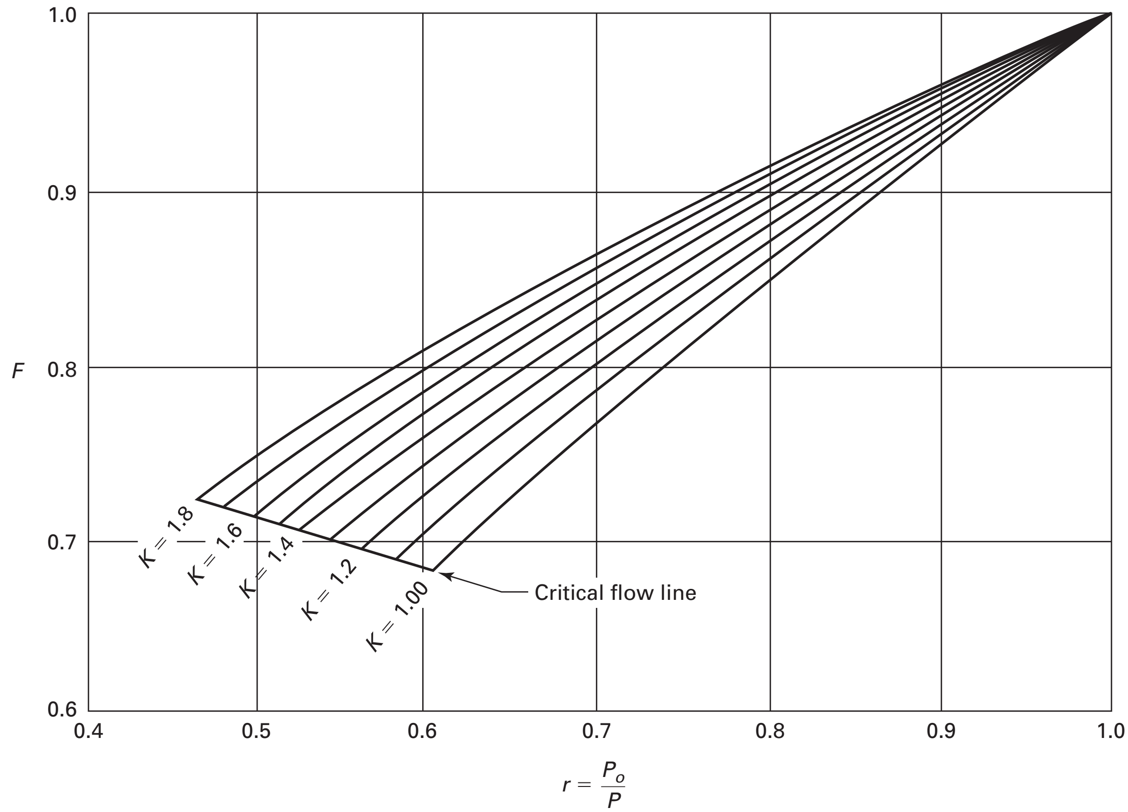
(b) The certified capacity associated with each set pressure shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within ±5% of the average capacity associated with each set pressure shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(c) Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

NC-7735.2 Valve Capacity in Excess of Test Facility Limits. For valves whose capacity exceeds that of the test facility, the certified capacity may be based on a flow coefficient K (NC-7734.2) determined from either blocked open flow tests or flow model tests, provided the orifice area is such that choked flow conditions are obtained. The certified capacity shall be calculated as directed in NC-7734.3.

NC-7735.3 Valve Demonstration of Function. The proper operation of the valve shall be demonstrated as prescribed in NC-7732.2.

Figure NC-7734.2(a)-1
Values of F for Nonchoking Flow



NC-7736 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve design is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification:

(1) the prorated capacity shall be 90% of the average slope determined in NC-7733 multiplied by the prorated relieving pressure (psia); or

(2) the prorated capacity shall be calculated using the appropriate equation from NC-7734.2 (where P is the prorated relieving pressure (psia) multiplied by the coefficient K.

NC-7737 Capacity Conversions

The relieving capacity of pressure relief valves for fluids other than the fluid used for certification shall be determined by the method of conversion given in Section III Appendices, Mandatory Appendix XVIII, Article XVIII-1000, except that valves for steam service shall be tested on steam.

NC-7738 Laboratory Acceptance of Pressure-Relieving Capacity Tests (15)

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of a representative from an ASME designated organization. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designated organization for review and acceptance.[86]

NC-7739 Laboratory Acceptance of Demonstration of Function Tests

The NV Certificate Holder shall assure that the tests are conducted at a place where the testing facilities, methods, and procedures provide for sufficient testing capacity and range of fluid properties so that the testing requirements of NC-7732.2 are met.

NC-7740 CAPACITY CERTIFICATION OF PRESSURE RELIEF VALVES — INCOMPRESSIBLE FLUIDS

NC-7741 General Requirements

NC-7741.1 Capacity Certification. Capacity certification procedures shall be as required in NC-7742 through NC-7745.

NC-7741.2 Test Medium. The test medium to be used for capacity certification shall be water at a temperature between 40°F (5°C) and 125°F (50°C).

NC-7741.3 Test Pressure. Tests shall be conducted at pressures which do not exceed the set pressure by more than 10% or 3 psi (20 kPa), whichever is greater.

NC-7741.4 Blowdown. Blowdown shall be recorded at time of the test.

NC-7741.5 Drawings. Prior to capacity certification tests, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and all test results to the ASME designated organization for review and acceptance.

NC-7741.6 Design Changes. When changes are made in the design of a pressure relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this subarticle shall be performed.

NC-7742 Valve Designs in Excess of Test Facility Limits

(a) For a valve design where test pressures will exceed test facility limits, the certified capacity may be based on a flow coefficient K (NC-7744.2) determined from blocked open flow tests at four pressures covering the range of the test facility.

(1) For a valve design to be certified at a single size and set pressure, a demonstration of function test shall be conducted as prescribed in NC-7732.2 on one valve at the specified pressure.

(2) For a valve design of a single size to be certified over a range of set pressures, demonstration of function tests shall be conducted as prescribed in NC-7732.2 on two valves covering the minimum set pressure for the design and the maximum set pressure which can be accommodated at the demonstration facility selected for the test.

(b) For a valve design which will be used over a range of set pressures and sizes, where test facility limitations make it impossible to perform tests of full-scale pressure relief valves, flow models of three different sizes may be utilized as a basis for capacity certification. The flow model test method in NC-7732.1 shall be used along with the coefficient of discharge method in NC-7744.

(1) A demonstration of function tests for three valves shall be performed as prescribed in NC-7732.2.

NC-7743 Slope Method

Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the appropriate range of pressures for which the valves are to be used within the range of the test facility. The instantaneous slope of each test point shall be calculated and averaged, where slope is defined as the measured capacity divided by the square root of the difference between the flow rating pressure and the valve discharge pressure. If any of the experimentally determined slopes fall outside of a range of ±5% of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the ±5% range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the square root of the difference between the flow rating pressure and the valve discharge pressure.

NC-7744 Coefficient of Discharge Method

Instead of individual capacity tests or the capacity curve method, a coefficient K may be established for a specific pressure relief valve design in accordance with the following subparagraphs.

NC-7744.1 Number of Valves to Be Tested. For each design, three valves for each of three different sizes shall be tested, for a total of nine valves. Each valve of a given size shall be set at a different pressure.

NC-7744.2 Establishment of Coefficient of Discharge.

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity in terms of pounds of water per hour. A coefficient of discharge K_D shall be established for each test run as follows:

$$K_D = \frac{\text{actual flow}}{\text{theoretical flow}} = \text{coefficient of discharge}$$

where Actual Flow is determined quantitatively by test and Theoretical Flow is calculated by the following equation. For test with water:

(U.S. Customary Units)

$$W_t = 2{,}407A\sqrt{(P - P_d)w}$$

(SI Units)

$$W_t = 5092A\sqrt{(P - P_d)w}$$

where

A = actual minimum discharge area through the valve at developed lift
P = (set pressure × 1.10) plus atmospheric pressure, psia (kPa abs), or set pressure plus 3 psi (0.02 MPa) plus atmospheric pressure, whichever is greater
P_d = pressure at discharge from valve
w = density of water at valve inlet conditions
W_t = Theoretical Flow

The average of the coefficients of discharge K_D of the tests shall be multiplied by 0.90 and the product shall be taken as the coefficient K of the design. The coefficient of the design shall not be greater than 0.878 (the product of 0.9 × 0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of ±5% of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the ±5% range, then the test shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design.

NC-7744.3 Calculation of Certified Capacity.

(a) The certified capacity of all sizes and pressures of a given design for which the value of K has been established under the provisions of NC-7744.2 shall not exceed the value calculated by the theoretical equation above multiplied by the coefficient K.

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d, for valves of the extreme ends of a larger range is within ±5% of the average coefficient, K. For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

NC-7745 Single Valve Method

Where a single valve at a single pressure is to be capacity tested, the capacity rating may be based on three separate tests of the single valve at the specified set pressure. The certified capacity rating of the valve shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within ±5% of the average capacity may be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

Should additional valves of the same design be constructed at a later date, the results of the tests on the original valve may be included as applicable to the particular test method selected.

NC-7746 Laboratory Acceptance of Pressure-Relieving Capacity Tests (15)

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation from a representative from an ASME designated organization. Acceptance of the testing facility is subject to review within each 5-year period. Capacity test data shall be submitted to the ASME designated organization for review and acceptance.[86]

NC-7747 Proration of Capacity

(a) The capacity of a pressure relief valve applied to a system may be prorated to an overpressure greater than the overpressure for which the valve design is certified. This overpressure shall be within the allowable limits of the system.

(b) Depending on the method used for the initial capacity certification:

(1) the prorated capacity shall be 90% of the average slope determined in NC-7743 multiplied by the prorated relieving pressure (psia); or

(2) the prorated capacity shall be calculated using the appropriate equation from NC-7744.2 [where P is the prorated relieving pressure (psia) multiplied by the coefficient K].

NC-7748 Capacity Conversion

The rated pressure-relieving capacity of pressure relief valves for liquids other than the liquids used for certification shall be determined by the method of conversion given in Section III Appendices, Mandatory Appendix XVIII, Article XVIII-1000. This conversion is not valid for liquid flashing valve operating conditions.

NC-7750 CAPACITY CERTIFICATION OF VACUUM RELIEF VALVES

NC-7751 General Requirements

NC-7751.1 Capacity Certification. Capacity certification procedures shall be as required in NC-7752 through NC-7755.

NC-7751.2 Test Media. Capacity certification tests for vacuum relief valves for air and gas service shall be conducted with dry steam, air, or gas. For steam test purposes the limits of 98% minimum quality and 20°F (10°C) maximum superheat shall apply. Capacity shall be corrected to dry saturated condition from these limits.

NC-7751.3 Test Method and Pressure. Capacity tests may be conducted by pressurizing the valve instead of using a vacuum, provided the inlet conditions of the valve (not the vessel) are known and the inlet pressure is not greater than 5 psi (35 kPa), and the direction of flow through the valve is the same on pressure as is experienced on vacuum. Tests shall be conducted at twice the set pressure or 1 psi (7 kPa), whichever is greater.

NC-7751.4 Blowdown. Blowdown shall be recorded at the time of the test.

NC-7751.5 Drawings. Prior to a test, the Certificate Holder shall submit drawings showing the valve construction to the Authorized Observer. The Authorized Observer shall submit the drawings and test results to the ASME designated organization for review and acceptance.

NC-7751.6 Design Change. When changes are made in the design of a vacuum relief valve in such a manner as to affect the flow path, lift, or performance characteristics of the valve, new tests in accordance with this Article shall be performed.

NC-7752 Single Valve Method

(a) When a single valve at a single pressure is to be capacity tested, the capacity rating may be based on three separate and distinct tests of the single valve at the specified set pressure. The certified capacity rating of the valve shall not exceed 90% of the average capacity established by the tests. Failure of the individual test capacities to fall within ±5% of the average capacity shall be cause for rejection of the test. The reason for the failure shall be determined and the test repeated.

(b) Should additional valves of the same design be constructed at a later date, the results of the test on the original valve may be included as applicable to the particular test method selected.

NC-7753 Slope Method

Four valves of each combination of pipe size and orifice size shall be tested. These four valves shall be set at pressures which cover the appropriate range of pressures for which the valves are to be used or set within the range of the test facility. The slope of each test shall be calculated and averaged, where slope is defined as the measured capacity divided by the quantity, $F[(P)(P - P_o)]^{1/2}$

where

$$F = \sqrt{\left(\frac{k}{k-1}\right)\left(r^{2/k}\right)\left[\frac{1 - (r)^{\frac{k-1}{k}}}{1 - r}\right]}$$

where

k = ratio of specific heats, c_v/c_p
P = inlet pressure
P_o = discharge pressure
r = pressure ratio, P_o/P

If any of the experimentally determined slopes fall outside of a range of ±5% of the average slope, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average slope shall be determined, excluding the replaced valve test results. If any individual slope is now outside of the ±5% range, then the tests shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design. The certified capacity shall be 90% of the average slope multiplied by the quantity, $F[(P)(P - P_o)]^{1/2}$.

NC-7754 Coefficient of Discharge Method

A coefficient K may be established for a specific vacuum relief valve design in accordance with NC-7754.1 and NC-7754.2.

NC-7754.1 Number of Valves to Be Tested. For each design, three valves of three different sizes, a total of nine valves, shall be tested. Each valve of a given size shall be set at a different pressure.

NC-7754.2 Establishment of Coefficient of Discharge.

(a) Tests shall be made on each relief valve to determine its lift, opening and closing pressures, and actual capacity. A coefficient of discharge K_D shall be established for each run as follows:

$$K_D = \frac{\text{actual flow}}{\text{theoretical flow}} = \text{coefficient of discharge}$$

where Actual Flow is determined quantitatively by test, and Theoretical Flow is calculated from the appropriate equation for the test fluid. The following equation may be used for other than saturated steam flow:

(U.S. Customary Units)

$$W = 735FA\left[\frac{MP(P - P_o)}{T}\right]^{1/2}$$

(SI Units)

$$W = 55.8FA\left[\frac{MP(P - P_o)}{T}\right]^{1/2}$$

(U.S. Customary Units)

$$Q = 279,000FA\left[\frac{P(P - P_o)}{MT}\right]^{1/2}$$

(SI Units)

$$Q = 1320FA\left[\frac{P(P - P_o)}{MT}\right]^{1/2}$$

where

$$F = \sqrt{\left(\frac{k}{k - 1}\right)\left(r^{2/k}\right)\left[\frac{1 - (r)^{\frac{k-1}{k}}}{1 - r}\right]}$$

or is obtained from Figure NC-7754.2(a)-1.

A = flow area
k = ratio of specific heats, c_v/c_p
M = molecular weight
P = inlet pressure
P_o = discharge pressure
Q = ft^3/hr at 14.7 psi and 60°F (m^3/h at 0.101 MPa and 15°C)
r = pressure ratio, P_o/P
T = temperature, deg Rankine (deg K)
W = lb/hr (kg/h)

The average of the coefficients of discharge K_D of the tests required shall be multiplied by 0.90 and their product shall be the coefficient K of that design. The coefficient of the design shall not be greater than 0.876 (the product of 0.9 × 0.975).

(b) If any of the experimentally determined coefficients fall outside of a range of ±5% of the average coefficient, the unacceptable valves shall be replaced by two valves of the same size and set pressure. Following the test of these valves, a new average coefficient shall be determined, excluding the replaced valve test results. If any individual coefficient is now outside of the ±5% range, then the test shall be considered unsatisfactory and shall be cause for the ASME designated organization to refuse certification of the particular valve design.

NC-7754.3 Calculation of Relieving Capacity.

(a) The certified relieving capacity of all sizes and pressures of a given design, for which the value of K has been established, shall be calculated by the appropriate equation given above multiplied by the coefficient K. Values obtained from pressurized tests may be converted to equivalent vacuum from the above equation.

(b) The coefficient shall not be applied to valves whose beta ratio (the ratio of valve throat and inlet diameter) lies outside the range of 0.15 to 0.75, unless tests have demonstrated that individual coefficients of discharge, K_d, for valves of the extreme ends of a larger range is within ±5% of the average coefficient, K. For designs where lift is used to determine the flow area, all valves shall have the same nominal lift-to-seat diameter ratio (L/D).

NC-7755 Laboratory Acceptance of Relieving Capacity Tests (15)

Tests shall be conducted at a place where the testing facilities, methods, procedures, and person supervising the tests (Authorized Observer) meet the applicable requirements of ASME PTC 25, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation from a representative from an ASME designated organization. Acceptance of the testing facility is subject to review within each 5-year period. Capacity test data shall be submitted to the ASME designated organization for review and acceptance.[86]

NC-7760 CAPACITY DETERMINATION OF RUPTURE DISK DEVICES

NC-7761 General Requirements

NC-7761.1 Test Media.

(a) Capacity tests of rupture disk devices for steam service shall be conducted with dry saturated steam. For test purposes, the limits of 98% minimum quality and 20°F (−10°C) maximum superheat shall apply. Capacity shall be corrected to the dry saturated condition from within these limits.

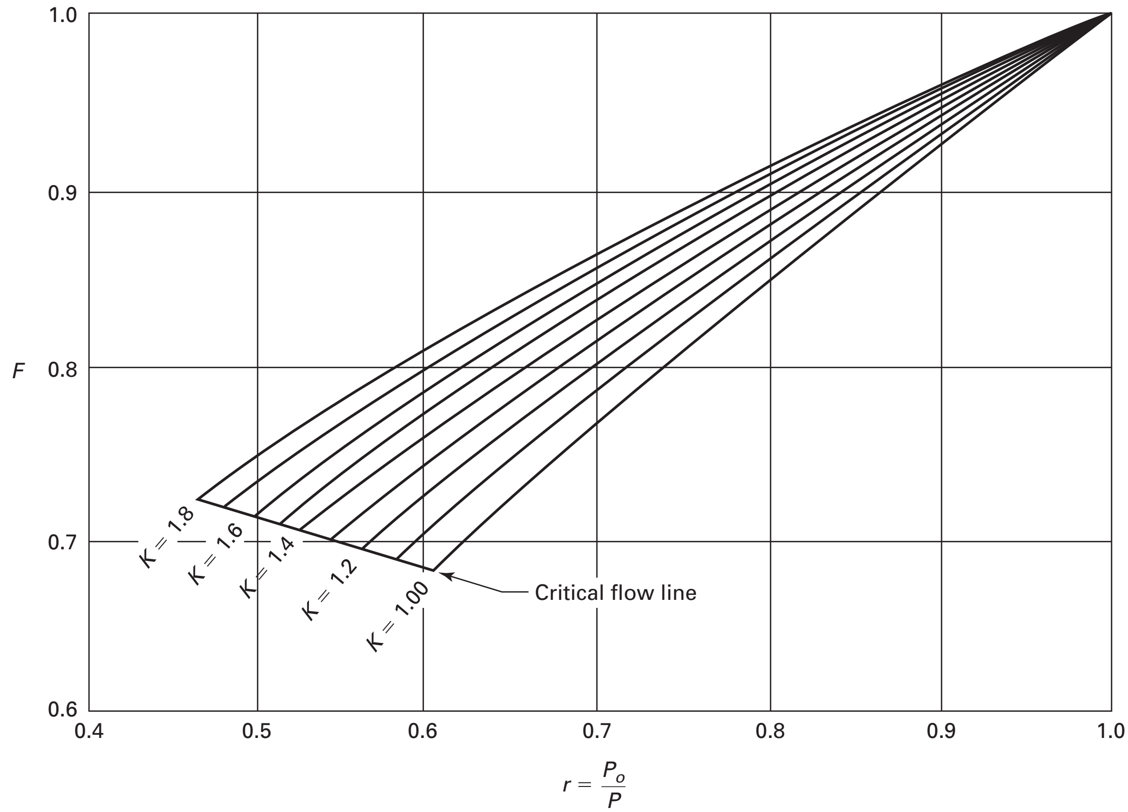
(b) Capacity tests for rupture disk devices for air and gas service shall be conducted with air, gas, or dry saturated steam.

NC-7761.2 Test Pressure.

(a) Capacity tests of rupture disk devices shall be conducted at a pressure not exceeding 110% of the stamped burst pressure.

(b) Capacity tests of rupture disk devices used at the inlet side of pressure relief valves shall be conducted at a pressure not exceeding 110% of the valve set pressure.

Figure NC-7754.2(a)-1
Values of F for Nonchoking Flow



NC-7762 Capacity Determination of Rupture Disk Devices in Combination With Pressure Relief Valves

NC-7762.1 Capacity Determination Without Flow Test.

(a) The rated capacity of the combination of a pressure relief valve when installed with a rupture disk device at the inlet side of the valve shall not exceed 80% of the certified capacity of the valve. Alternatively, the capacity of such a combination shall be established in accordance with NC-7762.2.

(b) The rated capacity of the combination of a pressure relief valve when installed with a rupture disk device at the outlet of the valve shall be the certified capacity of the valve.

NC-7762.2 Capacity of Pressure Relief Valves in Combination With a Rupture Disk Device at the Inlet. For each combination of pressure relief valve design and rupture disk device design, the Certificate Holder or the rupture disk device manufacturer shall have the capacity of the combination determined as prescribed in (a) and (b) below.

(a) The Certificate Holder or the rupture disk device manufacturer shall submit for tests the smallest rupture disk device size with the equivalent size of pressure relief valve that is intended to be used as a combination device. The pressure relief valve to be tested shall have the largest orifice used in the particular inlet size.

(b) Tests shall be performed in accordance with the requirements of (1) through (5) below. The rupture disk device and pressure relief valve combination to be tested shall be arranged to duplicate the combination assembly design.

(1) The test shall be made using the minimum burst pressure of the rupture disk device design that is to be used in combination with the pressure relief valve design. The stamped bursting pressure shall be between 90% to 100% of the stamped set pressure of the valve.

(2) The test procedure to be used shall be as follows:

(-a) The pressure relief valve by itself shall be tested for capacity without the rupture disk device at a pressure 10% above the valve set pressure.

(-b) The rupture disk device shall then be installed in front of the pressure relief valve and the disk burst to operate the valve. The capacity test shall be performed on the combination at 10% above the valve set pressure duplicating the test of (-a) above.

(3) The tests shall be repeated with two additional rupture disks of the same nominal rating for a total of three rupture disks to be tested with the single valve. The results of the test capacity shall fall within a range of 10% of the average capacity of the three tests. Failure to meet this requirement shall be cause to require retest for determination of cause of the discrepancies.

(4) From the results of the tests, a Combination Capacity Factor shall be determined. The Combination Capacity Factor is the ratio of the average capacity which is determined by the combination tests to the capacity which is determined by the test of (2)(-a) above. The Combination Capacity Factor shall be used as a multiplier to the certified capacity of the pressure relief valve in all sizes of the design, except when a different factor has been established for larger sizes and other pressures in accordance with NC-7762.3. The value of the Combination Capacity Factor shall not be greater than one. The Combination Capacity Factor shall apply only to combinations of the same design and manufacture of the pressure relief valve and the same design and manufacture of the rupture disk device as those tested.

(5) The test laboratory shall submit the test results to an ASME designated organization for acceptance of the Combination Capacity Factor.

NC-7762.3 Optional Testing of Rupture Disk Devices and Pressure Relief Valves.

(a) If desired, a Certificate Holder or a rupture disk manufacturer may conduct tests in the same manner as given in NC-7762.2 using the next two larger sizes of the same design of rupture disk device and pressure relief valve to determine a Combination Capacity Factor applicable to larger sizes. If a greater Combination Capacity Factor is established and can be approved, it may be used for all larger sizes of the combination, but the Factor shall not be greater than one.

(b) If desired, additional tests may be conducted at higher pressures in accordance with NC-7762.2 to establish a maximum Combination Capacity Factor to be used at all pressures higher than the highest tested, but the Factor shall not be greater than 1.

NC-7763 Capacity of Rupture Disk Devices

NC-7763.1 Calculated Capacity.

(a) The calculated capacity of a rupture disk device shall not exceed a value based on the applicable theoretical equation (Section III Appendices, Mandatory Appendix XVIII) for the various media multiplied by a value for K of 0.62. The area A in the theoretical equation shall be the minimum net flow area existing after disk burst.

(b) The minimum net flow area is the calculated net area after a complete burst of the disk, with appropriate allowance for any structural members which may reduce the net flow area through the rupture disk device. The net flow area for sizing purposes shall not exceed the nominal pipe size area of the rupture disk device.

NC-7763.2 Tested Capacity. A manufacturer may have the capacity of a given rupture disk device design approved for K_D in general accordance with the procedures of NC-7730, as applicable.

NC-7764 Laboratory Acceptance of Pressure-Relieving Capacity Tests (15)

Tests shall be conducted at a place where the testing facilities, methods, procedures, and Authorized Observer (person supervising the tests) meet the applicable requirements of ASME PTC 25, Pressure Relief Devices. The tests shall be made under the supervision of and certified by an Authorized Observer. The testing facilities, methods, procedures, and qualifications of the Authorized Observer shall be subject to the acceptance of the ASME Boiler and Pressure Vessel Committee on recommendation of an ASME designee. Acceptance of the testing facility is subject to review within each 5 year period. Capacity test data shall be submitted to the ASME designee for review and acceptance.[86]

NC-7800 MARKING, STAMPING WITH CERTIFICATION MARK, AND DATA REPORTS

NC-7810 PRESSURE AND VACUUM RELIEF VALVES

NC-7811 Marking and Stamping With Certification Mark

Each pressure relief valve shall be plainly marked by the Certificate Holder with the required data below in such a way that the marking will not be obliterated in service. The data shall be in characters not less than $^3/_{32}$ in. (2.5 mm) high. The marking shall be placed on the valve or on a nameplate securely fastened to the valve. The Certification Mark with NV Designator shall be stamped on the valve or nameplate, but the other required data may be stamped, etched, impressed, or cast. The marking shall include the following:

(a) name, or an acceptable abbreviation, of the Certificate Holder

(b) Certificate Holder's design or type number

(c) size ____ NPS (DN) of the valve inlet

(d) set pressure ____ psi (kPa)

(e) certified capacity and overpressure in percent or psi (kPa) in accordance with NC-7700

(1) Pressure Relief Valves

(-a) lb/hr (kg/h) of saturated steam for valves certified on steam, or

(-b) scfm (standard cubic feet per minute) at 60°F (15°C) and 14.7 psia (101 kPa abs) of air for valves certified on air or gas, or

(-c) gal/min (m^3/s) of water at 70°F (20°C) for valves certified on water

(2) Vacuum Relief Valves: scfh (standard cubic feet per hour) at 60°F (15°C) and 14.7 psi (101 kPa)

(f) applicable official Certification Mark, as shown in Table NCA-8100-1

In addition to the above, each pressure relief valve shall have a separate nameplate attached to the component that includes the marking requirements of NCA-8220 and NC-3593.2.

NC-7812 Report Form for Pressure and Vacuum Relief Valves

A Data Report Form NV-1 (see Section III Appendices, Mandatory Appendix V) shall be filled out and signed by the Certificate Holder and signed by the Inspector for each pressure and vacuum relief valve stamped with the Certification Mark with NV Designator.

NC-7820 RUPTURE DISK DEVICES

NC-7821 Rupture Disks

Every rupture disk shall be plainly marked by the manufacturer in such a way that the marking will not be obliterated in service. The rupture disk marking may be placed on the flange of the rupture disk or on a metal tab permanently attached thereto.[87] The marking shall include the following:

(a) name or identifying trademark of the manufacturer
(b) manufacturer's design or type number
(c) lot number
(d) size ____ NPS (DN)
(e) stamped bursting pressure ____ psi (kPa)
(f) specified disk temperature ____ °F (°C)
(g) capacity ____ lb/hr (kg/h) of saturated steam/hr or standard cu ft/min of air [60°F and 14.7 psia (15°C and 101 kPa abs)]
(h) year built

NC-7822 Disk Holders (If Used)

Rupture disk holders shall be marked with the following:

(a) name or identifying trademark of the manufacturer
(b) manufacturer's design or type number
(c) size ____ NPS (DN)
(d) year built
(e) serial number

NC-7830 PRESSURE RELIEF VALVE IN COMBINATION WITH RUPTURE DISK DEVICES

NC-7831 Marking When Capacity Is Approved in Accordance With NC-7762.1

The marking shall be placed either on the valve or the rupture disk holder or on a plate or plates securely fastened to the valve or the rupture disk holder. The marking shall include a Combination Capacity Factor of 0.8.

NC-7832 Marking When Capacity Is Approved in Accordance With NC-7762.2

The following marking shall be in addition to the marking required by NC-7811 and NC-7822. The marking shall be placed on the valve or the rupture disk holder or on a plate or plates securely fastened to the valve or the rupture disk holder. The marking shall include the following:

(a) name of the Certificate Holder
(b) design or type or serial number of valve
(c) name of manufacturer of rupture disk device
(d) design or type designation of rupture disk device
(e) approved Combination Capacity Factor

NC-7840 CERTIFICATE OF AUTHORIZATION TO USE CERTIFICATION MARK

Each pressure and vacuum relief valve within the scope of this Article shall be constructed by a Certificate Holder possessing a Certification Mark with NV Designator and a valid Certificate of Authorization. Pressure and vacuum relief valves shall have the Certification Mark with NV Designator applied in accordance with the rules of NC-8100.

ARTICLE NC-8000 NAMEPLATES, STAMPING WITH CERTIFICATION MARK, AND REPORTS

NC-8100 GENERAL REQUIREMENTS

The requirements for nameplates, stamping with Certification Mark, and reports shall be as given in Article NCA-8000.

ENDNOTES

1 Because of the different thermal coefficients of expansion of dissimilar materials, caution shall be exercised in construction under the provisions of this paragraph in order to avoid difficulties in service under extreme temperature conditions, or with unusual restraint such as may occur at points of stress concentration and also because of metallurgical changes occurring at high temperatures.

2 Any postweld heat treatment time that is anticipated to be applied to the material or item after it is completed shall be specified in the Design Specification. The Certificate Holder shall include this time in the total time at temperature specified to be applied to the test specimens.

3 T_{NDT} — temperature at or above the nil-ductility transition temperature NDT (ASTM E208); T_{NDT} is 10°F (5°C) below the temperature at which at least two specimens show no-break performance.

4 *Lowest Service Temperature* (LST) is the minimum temperature of the fluid retained by the component or, alternatively, the calculated minimum metal temperature whenever the pressure within the component exceeds 20% of the preoperational system hydrostatic test pressure.

5 The *Lowest Service Metal Temperature* shall be the lowest temperature that the metal may experience in service while the plant is in operation and shall be established by appropriate calculations based on atmospheric ambient conditions, the insulation or enclosure provided, and the minimum temperature that will be maintained inside the vessel during the plant operation.

6 The requirements for impact testing of the heat-affected zone (NC-4335.2) may result in reduced test temperatures or increased toughness requirements for the base material.

7 For pumps, valves, and fittings, use the nominal pipe wall thickness of the connecting pipe. For vessels, use the lesser of:
(a) the maximum radial thickness of the item, exclusive of integral butt welded projections;
(b) the vessel shell thickness to which the item is welded;
(c) the maximum shell thickness associated with the item for flat heads, tubesheets, or flanges.

8 The methods given in the Appendix of SFA–5.9, Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes, shall be used to establish a welding and sampling method for the pad, groove, or other test weld to ensure that the weld deposit being sampled will be substantially free of base metal dilution.

9 The volumetric examinations required by this paragraph need only be conducted from one surface.

10 It is recognized that high localized and secondary stresses may exist in components designed and fabricated in accordance with the rules of this Subsection; however, insofar as practical, design rules for details have been written to hold such stresses at a safe level consistent with experience.

11 Thermal protection devices, such as thermal sleeves in nozzles, may be used to reduce temperature differences or thermal shock.

12 *Adjacent points* are defined in (a) and (b) below.
(a) For surface temperature differences:
(1) on surfaces of revolution, in the meridional direction, adjacent points are defined as points that are less than the distance $2\sqrt{Rt}$, where R is the radius measured normal to the surface from the axis of rotation to the midjoint wall, and t is the thickness of the part at the point under consideration; if the product of Rt varies, the average value of the points shall be used;
(2) on surfaces of revolution, in the circumferential direction and on flat parts (such as flanges and flat heads) adjacent points are defined as any two points on the same surface.

(b) For through-thickness temperature differences, adjacent points are defined as any two points on a line normal to any surface.

13 *Normal service* is defined as any set of service conditions other than startup and shutdown that are specified for the vessel to perform its intended function.

14 *Adjacent points* are defined as points that are spaced less than the distance $2\sqrt{Rt}$ from each other, where R and t are the mean radius and thickness, respectively, of the vessel, nozzle, flange, or other part in which the points are located.

15 The head design curves have been developed considering membrane stress requirements, plastic collapse, cyclic load conditions, and the effects of maximum allowable tolerances in accordance with NC-4222. See Section III Appendices, Nonmandatory Appendix A, Article A-4000 for the design equations for the curves of Figure NC-3224.6-1.

16 Heads having $D/2h = 2$ have equivalent torispherical properties of a torisphere of $L/D = 0.90$ and $r/D = 0.17$.

17 The minimum thickness for all pipe materials is the nominal thickness listed in Table 2 of ASME B36.10M less $12\frac{1}{2}$%. For diameters other than those listed in the table, the minimum thickness shall be that of the next larger pipe size.

18 The equations provide safe construction as far as stress is concerned. Greater thicknesses may be necessary if deflection would cause leakage at threaded or gasketed joints.

19 When axial compressive loadings occur in addition to the external pressure, the combined axial loading shall meet the requirements of NC-3245.

20 *Stress* means the maximum normal stress.

21 Since $H_r\ h_r$ in some cases will subtract from the total moment, the moment in the flange ring when the internal pressure is zero may be the determining loading for the flange design.

22 The rules in NC-3329(f) apply to ligaments between tube holes and not to single openings. They may give lower efficiencies in some cases than those for symmetrical groups that extend a distance greater than the inside diameter of the shell as covered in NC-3329(c). When this occurs, the efficiencies computed by the rules under NC-3329(b) shall govern.

23 *Communicating chambers* are defined as appurtenances to the vessel that intersect the shell or heads of a vessel and form an integral part of the pressure-retaining enclosure, such as sumps.

24 *Side plates of a flat-sided vessel* are defined as any of the flat plates forming an integral part of the pressure-retaining enclosure.

25 Written for fittings with internal threads but also applicable to externally threaded and socket- or butt-welded fittings.

26 All dimensions given are nominal.

27 It is recognized that other acceptable procedures may exist which also constitute adequate design methods, and it is not the intention to rule out these alternative methods, provided they can be shown to have been satisfactory by actual service experience.

28 Expansion Joint Manufacturers Association, 25 North Broadway, Tarrytown, NY 10591.

29 See Section III Appendices, Mandatory Appendix II, II-1520(g).

30 The pressure term in eqs. NC-3652(8), NC-3653.1(a)(9a), NC-3653.1(b)(9b)and NC-3653.2(c)(11) may not apply for bellows and expansion joints.

31 Design Pressure may be used if the Design Specification states that peak pressure and earthquake need not be taken as acting concurrently.

32 Socket welds should not be used where the existence of crevices could accelerate corrosion.

33 Fillet and partial penetration welds should not be used where severe vibration is expected.

34 These rules do not limit storage tanks from being installed below grade or below ground, provided the tanks are not subject to external pressure resulting from earth or fill.

35 The limitation of the Design Pressure to *atmospheric* is not intended to preclude the use of these tanks at vapor pressure slightly above or below atmospheric within the range normally required to operate vent valves. If these pressures or vacuums exceed 0.03 psi (0.2 kPa), especially in combination with large diameter tanks, the forces involved may require special consideration in the design.

36 Any specified corrosion allowance for the shell plates shall be added to the calculated thickness.

37 The nominal thickness of shell plates refers to the tank shell as constructed. The thicknesses specified are based on erection requirements.

38 API Standard 2000, 1968 Edition, Venting Atmospheric and Low Pressure Storage Tanks, American Petroleum Institute, 1220 L Street, NW, Washington, DC, 20005-4070.

39 The decrease in yield stress at Design Temperature shall be taken into account.

40 The equations applying to self-supporting roofs provided for a uniform live load of 25 lb/ft^2 (1.2 kPa).

41 Whenever a tank is to be operated with liquid levels that at no time reach the top of the roof but is to be filled to the top of the roof during the hydrostatic test, it shall be designed for both of these maximum liquid level conditions, using in each case the density of the liquid employed. If a tank is not designed to be filled to the top of the roof, overfill protection is required.

42 A suitable margin shall be allowed between the pressure normally existing in the gas or vapor space and the pressure at which the relief valves are set so as to allow for the increases in pressure caused by variations in the temperature or gravity of the liquid contents of the tank and other factors affecting the pressure in the gas or vapor space.

43 This partial vacuum shall be greater than that at which the vacuum relief valves are set to open.

44 Recommended Rules for Design and Construction of Large, Welded, Low-Pressure Storage Tanks, published by American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005-4070.

45 These rules do not apply when the circumferential stress on a cylindrical wall is compressive as in a cylinder acted upon by external pressure.

46 In these expressions if the unit force is latitudinal, R shall be considered to be R_1 and, if meridional, R shall be considered as equal to R_2.

47 *(a)* Equation NC-3932.2(a)(2) has been derived from a summation of the components, normal to the surface, of the T_1 and T_2 forces acting on a unit area of the tank wall subjected only to a pressure P. To be technically correct, the normal to the surface components of other loads, such as metal, snow, or insulation, should be added to or subtracted from the term P. For the usual internal Design Pressure, these added loads are small compared to the pressure P, and can be omitted without significant error. When the pressure P is relatively small, including the case of a partial vacuum loading, the other load components can have a substantial effect on the calculated T_2 force and the resultant thickness.
(b) Example F.3.01 in Appendix F of API 620 Feb. 1970 Edition calculates the required roof thicknesses under a small vacuum by considering the metal, insulation, and snow loads in eqs. NC-3932.2(a)(1), NC-3932.2(a)(2), NC-3932.2(e)(1)(3), and NC-3932.2(e)(1)(4). The designer should note that if these loads had been omitted the calculated thicknesses would have been much less than the correct values.
(c) In eqs. NC-3932.2(a)(1), NC-3932.2(e)(1)(3), NC-3932.2(e)(2)(6), and NC-3932.2(e)(3)(8), the term W is intended to include loads, such as metal weight, of significant value. At points away from the vertical center line of the roof, the value of T_2 is required for the thickness calculations of eqs. NC-3932.3(d), Step 1(16), NC-3932.3(d), Step 3(18), and NC-3932.3(d), Step 5(20), and the value of P in eqs. NC-3932.2(a)(2), NC-3932.2(e)(1)(4), and NC-3932.2(e)(2)(7) must be modified by the normal components of the added loads for the correct determination of T_2.

48 These rules do not contain provisions in respect to the design of cylindrical sidewalls subject to partial internal vacuum in tanks constructed for storage of gases or vapors alone.

49 The vacuum relief valve or valves shall be set to open at a smaller partial vacuum so that the 1 oz/in.^{2} (0.43 kPa) partial vacuum will not be exceeded when the inflow of air or gas through the valves is at its maximum specified rate.

50 If external anchor bolts are used for resisting such uplift, it is recommended that their nominal diameter be not less than 1 in. (25 mm) plus a corrosion allowance of at least $^1/_4$ in. (6 mm) on the diameter.

51 These forces are computed by the applicable equations in NC-3932.

52 Use of a knuckle radius as small as 6% of the sidewall diameter will frequently require an excessively heavy thickness for the knuckle region. The thickness requirements for such region will be found more reasonable if a larger knuckle radius is used.

53 Because of the discontinuities and other conditions found in a compression ring region, biaxial stress design criteria are not considered applicable for a compressive force determined as in eq. NC-3933.4(b)(24). Experience has shown that a compressive stress of the order of 15.0 ksi (103 MPa) as indicated in eq. NC-3933.4(b)(25), is permissible in this case, provided the requirements of NC-3933.5 are satisfied.

54 Note that, unless the effect of the unit forces T_2 and T_{2s} on the resulting increments in width of participating plate may safely be neglected, the use of thicker plates involves recomputing not only w_h and w_c but also Q and A_c for the increased plate thicknesses; hence, the design of the compression ring region in this case resolves into a trial and error procedure.

55 See Figure NC-3933.5(d)-1 for some acceptable details of construction of compression rings.

56 Note that the value required for I_1 as calculated from eq. NC-3933.5(h)(26) is not applicable for materials other than steel.

57 See NC-4246 and NC-4247 for special weld joint requirements in storage tanks.

58 One test specimen may represent a group of forgings, provided they are of the same nominal dimensions, from the same heat of material and the same heat treatment lot, and forged in the same manner.

59 Written and illustrated with internal threads but also applicable to externally threaded and socket- or butt-welded fittings.

60 An *intermediate postweld heat treatment* for this purpose is defined as a postweld heat treatment performed on a weld within a temperature range not lower than the minimum holding temperature range to which the weld will be subjected during the final postweld heat treatment.

61 See NC-5250 for vessels designed to NC-3200. See NC-5280 for requirements for storage tank welds.

62 Welds in branch piping runs shall be examined as required by NC-5212 and NC-5222.

63 SNT-TC-1A is a Recommended Practice for Nondestructive Testing Personnel Qualification and Certification published by the American Society for Nondestructive Testing, 1711 Arlingate Lane, P.O. Box 28518, Columbus, Ohio 43228-0518.

64 Personnel qualified by examination and certified to previous editions of SNT-TC-1A are considered to be qualified to the edition referenced in Table NCA-7100-2 when the recertification is based on continuing satisfactory performance. All reexaminations and new examinations shall be in accordance with the edition referenced in Table NCA-7100-2.

65 *Employer* as used in this Article shall include: N Certificate Holders; Quality System Certificate Holders; Material Organizations that are qualified in accordance with NCA-3842; and organizations who provide subcontracted nondestructive examination services to organizations described above.

66 These tests may be made with the item being tested partially filled with liquid, if desired.

67 Temperature fluctuations within the piping system may affect the pressure. Precautions must be taken to ensure that the test is not biased by temperature effects.

68 Wherever the word *system* appears in this Article, it refers to the component or group of components for which overpressure protection is provided as described in the Overpressure Protection Report.

69 A *pressure relief device* is designed to open to prevent a rise of internal fluid pressure greater than a specified value, resulting from exposure to pressure transient conditions. It may also be designed to prevent excessive internal vacuum. It may be a pressure relief valve, a nonreclosing pressure relief device, or a vacuum relief valve.

70 A *pressure relief valve* is a pressure relief device that is designed to reclose and prevent the further flow of fluid after normal conditions have been restored.

71 A *nonreclosing pressure relief device* is a pressure relief device designed to remain open after operation.

72 A *safety valve* is a pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action.

73 A *safety relief valve* is a pressure relief valve characterized by rapid opening or pop action, or by opening generally proportional to the increase in pressure over the opening pressure.

74 A *relief valve* is a pressure relief valve actuated by inlet static pressure and having a gradual lift generally proportional to the increase in pressure over the opening pressure.

75 A *pilot-operated pressure relief valve* is a pressure relief valve in which the major relieving device is combined with and controlled by a self-actuated auxiliary pressure relief valve.

76 A *power-actuated pressure relief valve* is a pressure relief valve in which the major relieving device is combined with and controlled by a device requiring an external source of energy.

77 A *vacuum relief valve* is a pressure relief device designed to admit fluid to prevent an excessive internal vacuum; it is designed to reclose and prevent further flow of fluid after normal conditions have been restored.

78 A *rupture disk device* is a nonreclosing pressure relief device actuated by inlet static pressure and designed to function by the bursting of a pressure-containing disk.

79 *Expected system pressure transient conditions* are those associated with normal system transient operation.

80 *Unexpected system excess pressure transient conditions* are those associated with unusual or abnormal system transients, but still considered to be within the design basis.

81 A pressure relief valve that has no protrusions in the bore and wherein the valve disk lifts to an extent sufficient for the minimum area, at any section at or below the body seat, to become the controlling orifice.

82 The specified disk temperature supplied to the rupture disk manufacturer shall be the temperature of the disk when the disk is expected to burst.

83 The *manufacturing design range* is a range of pressure within which the stamped burst pressure must fall. This range is included in the Design Specification and the Overpressure Protection Report.

84 A *lot of rupture disks* is those disks manufactured of material at one time, of the same size, thickness, type, heat, and manufacturing process including heat treatment.

85 Rupture disks will not burst at Design Pressure if back pressure builds up in the space between the two rupture disks. This will occur should leakage develop in the rupture disk due to corrosion or other causes.

86 Valve capacities are published in "Pressure Relief Device Certifications." This publication may be obtained from the National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Avenue, Columbus, OH 43229.

87 In lieu of marking all of the listed items on the flange or tab of each rupture disk, the marking may consist of a manufacturer's coding number sufficient to identify each rupture disk with a certificate or tab that includes the required information and is supplied with each lot of rupture disks.

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