Procedures for Testing Casing and Tubing Connections

API RECOMMENDED PRACTICE 5C5
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Introduction

This recommended practice (RP) is part of a process to provide reliable threaded tubing and casing connections fit for purpose for the oil and natural gas industry. It has been developed based on improvements to API RP 5C5, Third Edition, with input from leading users, manufacturers, and testing consultants from around the world. This RP represents the knowledge of many years of testing experience.

The validation of the connection test load envelope and failure limit loads is relevant to design of tubing and casing for the oil and natural gas industries. Tubing and casing are subject to loads that include internal pressure, external pressure, axial tension, axial compression, bending, torsion, transverse forces, and temperature changes. The magnitude and combination of these loads result in various pipe body and connection failure modes. Connection failure modes and loads are generally different and often less than that of the pipe. Consequently, experimental validation is recommended when previous testing/analytical information and sufficient field experience are not available to provide confidence in the use of the connection. The user is responsible for appropriate interpretation of the test data and determination of the user's minimum connection performance envelope.

When evaluating a connection performance envelope, it is necessary to consider the possible range of performance parameters and to apply test and limit loads under conditions targeting the extremes of those parameters. Testing at the extremes of the performance parameters assures that the production population that falls within these limits meets or exceeds the performance of the test population. Variables that contribute to threaded connection performance include dimensional tolerances, mechanical properties, surface treatment, makeup torque, and the type and amount of thread compound. For typical proprietary connections, worst-case dimensional tolerances are assumed and defined in this RP. For other connection designs, analysis may be required to define worst-case tolerance combinations.

It is necessary that users of this RP be aware that further or differing requirements might be needed for individual applications. This RP is not intended to inhibit a vendor from offering, or a purchaser from accepting, alternate equipment or engineering solutions for an individual application. This is particularly applicable when there is innovative or developing technology. Where an alternative is offered, it is the responsibility of the vendor to identify any variations from this RP and to provide details.

For specific applications that are not evaluated by the tests herein, supplementary tests may be appropriate. Annex G describes some example of special applications where supplementary testing may be considered. The user and manufacturer should discuss well applications and the potential limitations of the connection under consideration.

Representatives of users and/or other third-party personnel are encouraged to monitor the tests.

Procedures for Testing Casing and Tubing Connections

1 Scope

This Recommended Practice (RP) defines tests to determine the galling tendency, sealing performance, and structural integrity of threaded casing and tubing connections. The words “casing” and “tubing” apply to the service application and not to the diameter of the pipe. This RP addresses the primary loads to which casing and tubing strings are subjected: fluid pressure (internal and/or external), axial force (tension and/or compression), bending (buckling and/or wellbore deviation), and temperature variations.

2 Normative References

The following referenced documents are indispensable for the application of this RP. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification 5CRA, *Specification for Corrosion-resistant Alloy Seamless Tubes for Use as Casing, Tubing and Coupling Stock*

API Specification 5CT, *Specification for Casing and Tubing*

API Technical Report 5C3, *Technical Report on Equations and Calculations for Casing, Tubing, and Line Pipe Used as Casing or Tubing; and Performance Properties Tables for Casing and Tubing*

API Specification 5L, *Specification for Line Pipe*

ASTM A370 [1], *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

3 Terms, Definitions, Symbols, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1.1
actual API collapse curve at ambient temperature
Derived for the test specimen from API 5C3 using measured maximum average outside diameter (OD), measured minimum average wall, and measured minimum ambient temperature material yield strength as input parameters.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *external pressure resistance*.

3.1.2
actual VME curve at ambient temperature
Derived for the test specimen from API 5C3 using measured maximum average OD, measured minimum wall (for hoop stress only), measured minimum average wall, and measured minimum ambient temperature material yield strength as input parameters.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *triaxial yield of pipe body*.

3.1.3
ambient temperature
Actual current temperature of the test lab environment at the time of testing.

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[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

3.1.4
axial-pressure load diagram
Plot of pressure versus axial load showing pipe body reference envelope, connection evaluation envelope (CEE), and test load envelope (TLE) or limit load extremes.

3.1.5
bi-axial scaling
The scaling of an original envelope or curve along both the axial load axis and the pressure load axis with the appropriate scaling factor, thus creating a second envelope or curve that is radially proportional to the original.

3.1.6
connection
One pin (male end) and its adjoining coupling side or integral box (female end).

3.1.7
connection evaluation envelope
CEE
Diagram containing the extents to which a connection shall be evaluated.

3.1.8
elevated temperature envelope or curve
Bi-axially scaled from the corresponding ambient temperature envelope or curve in both the axial load direction and the pressure load direction with the scaling factor being the ratio between the elevated temperature material yield strength and the ambient temperature material yield strength.

3.1.9
failure load
Load at which the pipe body or connection will fail as in axial separation, rupture, large permanent deformation (e.g. buckling or collapse), or loss of sealing integrity.

3.1.10
galling
Form of surface damage resulting from cold welding of contacting material surfaces followed by tearing of the metal during further sliding or rotation.

NOTE There are several degrees of galling used for repair and reporting purposes as defined in 8.2.

3.1.11
interference
Amount of geometric overlap of mating members created by the design and tolerances of the members.

3.1.12
leak
leakage
Passage of test medium outside of the containment space whether in the equipment or the connection.

3.1.13
leak tube displacement
Change in the graduated cylinder water level indicating a volume change due to changes in applied load, temperature, pressure, or a leak.

3.1.14
light galling
Galling that can be repaired by the use of abrasive paper in accordance with the manufacturer's field service procedures.

3.1.15
limit load
Load combination extreme (axial load and/or pressure) that defines the failure conditions for the connection, or load combination resulting in large permanent deformation (such as buckling) prior to catastrophic failure.

3.1.16
lot
Lengths of pipe with the same specified dimensions and grade from the same heat of steel that are heat-treated as part of a continuous operation (or batch).

3.1.17
material test coupon
MT
Cylinder of material from the pipe and/or coupling stock from which tensile test specimens are cut.

3.1.18
metal-to-metal seal
Seal or sealing system that relies on high contact stress of mating metal surfaces to achieve a seal.

NOTE The thread compound and surface treatment can affect, either beneficially or detrimentally, the performance of a metal seal.

3.1.19
moderate galling
Galling that can be repaired by the use of fine files and abrasive paper in accordance with the manufacturer's field service procedures.

3.1.20
mother joint
Length of pipe or coupling stock from which short lengths are cut for machining connection test specimens.

3.1.21
multiple seals
Sealing system having more than one independent barrier, with each barrier forming a seal.

3.1.22
nominal API collapse curve at ambient temperature
Performance curve derived for the test specimen from API 5C3 using API specified OD, API specified wall, and API specified minimum material yield strength as input parameters.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *external pressure resistance*.

3.1.23
nominal VME curve at ambient temperature
Performance curve derived for the test specimen from API 5C3 using API specified OD, API specified wall, k_{wall} (for minimum wall), and API specified minimum material yield strength as input parameters.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *triaxial yield of pipe body*.

3.1.24
pipe body reference envelope
Diagram containing the extremes of pipe body performance based on measured material properties and geometries.

NOTE Pipe body performance is also known as VME yield; see API 5C3 for collapse.

3.1.25
proprietary high collapse curve at ambient temperature
Uni-axially scaled from the ambient temperature nominal API collapse curve in the pressure direction only with the scaling factor being the ratio between the uni-axial proprietary collapse pressure and the uni-axial nominal API collapse pressure.

3.1.26
pup joint or pup
Short pipe length usually with threaded ends.

3.1.27
QI-QIII cycles
Load cycling between QI (tension and internal pressure) at ≤150 °F (65 °C) and QIII (compression and external pressure) at 356 °F (180 °C).

3.1.28
resilient seal
Seal or sealing system that relies on entrapment of a seal ring within a machined groove in the connection (e.g. in the thread-form or on a seal area) to achieve a seal.

3.1.29
seal
Pressure barrier to prevent the passage of the test medium.

3.1.30
seal ovality
Maximum seal diameter minus the minimum seal diameter divided by the average seal diameter multiplied by 100.

3.1.31
severe galling
Galling that cannot be repaired by the use of fine files and abrasive paper in accordance with the manufacturer's field service procedures.

3.1.32
single seal
One pressure barrier or multiple pressure barriers that cannot be physically differentiated in their function.

3.1.33
specimen
Two pups, each with a pin connection and a shared coupling forming a coupled assembly, or two pups, one with a pin connection and one with a box connection forming an integral assembly.

3.1.34
tensile test specimen
Full-body wall strip or round specimen taken from a material test coupon (MT).

3.1.35
test load envelope
TLE
Test load points (axial, pressure, bending) in the four quadrants derived from the CEE.

3.1.36
thread lot
All products manufactured on a given machine during a continuous production cycle that is not interrupted by a tool failure or machine malfunction (excluding worn tools or minor tool breakage), tool holder change (except rough boring bar), or any other malfunction of either threading equipment or inspection gauges.

3.1.37
thread seal
Seal or sealing system, which relies on intimate fitting of the thread form and usually entrapment of the thread compound within the thread form to achieve a seal.

3.1.38
uni-axial scaling
The scaling of an original envelope or curve along the pressure load axis only with the appropriate scaling factor, thus creating a second envelope or curve that has the largest separation on the pressure load axis and converges with the original at the same point on the axial load axis.

3.1.39
VME stress
Equivalent stress based on the von Mises-Hencky maximum distortion energy criterion.

3.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

A connection A, mill end

AMYS actual minimum yield strength

B connection B, field end

BO breakout

CAL connection assessment level

CCW counter-clockwise direction around the test load envelope

CEE connection evaluation envelope

CEPL capped end pressure load (tension) at the designated pressure

CRA corrosion-resistant alloy

CW clockwise direction around the test load envelope

EP external pressure

FEA finite element analysis

FMU final makeup specimen condition

H maximum (high) thread or seal interference range

H/H maximum specified amount of thread compound/maximum specified torque value, and in Figures 4 through 7, maximum thread interference/maximum seal interference

H/L maximum specified amount of thread compound/minimum specified torque value, and in Figures 4 through 7, maximum thread interference/minimum seal interference

IJ integral joint

IP internal pressure

L minimum (low) thread or seal interference range

L/H minimum specified amount of thread compound/maximum specified torque value, and in Figures 4 through 7, minimum thread interference/maximum seal interference

LL limit load

LL1 limit load test path 1

LL2 limit load test path 2

LL3 limit load test path 3

LL4 limit load test path 4

LL5 limit load test path 5

LP load point

MBG makeup/breakout galling test

MC mechanical cycle

MT material test coupon

MU makeup

OCTG oil country tubular goods

OD outside diameter

PBVME pipe body von Mises envelope

PF-BS pin fast taper–box slow taper

PS-BF pin slow taper–box fast taper

PTFE polytetrafluoroethylene

SMYS specified minimum yield strength

TC thermal cycle

T&C threaded and coupled

TLE test load envelope

TS-A test series A

TS-B test series B

TS-C test series C

VME von Mises equivalent stress

XH extreme maximum (high) thread or seal interference range

XL extreme minimum (low) thread or seal interference range

3.3. Symbols

For the purposes of this document, the following symbols apply.

A^a cycles in TS-A at ambient temperature using gas for internal pressure and liquid for external pressure; for CAL I, liquid may be used for internal pressure

A^e cycles in TS-A at 356 °F (180 °C) for CAL III and CAL IV using gas for internal pressure and an appropriate liquid for external pressure

A_p nominal or average pipe body cross-section area; based on D and d for nominal, D_{avg} and d_{avg} for average

B^a cycles in TS-B, without bending, at ambient temperature using gas for CAL II through CAL IV; for CAL I, liquid may be used for internal pressure

B^a_b cycles in TS-B, with bending, at ambient temperature using gas for CAL II through CAL IV; for CAL I, liquid may be used for internal pressure

B^e_b cycles in TS-B, with bending, using gas at 356 °F (180 °C) for CAL III and CAL IV, or at 275 °F (135 °C) for CAL II

C compressive axial force

$\mathrm{CEE}^a{}_c$ connection evaluation envelope compression at zero pressure at ambient temperature

$\mathrm{CEE}^a{}_t$ connection evaluation envelope tension at zero pressure at ambient temperature

D API specified (nominal for non-API pipe) pipe OD

D_{avg} maximum of average ODs of test specimen pipe body based on measured dimensions at specified planes

D_i inside diameter

D_{leg} effective dogleg severity expressed in degrees per 100 ft or degrees per 30 m

D_o outside diameter

d nominal inside diameter of pipe body; based on D and t

d_{avg} average inside diameter of test specimen pipe body based on measurements; based on D_{avg} and t_{avg}

d_{wall} maximum inside diameter of nominal pipe body or test specimen pipe body; based on D and t_{min} for nominal pipe body and D_{avg} and t_{min} for test specimen pipe body

E_r error in load frame calibration

E_{rp} error in load frame calibration expressed in percent

F_{CEPL} capped-end pressure load acting on the connection

F_a total axial force, tension or compression (sum of applied loads: F_b, F_i, F_{CEPL})

F_b bending equivalent axial force

F_c pipe body reference envelope compression load at 0 pressure (uni-axial compression)

F_f load frame axial force, tension or compression

F_i indicated load frame axial force, tension or compression

F_t pipe body reference envelope tension load at 0 pressure (uni-axial tension)

f_{ymn} specified minimum material yield strength

I moment of inertia

I_{max} maximum design interference between thread or seal members, resulting from pin and box diameter specification and tolerances

I_{min} minimum design interference between thread or seal members, resulting from pin and box diameter specification and tolerances

I_{range} range of design interference between thread or seal members, equal to $I_{max} - I_{min}$

K_{hc} scaling factor for proprietary high collapse pipe

K_{temp} scaling factor for elevated temperature yield strength

k_{wall} factor to account for the specified manufacturing tolerance of the pipe wall (e.g. for a tolerance of −12.5 %, $k_{wall} = 0.875$)

L_A length of pin A end from coupling face (or connection) to end cap or grip

L_B length of pin B end from coupling face (or connection) to end cap or grip

L_C length of coupling or connection if integral

L_D length from face of integral box to Section 5 measurement plane on pup joint A

L_{MA} length between Sections 1 and 5 measurement planes on pup joint A

L_{MB} length between Sections 1 and 5 measurement planes on pup joint B

L_{pj} minimum unsupported pup joint length

P_d pipe body reference envelope pressure at 0 axial load (uni-axial internal pressure)

p_c API collapse rating for specified OD, specified wall thickness, and specified minimum yield strength (see API 5C3)

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *external pressure resistance*.

p_i internal pressure

p_{ib} internal pressure with bending

p_o external pressure

q_{ac} actual leak rate to be reported

q_o observed leak rate

R radius of curvature of the pipe body at the axis of the pipe

T tension axial force

t API specified (nominal for non-API pipe) wall thickness of pipe body

t_{avg} average wall thickness of test specimen pipe body based on measurements

t_{min} minimum wall thickness of pipe body

η_{lds} leak detection system efficiency

σ stress

σ_a axial stress without bending

σ_{ab} axial stress with bending

σ_b axial stress due to bending

σ_c axial compressive yield strength, if available; otherwise, use axial tensile yield strength

σ_e equivalent stress

σ_h hoop (tangential) stress

σ_{ho} hoop (tangential) stress at OD

σ_r radial (normal) stress

σ_{ro} radial (normal) stress at OD

σ_t transverse tensile yield strength if available, otherwise use axial tensile yield strength

σ_{tc} defined transverse compressive yield strength if available; otherwise use axial tensile yield strength

σ_y axial tensile yield strength

4 General Requirements

4.1 General Information

This RP consists of the following major parts.

a) Sections 4 through 8 outline the requirements and procedures to conduct tests on connections based on connection data supplied by the manufacturer.

b) Annex A lists the requirements for the manufacturer's connection specification sheet and test specimen datasheets.

c) Annex B includes the forms required to present the data collected during the tests.

d) Annex C lists the information required to be provided in the full test report (also refer to Section 9).

e) Annex D provides a methodology for calculating and examples of pipe body reference envelopes, the TLE, and the test load points.

f) Annex E gives an example of a load frame calibration.

g) Annex F provides considerations for connection product-line evaluation.

h) Annex G provides guidelines for supplemental tests that can be used for special applications.

4.2 Connection Testing Flow Chart

The connection testing flow chart depicts in a series of figures the critical path for each specimen in determining how it shall be tested. Specimen characterization (Figure 1), pipe body reference envelope and CEE (Figure 2), and TLEs and test load schedules (Figure 3) are developed individually for each test specimen. Refer to 5.5 for material characterization. Refer to 7.3 for pipe body reference envelope, CEE, TLE, and test load schedule determination.

NOTE This section assumes that the coupling or box is not the weaker member of the connection assembly.

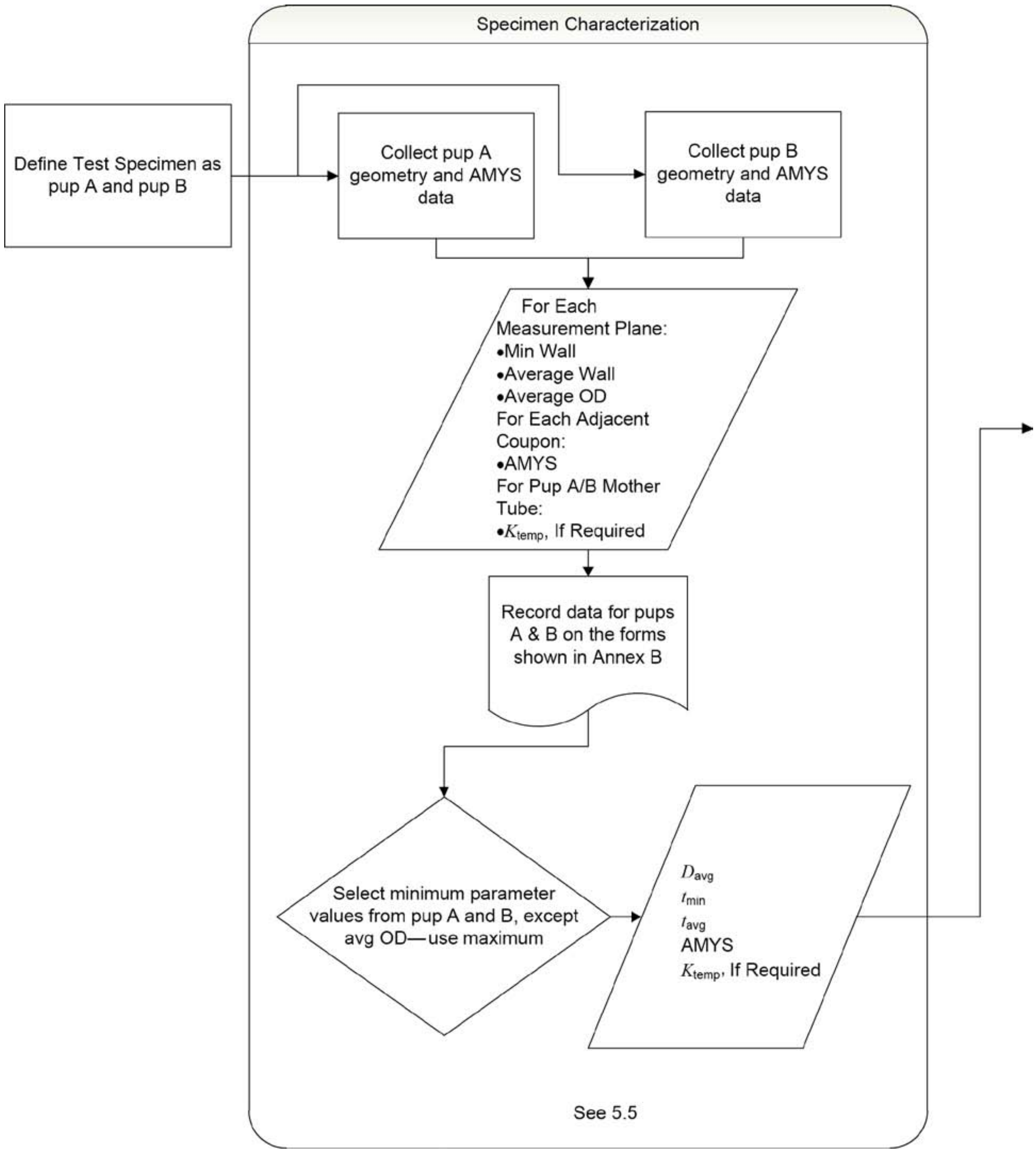


Figure 1—Flow Chart for Determining Input Parameters Used to Construct Pipe Body Reference Envelope for a Test Specimen

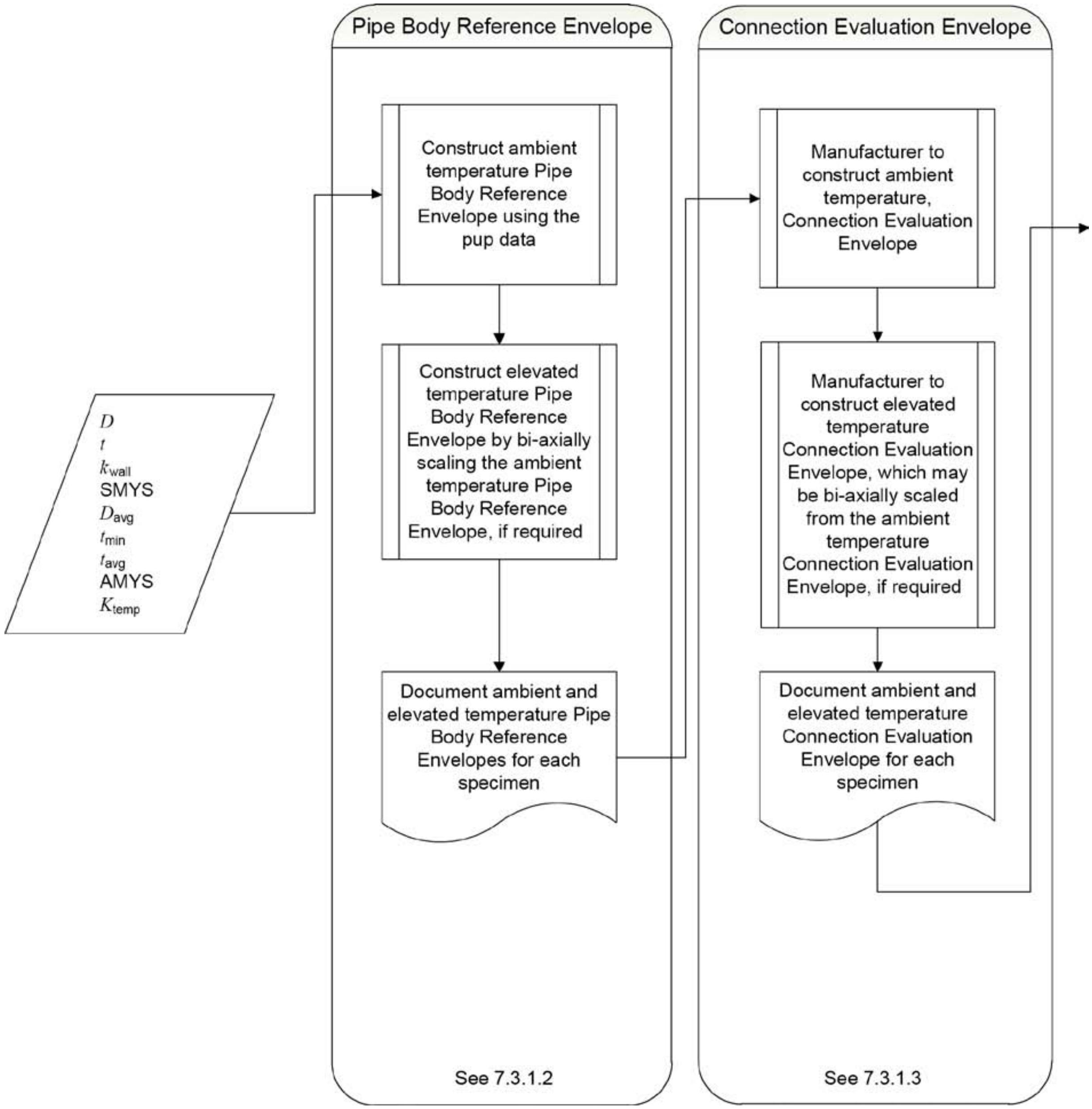


Figure 2—Flow Chart for Determining Ambient and Elevated Temperature Pipe Body Reference Envelope and Connection Evaluation Envelope for a Test Specimen

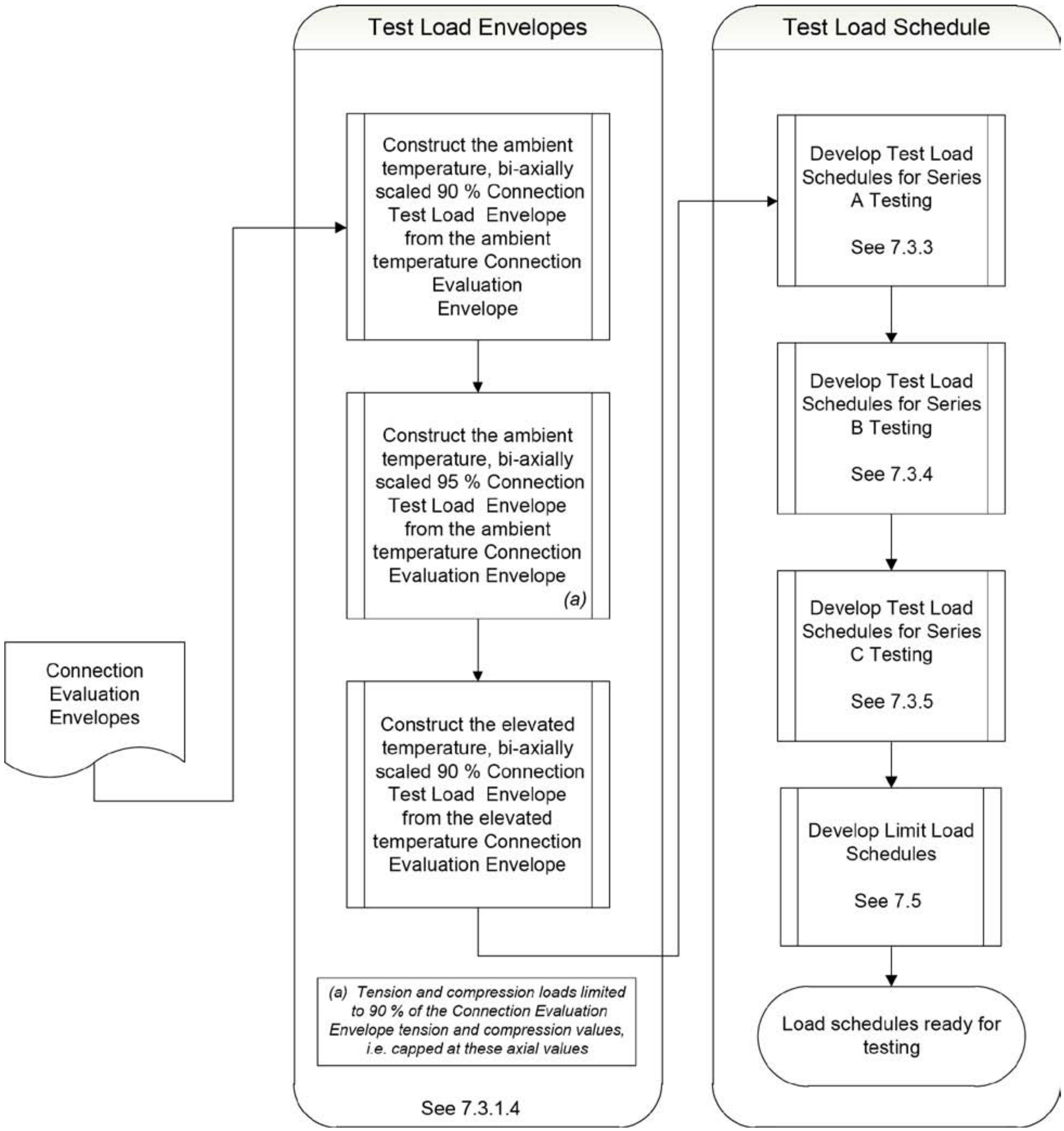


Figure 3—Flow Chart for Determining Ambient and Elevated Temperature Test Load Envelopes and Test Load Schedules for a Test Specimen

4.3 Connection Specification Sheet and Test Specimen Datasheet

Prior to beginning a test, the manufacturer shall provide a test plan. The test plan shall contain a connection specification sheet stating the intended assessment level to which test is performed, its geometry, and a connection datasheet stating the claimed minimum performance properties in terms of tension, compression, internal pressure, external pressure, bending, and torque based on minimum API pipe body performance properties for specified minimum material yield strength, specified OD, specified wall, and minimum wall (see Table A.1 for the connection specification sheet). The manufacturer shall provide a drawing representative of the cross-sectional area of the connection and documentation detailing the specifications, processes, and procedures required for the complete manufacture and inspection of the connection. The manufacturer shall provide the connection makeup parameters and repair procedures. Additionally, the manufacturer shall identify any specific pipe body attributes (examples include 90 % minimum specified wall, high collapse, or controlled yield strength) that are required for the connection being evaluated.

For each test specimen, the manufacturer shall provide a test specimen datasheet. For each test specimen, the manufacturer shall provide the following plots in two-dimensional graphical form for both ambient and elevated temperature testing.

a) Pipe body reference envelope (VME plot with appropriate collapse curves).

b) CEE (polygon or other form, presented on same axes and scale as the pipe body reference envelope).

c) TLE.

The manufacturer's method of calculation should be used to derive the CEE. The CEE shall include the required CEE points specified in Table 7. Performance data may be used to determine the CEE. The TLE shall be bi-axially scaled as a percentage (80 %, 90 %, 95 %, or 100 %, whichever applies) of the CEE, shall include the required load points specified in Table 7, and shall be used to calculate the test load schedules.

The manufacturer should define as completely as possible the limit loads for each test specimen (see 7.4 and 7.5).

In the calculation of both the pipe body reference envelope and CEE, it is the intent of this RP to test each specimen to as high a load or combination of loads as safely practical.

4.4 Quality Control

Quality control procedures for the manufacturing of test specimens shall be documented and be consistent with procedures used for connections manufactured for well service. The connection manufacturer shall ensure that the connections manufactured for the purpose of these design validation tests are of the same design and manufactured to the same dimensions and extremes of tolerances (see 6.5) as those supplied for well service. The connection manufacturer shall issue a declaration of conformity. The manufacturer shall provide the process control plan, which shall include the product drawing number(s) and associated revision level(s) as well as the procedure number and the associated revision levels for applicable sub-tier documents, e.g. manufacturing, gauge calibration, gauging procedure, surface treatment (type and/or thickness), thread compound (type and quantity, or other amount indicators), and makeup procedures. These procedures and any others determined necessary to provide a consistent product for well service shall be used during manufacturing of test specimens (see A.1.6).

4.5 Test Facility Safety

The test guidelines in this RP may include loads approaching the actual yield envelope for the test specimen. Testing may result in failure of the test specimen or equipment. For safety reasons, the following shall be taken into consideration.

a) Filler bar.

   1) Test specimens subjected to internal pressure should include filler bars to reduce the volume of compressed pressurizing media, thereby reducing the energy that would be released in the event of a catastrophic failure.

   2) Filler bars should be non-permeable to the pressurizing media (gas or liquid) and shall not trap or retain pressurized media. The filler bar should be dimensioned to reduce the internal specimen volume substantially, but shall not result in any mechanical interference with the specimen when the specimen deforms during test execution.

   3) Filler bars located within the connection of the test specimen shall be radially positioned in such a way that there is minimal contact with the connection inner diameter (D_i). Filler bars should extend (without contacting the connection inner diameter) at least one-half the pipe diameter beyond the

face of the box and the end of the pin for an integral connection or beyond the face of both ends of the coupling for a coupled connection, and centered over the length of the connection.

b) Specimen containment.

1) Load frames and pressure vessels should have sufficient barriers to contain ejected material, high-pressure liquids, or high-pressure gasses resulting from testing or failure of the test specimen.

2) For elevated temperature external pressure testing, leak detection shall be a closed system that prevents hot fluid from escaping in an unsafe manner.

3) Testing in quadrants II and III potentially have high compressive loading, which may result in load frame damage. Anti-buckling equipment is recommended.

c) Test media.

1) When testing at elevated temperatures, non-flammable materials, fluids with flash points in excess of the test temperature extremes, and heat-resistant materials should be used to minimize fire potential.

2) During limit load testing, the test media shall be liquid.

d) Fire safety.

The test facility shall have a safety procedure in place which covers actions to take in the event of a fire in the test area.

5 General Test Requirements

5.1 Test Principle

5.1.1 Overview

Connection performance data are generated by testing. Four test programs, known as connection assessment levels (CALs) are presented. The increasingly arduous test programs are developed to provide means to assess connection performance. These test programs increase in rigor by increasing the number of test parameters and test specimens.

Users of this RP should be aware that the recommendation to apply test loads in each of the four quadrants (QI, QII, QIII, and QIV) may result in load-path-dependent connection behavior. The four quadrant testing approach presented herein is intended to make the testing program more efficient; however, the program may not reflect the loading on any individual connection. This is due to the practical fact that no connection used in a casing or tubing string will experience the high loads associated with service at both the top and bottom of the string. Testing programs that apply realistic load combinations accounting for service separately at the top or bottom of the strings can provide more representative connection performance test outcomes in cases where the connections are influenced by this load path dependency. As a result of these and other considerations, it is important that users of this RP apply appropriate engineering judgement in the development and application of these test procedures and in the interpretation of test outcomes.

The test programs do not include all possible service scenarios. For example, the presence of a corrosive fluid that may influence the service performance of a connection is not considered and is beyond the scope of this RP.

Users of this RP shall specify the CAL required based on the needs for the particular service intended. Users of the connection should be familiar with the defined connection test rigor, the performance limits, and limit loads. The CALs are defined as follows.

a) *CAL IV (5 Specimens)—Most Testing Rigor.*

CAL IV is the most rigorous test plan. CAL IV test matrix exposes the connection to repeated path-dependent test loads including internal pressure, external pressure, tension, compression, and bending at ambient and elevated temperature. The total cumulative hold time is approximately 238 hours. CAL IV test conditions subject the connection to extensive thermal loading at an elevated temperature of 356 °F (180 °C). Limit load tests are performed to failure in quadrants I, II, and III of the axial/pressure load diagram.

b) *Connection Assessment Level III (Five Specimens)—Significant Testing Rigor.*

CAL III is a significantly rigorous test plan. As with CAL IV, CAL III test matrix exposes the connection to repeated, path-dependent test loads including internal pressure, external pressure, tension, compression, and bending at ambient and elevated temperature. CAL III test conditions subject connections to less severe thermal cycling levels than CAL IV. The total cumulative hold time is approximately 185 hours. Elevated temperature requirements are maintained at 356 °F (180 °C). Limit load tests are performed to failure in quadrants I, II, and III of the axial/pressure load diagram.

c) *Connection Assessment Level II (Three Specimens)—Moderate Testing Rigor.*

CAL II is a moderate rigor test plan. The CAL II test matrix exposes the connection to repeated, path-dependent test loads including internal pressure, tension, compression, and bending at ambient and elevated temperature. External pressure is evaluated only at ambient temperature and has a reduced number of cycles. Internal pressure testing temperatures are limited to 275 °F (135 °C). Limit load tests are performed to failure in quadrants I and III of the axial-pressure load diagram. The total cumulative hold time is approximately 80 hours.

d) *Connection Assessment Level I (Two Specimens)—Less Testing Rigor.*

CAL I is a reduced rigor test plan that may utilize liquid or gas as an internal pressurization medium. Testing is conducted at ambient temperature with one test specimen exposed to internal pressure testing under tension and compression loading and bending. External pressure is evaluated at ambient temperature and has a reduced number of cycles. Limit load testing is performed to failure in quadrant I of the axial/pressure load diagram. The total cumulative hold time is approximately 20 hours.

5.1.2 Previous Tests

The testing required by this edition of API 5C5 is more rigorous than for prior editions of API 5C5 for each CAL. Connections previously tested to prior versions of this RP shall retain the CAL test class and edition to which they were successfully tested. The test protocol used and the date of the test protocol used shall be stated in the test report. See Annex C for reporting format. Connection test data obtained from tests performed prior to the establishment of this RP may also be used as part of a design verification process or application test sequence.

5.1.3 Alternative Tests and Deviations

Alternative testing programs may also be performed. The alternative testing program may be chosen for alignment with users' design methodologies, desire to probe additional features and performance of a connection, or to only probe performance up to a limit as required for a specific application (often known as testing to "project loads"). The alternative testing programs may use large portions of this RP as the basis or may differ substantially. Alternative testing programs may be as appropriate as the test protocols in this RP for judging a connection's suitability for use. However, alternative test programs should not be referred to as being tested in accordance with this RP even when they use a portion of this protocol as their basis.

Some of the tests herein, rather than the complete test program, may be adequate to verify suitability for specific applications when experience and related test data are available, for example, on other sizes, weights, and grades. Deviations to the tests specified herein are acceptable and can be referred to as being tested in accordance with this RP (as modified), provided:

a) the planned deviations are documented in advance,

b) there is agreement between the parties involved, and

c) the deviations (planned and unplanned) are identified in the full test report.

A discussion of product line evaluation and use of interpolation and extrapolation considerations is provided in Annex F. Note that Annex F is informative only and the information and data presented there are only examples and not intended to be prescriptive recommendations. More stringent acceptance requirements, sensitivity requirements, and/or more extended informative data may be agreed by the user and manufacturer.

5.2 Test Matrix

Table 1 shows a matrix relating the CAL to the relevant total number of test specimens, their identification numbers and the relevant tests. Figures 4 through 7 are a summary of each CAL test program and should be read and followed from the top down.

Table 1—Test Matrix—Sealability Test Series and Specimen Identification Numbers

Connection Assessment Level	Series A 4 Quadrants with Mechanical Cycles (see 7.3.3)	Series A QI-QIII Cycles (see 7.3.3)	Series B 2 Quadrants with Mechanical Cycles (see 7.3.4)	Series C Thermal Cycling Thermal/Pressure and Tension Cycling (see 7.3.5)	Bake-out and Elevated Temperature Tests	Internal Test Pressure Medium (external is liquid)
IV	At ambient and 356 °F (180 °C)	QI at ≤150 °F (65 °C) QIII at 356 °F (180 °C)	Bending required at ambient and 356 °F (180 °C)	10 thermal cycles with pressure/tension 5 mechanical cycles at ≤95 °F (35 °C)	Bake-out @ 356 °F (180 °C) Test @ 356 °F (180 °C)	Gas
Total number of sealability specimens 4	Specimens 1, 2, 3, 4	Specimens 1, 2, 3, 4	Specimens 1, 2, 3, 4	Specimens 1, 2, 3, 4		
III	At ambient and 356 °F (180 °C)	Not applicable	Bending required at ambient and 356 °F (180 °C)	10 thermal cycles with pressure/tension 5 mechanical cycles at ≤95 °F (35 °C)	Bake-out @ 356 °F (180 °C) Test @ 356 °F (180 °C)	Gas
Total number of sealability specimens 4	Specimens 1, 4		Specimens 1, 2, 3, 4	Specimens 1, 4		
II	At ambient (reduced cycles)	Not applicable	Bending required at ambient and 275 °F (135 °C)	Not applicable	Bake-out @ 275 °F (135 °C) Test @ 275 °F (135 °C)	Gas
Total number of sealability specimens 2	Specimen 1		Specimens 1, 4			
I	At ambient (reduced cycles)	Not applicable	Bending required at ambient temperature	Not applicable	Bake-out @ 275 °F (135 °C) Bake-out only	Gas or liquid
Total number of sealability specimens 1	Specimen 1		Specimen 1			

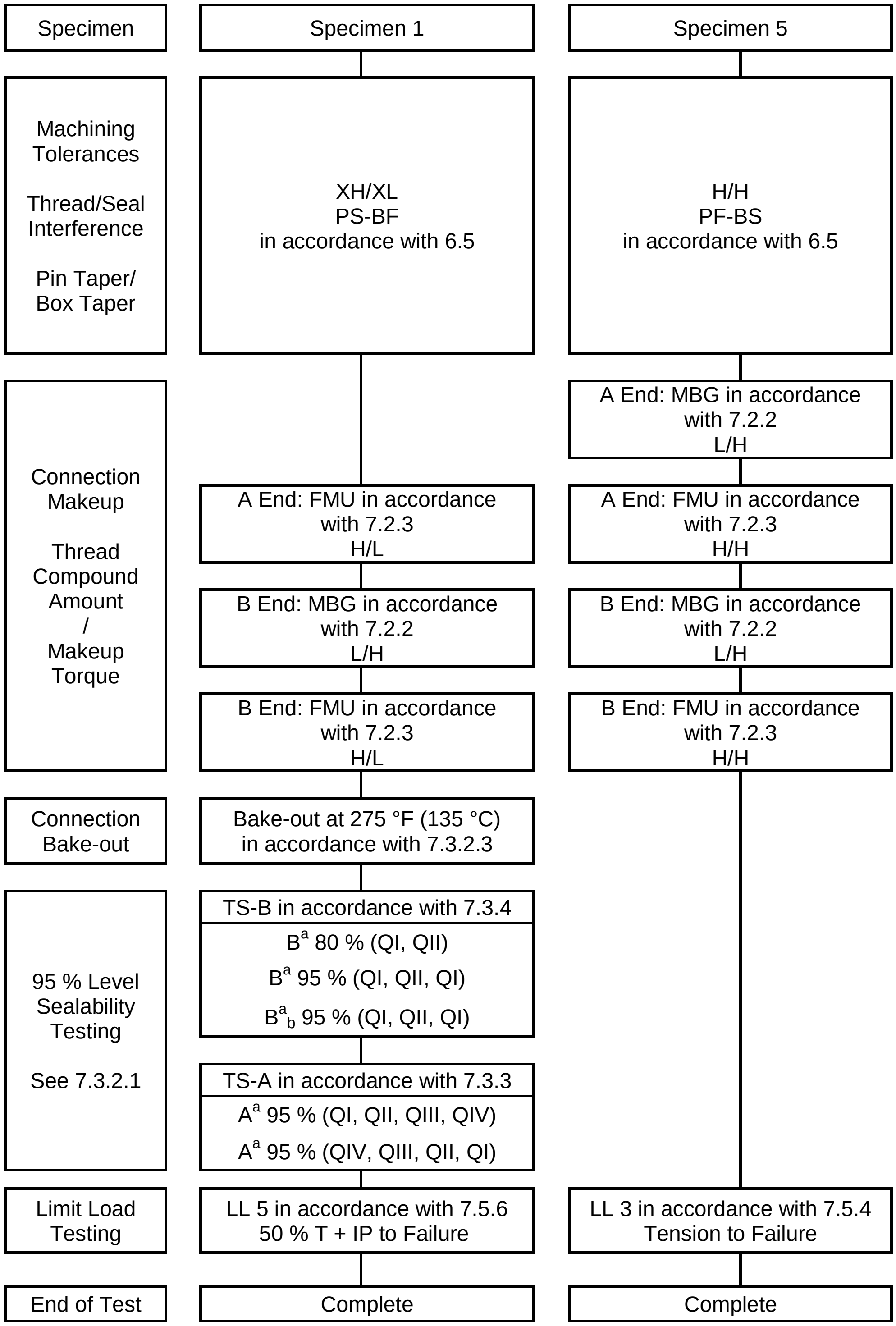


Figure 4—CAL I Test Requirements and Sequence

Specimen	Specimen 1	Specimen 4	Specimen 5
Machining Tolerances Thread/Seal Interference Pin Taper/ Box Taper	XH/XL PS-BF in accordance with 6.5	L/L PS-BF in accordance with 6.5	H/H PF-BS in accordance with 6.5
Connection Makeup Thread Compound Amount / Makeup Torque	A End: FMU in accordance with 7.2.3 H/L B End: MBG in accordance with 7.2.2 L/H B End: FMU in accordance with 7.2.3 H/L	A End: FMU in accordance with 7.2.3 H/H B End: MBG in accordance with 7.2.2 L/H B End: FMU in accordance with 7.2.3 H/H	A End: MBG in accordance with 7.2.2 L/H A End: FMU in accordance with 7.2.3 H/H B End: MBG in accordance with 7.2.2 L/H B End: FMU in accordance with 7.2.3 H/H
Connection Bake-out	Bake-out at 275 °F (135 °C) in accordance with 7.3.2.3	Bake-out at 275 °F (135 °C) in accordance with 7.3.2.3	
90 % Level Sealability Testing See 7.3.2.1	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI) TS-A in accordance with 7.3.3 A^a 90 % (QI, QII, QIII, QIV) A^a 90 % (QIV, QIII, QII, QI)	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI)	
95 % Level Sealability Testing See 7.3.2.1	TS-A in accordance with 7.3.3 A^a 95 % (QI, QII, QIII, QIV) A^a 95 % (QIV, QIII, QII, QI)	TS-B in accordance with 7.3.4 B^a_b 95 % (QI, QII, QI)	
Limit Load Testing	LL 5 in accordance with 7.5.6 50 % T + IP to Failure	LL 4 in accordance with 7.5.5 IP + C to Failure	LL 3 in accordance with 7.5.4 Tension to Failure
End of Test	Complete	Complete	Complete

Figure 5—CAL II Test Requirements and Sequence

Specimen	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
Machining Tolerances Thread/Seal Interference Pin Taper/ Box Taper	XH/XL PS-BF in accordance with 6.5	XH/XL PS-BF in accordance with 6.5	L/H PF-BS in accordance with 6.5	L/L PS-BF in accordance with 6.5	H/H PF-BS in accordance with 6.5
Connection Makeup Thread Compound Amount / Makeup Torque			A End: MBG in accordance with 7.2.2 L/H		A End: MBG in accordance with 7.2.2 L/H
	A End: FMU in accordance with 7.2.3 H/L	A End: FMU in accordance with 7.2.3 H/L	A End: FMU in accordance with 7.2.3 H/H	A End: FMU in accordance with 7.2.3 H/H	A End: FMU in accordance with 7.2.3 H/H
	B End: MBG in accordance with 7.2.2 L/H			B End: MBG in accordance with 7.2.2 L/H	B End: MBG in accordance with 7.2.2 L/H
	B End: FMU in accordance with 7.2.3 H/L	B End: FMU in accordance with 7.2.3 H/L	B End: FMU in accordance with 7.2.3 H/H	B End: FMU in accordance with 7.2.3 H/H	B End: FMU in accordance with 7.2.3 H/H
Connection Bake-out	Bake-out at 356 °F (180 °C) in accordance with 7.3.2.3	Bake-out at 356 °F (180 °C) in accordance with 7.3.2.3	Bake-out at 356 °F (180 °C) in accordance with 7.3.2.3	Bake-out at 356 °F (180 °C) in accordance with 7.3.2.3	
90 % Level Sealability Testing See 7.3.2.1	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI)	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI)	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI)	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI)	
	TS-C in accordance with 7.3.5 10 Thermal Cycles 5 Mechanical Cycles			TS-C in accordance with 7.3.5 10 Thermal Cycles 5 Mechanical Cycles	
	TS-A in accordance with 7.3.3 A^e 90% (QI, QII, QIII, QIV) A^e 90% (QIV, QIII, QII, QI) A^a 90% (QI, QII, QIII, QIV) A^a 90% (QIV, QIII, QII, QI)			TS-A in accordance with 7.3.3 A^e 90 % (QI, QII, QIII, QIV) A^e 90 % (QIV, QIII, QII, QI) A^a 90 % (QI, QII, QIII, QIV) A^a 90 % (QIV, QIII, QII, QI)	
95 % Level Sealability Testing See 7.3.2.1		TS-B in accordance with 7.3.4 B^a_b 95 % (QI, QII, QI)	TS-B in accordance with 7.3.4 B^a_b 95 % (QI, QII, QI)		
	TS-A in accordance with 7.3.3 A^a 95% (QI, QII, QIII, QIV) A^a 95% (QIV, QIII, QII, QI)			TS-A in accordance with 7.3.3 A^a 95 % (QI, QII, QIII, QIV) A^a 95 % (QIV, QIII, QII, QI)	
Limit Load Testing	LL 5 in accordance with 7.5.6 50 % T + IP to Failure	LL 4 in accordance with 7.5.5 IP + C to Failure	LL 1 in accordance with 7.5.2 High IP + T to Failure	LL 2 in accordance with 7.5.3 50 % C + EP to Failure	LL 3 in accordance with 7.5.4 Tension to Failure
End of Test	Complete	Complete	Complete	Complete	Complete

Figure 6—CAL III Test Requirements and Sequence

Specimen	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
Machining Tolerances Thread/Seal Interference Pin Taper/ Box Taper	XH/XL PS-BF in accordance with 6.5	XH/XL PS-BF in accordance with 6.5	L/H PF-BS in accordance with 6.5	L/L PS-BF in accordance with 6.5	H/H PF-BS in accordance with 6.5
Connection Makeup Thread Compound Amount / Makeup Torque	A End: FMU in accordance with 7.2.3 H/L B End: MBG in accordance with 7.2.2 L/H B End: FMU in accordance with 7.2.3 H/L	A End: FMU in accordance with 7.2.3 H/L B End: FMU in accordance with 7.2.3 H/L	A End: MBG in accordance with 7.2.2 L/H A End: FMU in accordance with 7.2.3 H/H B End: FMU in accordance with 7.2.3 H/H	A End: FMU in accordance with 7.2.3 H/H B End: MBG in accordance with 7.2.2 L/H B End: FMU in accordance with 7.2.3 H/H	A End: MBG in accordance with 7.2.2 L/H A End: FMU in accordance with 7.2.3 H/H B End: MBG in accordance with 7.2.2 L/H B End: FMU in accordance with 7.2.3 H/H
Connection Bake-out	Bake-out at 356 °F (180 °C) in accordance with 7.3.2.3	Bake-out at 356 °F (180 °C) in accordance with 7.3.2.3	Bake-out at 356 °F (180 °C) in accordance with 7.3.2.3	Bake-out at 356 °F (180 °C) in accordance with 7.3.2.3	
90 % Level Sealability Testing See 7.3.2.1	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI) TS-C in accordance with 7.3.5 10 Thermal Cycles 5 Mechanical Cycles TS-A in accordance with 7.3.3 A^e 90 % (QI,QII,QIII,QIV) A^e 90 % (QIV,QIII,QII,QI) 90 % 5 QI-QIII Cycles A^a 90 % (QI,QII,QIII,QIV) A^a 90 % (QIV,QIII,QII,QI)	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI) TS-C in accordance with 7.3.5 10 Thermal Cycles 5 Mechanical Cycles TS-A in accordance with 7.3.3 A^e 90 % (QI,QII,QIII,QIV) A^e 90 % (QIV,QIII,QII,QI) 90 % 5 QI-QIII Cycles A^a 90 % (QI,QII,QIII,QIV) A^a 90 % (QIV,QIII,QII,QI)	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI) TS-C in accordance with 7.3.5 10 Thermal Cycles 5 Mechanical Cycles TS-A in accordance with 7.3.3 A^e 90 % (QI,QII,QIII,QIV) A^e 90 % (QIV,QIII,QII,QI) 90 % 5 QI-QIII Cycles A^a 90 % (QI,QII,QIII,QIV) A^a 90 % (QIV,QIII,QII,QI)	TS-B in accordance with 7.3.4 B^a 80 % (QI, QII) B^a 95 % (QI, QII, QI) B^e_b 90 % (QI, QII, QI) B^a_b 90 % (QI, QII, QI) TS-C in accordance with 7.3.5 10 Thermal Cycles 5 Mechanical Cycles TS-A in accordance with 7.3.3 A^e 90 % (QI,QII,QIII,QIV) A^e 90 % (QIV,QIII,QII,QI) 90 % 5 QI-QIII Cycles A^a 90 % (QI,QII,QIII,QIV) A^a 90 % (QIV,QIII,QII,QI)	
95 % Level Sealability Testing See 7.3.2.1	TS-A in accordance with 7.3.3 A^a 95 % (QI,QII,QIII,QIV) A^a 95 % (QIV,QIII,QII,QI)	TS-A in accordance with 7.3.3 A^a 95 % (QI,QII,QIII,QIV) A^a 95 % (QIV,QIII,QII,QI)	TS-A in accordance with 7.3.3 A^a 95 % (QI,QII,QIII,QIV) A^a 95 % (QIV,QIII,QII,QI)	TS-A in accordance with 7.3.3 A^a 95 % (QI,QII,QIII,QIV) A^a 95 % (QIV,QIII,QII,QI)	
Limit Load Testing	LL 5 in accordance with 7.5.6 50 % T + IP to Failure	LL 4 in accordance with 7.5.5 IP + C to Failure	LL 1 in accordance with 7.5.2 High IP + T to Failure	LL 2 in accordance with 7.5.3 50 %C + EP to Failure	LL 3 in accordance with 7.5.4 Tension to Failure
End of Test	Complete	Complete	Complete	Complete	Complete

Figure 7—CAL IV Test Requirements and Sequence

5.3 Test Program

5.3.1 Full-scale Testing

Conduct a full-scale test program of makeup/breakout tests, TLE tests, and limit load tests in accordance with the procedures stated in this RP.

Instructions in this RP shall be followed. If adverse conditions not specifically addressed in this RP are encountered, deviations from this RP shall be documented in the test report. In addition, statements should be provided to justify why the modified tests as a result of the deviations should be considered adequate.

5.3.2 Evaluation of Test Results

5.3.2.1 General

Evaluate the results of the physical test program in accordance with Section 8 following the procedure given in 5.3.2.

5.3.2.2 Test Results that Conform to Stated Connection Assessment Level

Completing the tests according to the requirements of this RP for make/break tests, the TLE tests, and the limit load tests, the connection in the size, mass (label: weight), and grade of material [i.e. same specified minimum yield strength (SMYS) and equivalent chemical composition] tested has demonstrated validation of the connection TLE at the stated CAL.

If each of the tests conducted at the 90 % level sealability testing pass, the 95 % level sealability testing tests shall be performed. If the tests conducted at the 95 % level sealability testing fail, the connection has conformed to the stated assessment level at a 90 % level sealability testing. If each of the tests conducted at the 90 % and 95 % level sealability testing pass, the connection has conformed to the stated assessment level at the 95 % level sealability testing. See Figures 4 through 7 for the test requirements and test sequence.

Limit load tests have termination criteria as defined in 7.4.2. The loads at test termination shall be compared to the anticipated failure load calculated by the manufacturer as defined in A.1.5. Limit loads shall exceed the CEE. If the limit load does not exceed the CEE, the CEE may be revised such that the resultant CEE is now smaller than the limit load results and no further testing is required. If a failed 90 % or 95 % level sealability test specimen does not allow continuing to the limit load test, a replacement specimen shall be manufactured to complete the limit load test. For the replacement specimen, use the specified final makeup (FMU) and bake-out for that specimen; however, sealability testing is not required prior to the limit load test.

5.3.2.3 Test Results that Do Not Conform to Stated Connection Assessment Level

When the test results do not conform to the requirements of the TLE tests, the results may be evaluated for either: (1) a connection design revision followed by a full retest or (2) a reduced CEE, followed by a retest of any test specimen(s) that have not already achieved a larger CEE.

In case of the malfunctioning of testing facilities or test execution, which is not related to product design, neither a connection design revision, CEE revision or limit load revision is required, but the test specimen(s) or replacement test specimen(s) shall be retested in full. Any event not conforming to acceptance criteria shall be reported. The number of retests and the need for the retests shall be included in the test report.

5.3.2.4 Reporting of Test Results

For each test conducted, the results shall be reported in accordance with Section 9. Leakage, whether during the TLE hold periods or with the equipment, regardless of volume or rate, shall be reported on the datasheets and identified on the pressure plots. During load changes, displacement changes may be a function of volumetric changes and not leakage. Record displacement levels prior to and after load changes.

5.4 Calibration and Accreditation Requirements

5.4.1 Accreditation

The laboratory conducting these tests shall either:

a) be accredited by a recognized national or international accreditation body or

b) comply in full with 5.4.2 to 5.4.5.

5.4.2 Equipment Calibration

Before testing begins, ensure that the load frames to be used for the tests have been calibrated to traceable national standards. In addition, based on the connection manufacturer's or test laboratory's experience, measuring and recording instruments, such as pressure gauges, shall be calibrated periodically. The test laboratory standards for calibration and each calibration shall be documented. Copies of current calibration test reports for the load frame, pressure, and torque measuring devices shall be included in the detailed test report.

Equipment calibration during a test program may be appropriate based on the required test loads and past equipment usage.

The test lab should have a procedure to ensure that the thermocouple temperature readings are accurate.

5.4.3 Annual Load Frame Calibration

Each load frame used in an axial load or combined load test shall be calibrated in both tension and compression modes at least annually with device(s) (i.e. load cells) traceable to national standards.

The calibration should consist of two passes of a minimum of 10 equal increments ranging from the minimum calibration load to the maximum calibration load (defined as the "loading range"). The calibration range of the load frame shall cover the range of loads that will be applied in the test program. The maximum frame calibration load shall be greater than the maximum anticipated failure load of the connection/pipe being evaluated.

The error, E_r, and the percent error, E_{rp}, are calculated as follows:

$$E_r = F_i - F_f \tag{1}$$

$$E_{rp} = 100\frac{E_r}{F_f} \tag{2}$$

where

F_i is the indicated frame load;

F_f is the actual frame load.

The percent error for the loads within the loading range of the frame (at least 10 % to 100 % of tension/compression capacity) shall not exceed ±1.0 % when approached from both directions in tension and compression (see Annex E for an example).

5.4.4 Load Frame Verification

In the event that the load frame is subjected to unusual loads, such as applying a load beyond the calibration range or if a failure occurs at an unexpected load that could indicate a calibration problem, a verification bar shall be used to verify the load frame calibration. This verification bar shall be traceable to national standards bodies and certified triennially. In lieu of using the verification bar, a full annual calibration may be performed.

5.4.5 Pressure Transducer Calibrations

Each pressure transducer shall be calibrated at least annually. The percent error for pressures within the loading range shall not exceed ±1.0 % of full scale. Appropriate pressure transducers should be selected and used based on the maximum anticipated test pressure being monitored.

5.5 Material Characterization

5.5.1 General

The pipe shall be mechanically tested to determine the yield strength for calculation of the pipe body reference envelope for each test specimen. The coupling stock shall be mechanically tested to determine its yield strength. The pup and coupling stock mechanical test data should be considered in the determination of the CEE for each test specimen.

The mechanical properties of the pipe and coupling stock shall be characterized by a documented procedure consistent with the specification for the material. Typically this is API 5CT for low alloy steel or API 5CRA for corrosion-resistant alloys (CRAs). For connections machined on line pipe, the procedure shall be in accordance with API 5L.

Report the material property data required on the material property datasheet, Figure B.3.

For ambient temperature longitudinal tensile testing, refer to API 5CT and ASTM A370. For elevated temperature longitudinal tensile testing, refer to ASTM E21.

For elastic modulus, refer to API 5C3. For specific materials, elastic modulus may be determined at ambient and elevated temperatures and used where applicable. ASTM E111 may be used as a reference for performing these evaluations.

Measure wall thicknesses of each pup and establish the minimum wall and minimum average wall for each. Use these data for calculation of the pipe body reference envelope for each test specimen (see 5.5.3 and Figure B.5).

Measure OD of each pup and establish the maximum average OD for each. Use these data for calculation of the pipe body reference envelope for each test specimen (see 5.5.3 and Figure B.5).

For test couplings, measure the OD and establish a minimum OD and average OD for each (see 5.5.3 and Figure B.5).

5.5.2 Material Property Tests

5.5.2.1 Material Test Coupons

MTs shall be extracted from each length of pipe and coupling stock used to manufacture the test specimens. MTs shall be extracted from the mother joint or coupling stock mother tube (regardless of their length) adjacent to the connection of each test specimen pup or at least one test coupling when applicable.

See Figure B.1 for recommended options for mapping. For each specimen, the coupons adjacent to the test connection shall be used for the determination of the ambient temperature yield strength (see 5.5.2.5). In addition, at least one of the MTs from each mother joint or coupling stock mother tube shall be used to determine the corresponding elevated temperature scaling factor for that mother joint (see 5.5.2.6).

The MTs shall be traceable to the mother joint or coupling stock mother tube and the axial location within the tube.

5.5.2.2 Longitudinal Tensile Test Specimens

Longitudinal material property tests shall be conducted on tensile test specimens. Tensile test specimens shall be cut from MTs.

Extraction of longitudinal tensile test specimens from each MT is as follows.

a) For determining the ambient temperature yield strength, machine at least four specimens for ambient temperature testing (see 5.5.2.5). The longitudinal tensile test specimens shall be full-body wall strips unless the full-body strips are beyond the capacity of the testing equipment or otherwise impractical; then round tensile test specimens may be used.

b) If elevated temperature testing is performed on the MTs, machine at least four specimens for ambient temperature testing and at least four specimens for elevated temperature testing to determine the elevated temperature scaling factor (see 5.5.2.6). Identical specimen geometry shall be used for both ambient and elevated testing. Round tensile specimens are the most practical, and use of the largest practical size in accordance with API 5CT and ASTM A370 is recommended.

At least one longitudinal tensile test specimen shall be taken from each quadrant of the MT. For elevated temperature testing, circumferential locations of the ambient and elevated temperature longitudinal tensile test specimens within each MT shall be adjacent (as close as practical).

The longitudinal tensile test specimens and results of the material property tests shall be traceable to the MT. The circumferential locations shall be traceable within the MT. Sketches of the geometries and axial and circumferential locations selected for the ambient and elevated (if performed) longitudinal tensile test specimens from the MT shall be shown in the material property datasheet, Figure B.3.

The recommended layout for test specimen pups or test couplings and MTs shown in Figure B.1 provides the material strength directly adjacent to the connection of each test specimen pup or test coupling. If the test specimen pups, the test couplings, or the MTs are not cut as shown in Figure B.1, the manufacturer shall modify the material property datasheet shown in Figure B.3 and shall provide a sketch similar to Figure B.1 showing the actual locations.

See 6.3.3 to ensure sufficient pipe and coupling stock is tested and that mechanical properties meet the requirements stated in this RP.

5.5.2.3 Transverse Tensile and Compression Test Specimens

In cases where the sample material exhibits strength anisotropy (e.g. cold-worked CRA), it shall be characterized. Testing may be performed as necessary to characterize the anisotropy. If anisotropy test data pertinent to the specific manufacturing process, material grade and size are available, these data may be used instead of testing if agreed with the purchaser. These supporting data shall be documented in the test report.

When testing is performed to characterize the anisotropy, axial compression yield values, axial tensile yield values, and transverse tensile yield values shall be determined.

Extraction of test specimens from the MT is as follows.

a) For determining the transverse scaling factor, machine at least four longitudinal tensile test specimens and four transverse specimens for ambient temperature testing (see 5.5.2.7). Identical specimen geometry shall be used for longitudinal and transverse testing. Round test specimens are the most practical and shall be the largest practical size in accordance with API 5CT and ASTM A370.

b) For determining the longitudinal compressive scaling factor, machine at least four longitudinal tensile test specimens and four longitudinal compressive specimens for ambient temperature testing (see 5.5.2.7). ASTM E9 should be used for guidance to conduct ambient temperature compression testing.

If transverse tensile or compression tests are performed, the manufacturer shall provide a documented procedure (to be included in the test report) detailing the sampling locations, test specimen geometry, and test parameters. The minimum yield strength values from these tests may be used to determine the CEE as long as this is clearly documented in the test report.

5.5.2.4 Minimum Test Scope

5.5.2.4.1 Material Property Tests

The following shall apply to material property tests.

a) At least four longitudinal tensile tests (one from each quadrant) at ambient temperature from each MT.

   At least four longitudinal tensile tests (one from each quadrant) at elevated temperature from one of the MTs from within the middle 50 % of the mother joint subjected to elevated temperature testing.

b) For ambient temperature tensile tests, pull rates shall be at a maximum strain rate of 0.005 in./in./min.

c) For elevated temperature tensile tests, pull rates shall be at a maximum strain rate of 0.003 in./in./min.

5.5.2.4.2 Elevated Temperature Test Temperatures

The following shall apply to elevated temperature test temperatures.

a) For CAL II this is 302 °F (150 °C), +0 °F/−9 °F (+0 °C/−5 °C).

b) For CAL III and CAL IV this is 383 °F (195 °C), +0 °F/−9 °F (+0 °C/−5 °C).

5.5.2.4.3 Tensile Test Report

The following shall apply to the tensile test report.

a) Acquired stress/strain plot from zero strain to 2 % strain or to specimen failure, whichever occurs first.

b) Yield strength as defined by API reference for materials and grades defined in API 5CT, API 5CRA, or API 5L. Additionally, the 0.2 % offset proof stress shall be reported.

c) Ultimate strength.

d) Total elongation.

See C.2, Section 3 for reporting requirements.

5.5.2.4.4 Temperature Monitoring Requirements

For each ambient temperature test, the temperature shall be recorded. For each elevated temperature test, monitor the actual test specimen temperature with a thermocouple attached to the material test specimen, and include the temperature history data in the test report.

5.5.2.5 Ambient Temperature Material Yield Strength

The ambient temperature material yield strength for each test specimen pup or test coupling is established as the minimum ambient temperature material yield strength of the MT adjacent to the test specimen pup or test coupling.

The material yield strength of a test coupon shall be established as the lowest result obtained from the testing of the four or more longitudinal tensile test specimens taken from that MT in accordance with 5.5.2.2. When both strip and round bar tests results are available, only strip data shall be used for the determination of the longitudinal material yield strength. In the event that a result is below the SMYS of the grade, two additional tensile tests may be performed on the same material coupon from the same quadrant. If the yield strength of either of the additional tests is below the SMYS, the joint shall not be used.

5.5.2.6 Elevated Temperature Scaling Factor

The minimum basis for definition of the elevated temperature scaling factor is a single MT taken from within the middle (between 25 % and 75 % of the total length as measured from an end) of the mother joint or coupling stock mother tube.

The elevated temperature scaling factor for the mother joint or coupling stock mother tube is the ratio between the average of all longitudinal tensile test yield strength results at elevated temperature and the average of all longitudinal tensile test yield strength results at ambient temperature for the specimens cut for elevated temperature scaling factor determination. The ambient temperature strip test results shall not be used for the determination of the elevated temperature scaling factor. Test specimens used for the elevated temperature scaling factor shall be of the same size and geometry as specified in 5.5.2.2. For elevated temperature scaling factor determination of the mother joint or coupling stock, all valid test results from tensile test specimens shall be used.

The elevated temperature scaling factor shall be used to determine the elevated temperature pipe body reference envelope for each test specimen taken from the mother joint.

5.5.2.7 Anisotropy Scaling Factor

The transverse tensile anisotropy scaling factor for the mother joint or coupling stock mother tube is the ratio between the average of all transverse test results and the average of all longitudinal tensile test results. The ambient temperature strip test results shall not be used for the determination of the transverse tensile anisotropy scaling factor. Test specimens used for the transverse anisotropy scaling factor shall be of the same size and geometry as specified in 5.5.2.3.

The compression anisotropy scaling factor for the mother joint or coupling stock mother tube is the ratio between the average of all longitudinal compressive test results and the average of all longitudinal tensile test results. Only the round bar longitudinal tensile test data and the ASTM E9 compression test data should be used for the determination of the compression anisotropy scaling factor (see 5.5.2.3).

Use of anisotropy scaling factors already obtained from prior testing may be acceptable if agreed with the purchaser and supported by data pertinent to the manufacturing process, material grade, and size (see 5.5.2.3).

These scaling factors may be used for determining the CEE.

5.5.3 Material Dimensional Measurements

5.5.3.1 General

For each test specimen pup, the critical dimensions required for calculating the pipe body reference envelope shall be measured and recorded (see Figure B.5).

For each test specimen pup, establish five planes along the pup axis as follows (see Figure B.2).

a) Establish plane #1 at 3 in. from the end of the grip length or test cap.

b) Establish plane #5 at 3 in. from the box face (on plain end pin pups), 3 in. from the end of integral flush box connections, or 3 in. from the end of the expansion/upset transition zone [on integral joint (IJ) boxes and upset pins/boxes].

c) Establish planes #2, #3, and #4 equally spaced between plane #1 and plane #5.

In each of the five planes, find the location of the minimum wall. Mark the location on the pup as 0° and record the minimum wall reading (see Figure B.5).

In each plane, mark seven additional locations equally spaced around the circumference of the pup as 45°, 90°, 135°, 180°, 225°, 270°, and 315°. Measure and record the wall thickness at each location in each of the five planes (see Figure B.5).

The manufacturer is responsible for measuring and recording dimensions required to establish the CEE.

5.5.3.2 Minimum Wall

For each test specimen pup, the minimum wall is established as the smallest of the five minimum wall measurements taken for each measurement plane (see Figure B.5).

The established minimum wall for each test specimen is the smallest of the minimum walls between the two pups. The test specimen established minimum wall shall be used to calculate the actual VME curve at ambient temperature (see 7.3.1.2.3).

5.5.3.3 Minimum Average Wall

From the eight wall measurements in each of the five planes on each test specimen pup, determine and record the average wall for each measurement plane (see Figure B.5).

For each test specimen pup, the minimum average wall is established as the smallest of the five average walls determined in the five measurement planes (see Figure B.5).

The established minimum average wall for each test specimen is the smallest minimum average wall between the two pups. The test-specimen-established minimum average wall shall be used to calculate the actual VME curve at ambient temperature and the actual API collapse curve at ambient temperature (see 7.3.1.2.3).

5.5.3.4 Maximum Average OD

From the four OD measurements in each of the five planes on each test specimen pup, determine and record the average OD for each measurement plane (see Figure B.5).

For each test specimen pup, the maximum average OD is established as the largest of the five average ODs in the five measurement planes. The established maximum average OD for each test specimen is the largest average OD between the two pups.

The test-specimen-established maximum average OD shall be used to calculate the actual VME curve at ambient temperature and the actual API collapse curve at ambient temperature (see 7.3.1.2.3).

5.6 Makeup and Breakout Procedures

5.6.1 Principle

Makeup and breakout procedures, thread compound, and the surface treatment used during testing should be consistent with the manufacturer’s RP for field usage.

5.6.2 Makeup Thread Compound

The connection manufacturer shall specify the type and amount, with tolerances (default tolerance is ±1 g), of thread compound that shall be applied to the connection, as well as the areas to which the thread compound shall be applied. These thread compound criteria shall be the same as those used for field applications. The same thread compound shall be used for each test specimen. Preferably, the maximum and minimum quantities should be specified as mass for the thread compound to be used in testing. The specific gravity of the thread compound used shall also be provided on the datasheet. In addition, the manufacturer shall provide photographs and descriptions of how to apply the thread compound for mill and field applications. This includes photographs of connections with minimum and maximum thread compound.

It is recognized that connections exist in the industry that have surface treatments that do not require thread compound and therefore 5.6.2 may not apply. However, additional testing may be conducted with a combination of thread compound and surface treatment to verify performance.

5.6.3 Makeup Torques

The makeup torques specified in Section 7 are either the maximum or minimum torque recommended by the manufacturer. For a high specified torque, the test specimen makeup is acceptable if the torque is more than the sum of 80 % of the maximum torque recommended by the manufacturer plus 20 % of the minimum torque recommended by the manufacturer. For a low specified torque, the test specimen makeup is acceptable if the torque is less than the sum of 80 % of the minimum torque recommended by the manufacturer plus 20 % of the maximum torque recommended by the manufacturer.

For each of the single makeup test specimens in a test series, if the actual makeup torque is less than the manufacturer's minimum because of a testing error, the specimen may be broken out and reassembled a second time to achieve the manufacturer's minimum torque. If the second makeup also does not achieve the manufacturer's minimum torque, that specimen may be tested as is or it shall be replaced.

5.6.4 Makeup Procedure

Make up each connection in the manner described below. Record the results in Figure B.4.

For each makeup, clean and dry the connection completely, then weigh and record the amount of thread compound applied to each connection member (pin and coupling side or integral box). Monitor and record makeup and breakout torques on torque-versus-turn plots. The turn resolution shall be at least 1/1000th of a turn. Torque-versus-turn plots for makeups of Section 7 and any additional makeups considered relevant shall be included in the full test report (see Section 9 and Annex C). At the time of makeup, annotate each plot to indicate the test specimen, pin end and box end, makeup number, date, time, and any other observations.

Connections should be made up using tongs and tong dies typical of those used in the field. Additional attention should be exercised in selecting the type of tongs and dies used on CRA materials. Vertical makeup should be used. For coupled connections, floating of the coupling is prohibited (i.e. each side shall be made up separately). Photograph makeup equipment and at least one connection being made up. In addition, the makeup speed shall be recorded for each makeup. Make and breaks should be conducted with the tong in low gear. When gripping couplings (or boxes), clamping forces should be controlled to prevent adverse distortion of the internally threaded member.

When performing the makeup and breakout procedure, it is recommended to install a plug in the coupling end that is not being made up to help avoid damage to that connection by providing additional rigidity to that coupling end during the makeup of the other coupling end. The plug should have a thread design compatible with the test specimen; however, achieving specific geometric tolerance is not required. As an alternative to a plug, a hand-tight pin may also be used.

Use of strain gauges is optional (see 5.9.3).

5.6.5 Breakout Procedure

Break out the connection test specimen with the same tongs and instrumentation as in 5.6.4 in accordance with the manufacturer's procedure. Record the results in Figure B.4.

5.6.6 Breakout Refurbishment

Following each breakout, pins and boxes may be refurbished using only techniques, equipment, and tools stipulated by the connection manufacturer for field use. Such repairs shall be fully documented, including repair time. Any galling or other nonconformity shall be reported. A galling evaluation, including a clear description of the size and nature of the damage, shall be part of the final report. Photographs shall be made of the galled surface, repaired surface, repaired surface after the next breakout, and the repaired surface after the final breakout and shall be included in the final report.

5.6.7 Test Specimen Connection Inspection

Inspect the test specimen connections carefully following each breakout. Evaluate and document on the torque-versus-turn plots any correlation with observed connection galling. On the torque-versus-turn plots, document any observations or variances that contributed to other makeup concerns (coupling or pin spinning in tong dies, computer error/electrical spike that results in no torque-versus-turn printout, etc.).

5.7 Internal Pressure Leak Detection for TS-B and TS-C Setup

5.7.1 Principle

Leak detection requirements are critical for those connections that are required to be gas or liquid tight. Two proven methods of leak detection are described in 5.7.5 and 5.7.6 for use on different types of connections; however, any method of leak detection that can be calibrated to known traceable standards and meets the sensitivity requirements outlined in 5.7.4 may be used. For TS-B and TS-C, casing and tubing specimens that are subjected to internal pressure shall be monitored with a system capable of trapping and measuring leakage volume or flow rate.

Displacements during load changes shall be recorded on the datasheets; however, these displacements are not considered as a connection leak. Pressure sealing acceptance criteria are shown in 8.3. Connection leaks shall be identified on the pressure plots.

5.7.2 Pressurization Media

For CAL II, CAL III, and CAL IV, internal pressure tests to validate the TLE shall be conducted with dry nitrogen. For CAL I, tests with internal pressure to verify the TLE shall be conducted with liquid or dry nitrogen as specified in the test plan. By agreement between the parties of the test, a helium tracer gas may be added.

For the elevated temperature cycles in TS-B, and TS-C, the requirements in 5.10 apply.

5.7.3 Internal Pressure Leak Detection Sensitivity

The monitoring and measuring system for internal pressure leak detection shall meet a minimum leak indication sensitivity of 0.9 cm^3/15 min time period using a graduated cylinder of 0.1 cm^3 graduations or a sensitivity of 1×10^{-4} cm^3/s under standard conditions for gas chromatograph or spectrometer system. If helium tracer gas is used, the graduated cylinder based system shall have the capability of capturing the accumulated gas for the analysis of helium content to verify or discount leak events.

When using a graduated cylinder, take care to compensate for changes in barometric pressure or other non-test relevant events because these changes can affect the leak detection sensitivity. It is recommended that prior to beginning any tests, a separate graduated cylinder (see Figure 11) replicating the leak detection device be set up. This separate graduated cylinder can be used during analysis to determine whether a connection is leaking or whether the change is due to a change in barometric pressure. When used, the separate graduated cylinder shall contain a gas bubble consistent with the size of the bubble in the inverted graduated cylinders of the connections being monitored.

5.7.4 Leak Indicators

Leak indicators can be evaluated regarding their source if there is reason to believe the indication is not from the connection. A sensor calibrated to detect helium may be used to verify that any bubbles detected are coming from the pressure medium and not from thread compound de-gassing or from thermal expansion of the connection or test equipment. Evaluation of the leakage source shall be based on conclusive analysis of the leakage gas. If leakage is generated from a source other than the connection (e.g. the end caps), the source of the leakage shall be repaired and testing continued. Report leaks and their source (e.g. pressure fitting, valve, connection). Leak indicators shall be reported and the basis for discounting connection leakage clearly explained in the test report.

5.7.5 Internal Pressure Leak Trap Device

5.7.5.1 Principle

During the pressure test, the connection test specimen shall contain one or more of the internal pressure leak trap devices described in 5.7.6.2 through 5.7.6.4. When the tests will be at elevated temperature, the leak trap device materials shall be rated for a temperature above the maximum test temperature.

5.7.5.2 Collared Leak Trap Device

A collared leak trap device consists of an O-ring held against the face or OD of the box by a ported collar containing a flange with at least four bolt holes. Four longitudinal bolts maintain the collar tight against the face for sealing. A second O-ring is used to seal the collar against the pipe body using a separate bolted ring as shown in Figure 8.

5.7.5.3 Flexible Boot Leak Trap Device

A flexible boot trap device consists of a flexible material, such as silicone, that encapsulates the end of the box. A sealant is used between the pipe OD, box OD, and the boot. Hose clamps are used to secure the boot to the pipe and the box OD. A tube is placed between the boot and pipe OD, using the sealant to ensure that escaping gas exits by the boot as shown in Figure 9.

5.7.5.4 Ported Box Leak Trap Device

A vent hole is drilled through the box over the pin run-out threads near the end of the box face to allow escaping gas to exit the connection. The hole is tapped and fitted with a threaded adapter to which a flexible hose is attached. The face of the box shall be sealed to prevent any gas from escaping out of the end of the box as shown in Figure 10.

Assemble the ported box (Figure 10) in the following manner:

a) drill, tap, de-burr, and plug ports before connection makeup;

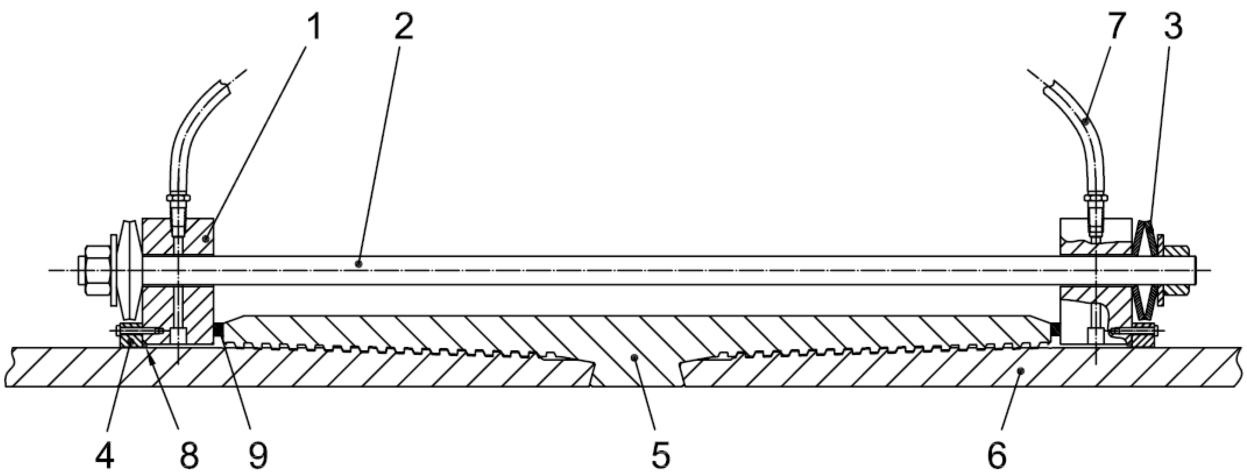
b) assemble connection;

c) install threaded fittings into holes using thread sealer [such as polytetrafluoroethylene (PTFE)];

d) clean and seal the ends of the coupling with silicone sealant or equivalent;

e) allow sealant to cure;

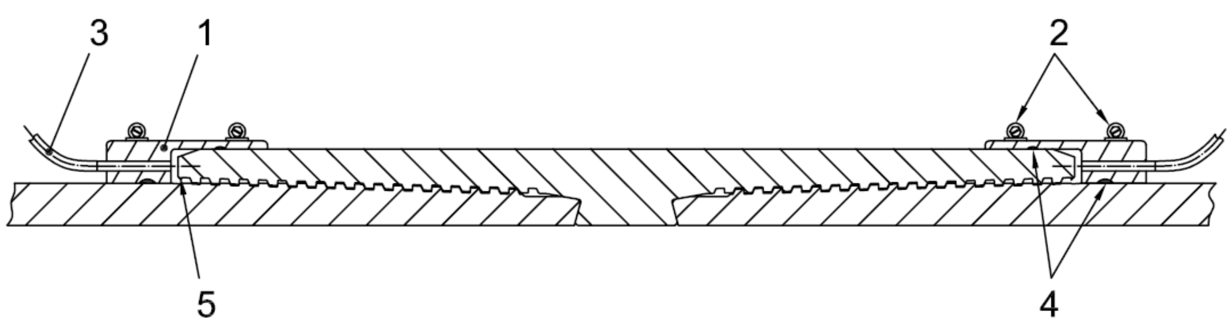
f) ports may be close to metal-to-metal seal.



Key

1 metallic flange
2 threaded rod
3 springs
4 threaded nut
5 coupling
6 pipe
7 flexible hose (heat resistant for elevated temperature tests)
8 O-ring
9 flat face gasket

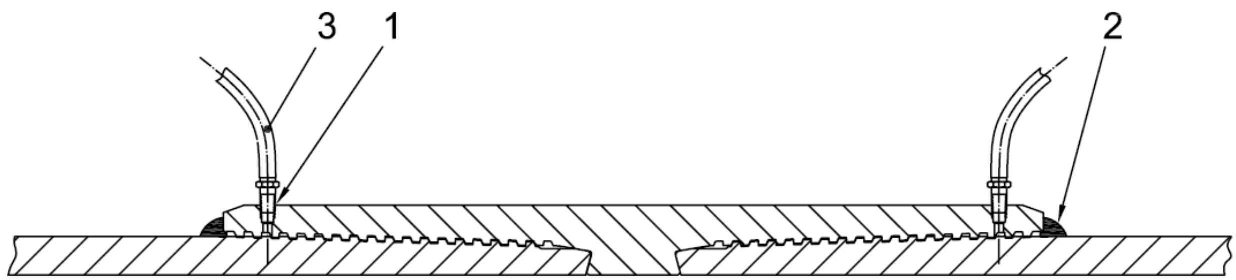
Figure 8—Collared Leak Trap Device for Internal Pressure Leak Detection



Key

1 flexible boot
2 hose clamps
3 metal tube or flexible hose (heat resistant for elevated temperature tests)
4 sealant
5 small gap for good leak-detection sensitivity

Figure 9—Flexible Boot Leak Trap Device for Internal Pressure Leak Detection



Key

1 tapped hole in run out threads with threaded fitting

2 sealant

3 flexible hose (heat resistant for elevated temperature tests)

Figure 10—Ported Box Leak Trap Device for Internal Pressure Leak Detection

5.7.6 Internal Pressure Leak Detection by Bubble Method for Gas Testing

5.7.6.1 Principle

A leak detection system based on the bubble method is shown in Figure 11. The system is based on capturing gas that passes through a connection and collecting the gas in a container for measuring the volume. The main components of the system are as follows.

a) A means of trapping the gas, such as the leak trap devices described (see 5.7.5).

b) A tube or flexible hose that connects the leak trap device to a bubble collection tube.

c) A bubble collection tube that consists of a clear graduated cylinder with 0.1 cm^3 or smaller-scale divisions.

   1) The cylinder is filled with water and a flexible hose is placed inside the open end of the cylinder.

   2) The cylinder and the end of the hose are submerged in a container of water and then inverted (see Figure 11).

d) Pressure sealing acceptance criteria are stated in 8.3.

Leakage is visually detected if bubbles rise in the cylinder. The source of the leak shall be evaluated to determine if the leakage is the result of a connection leak or from some other source, such as thread compound de-gassing (see 5.7.4).

5.7.6.2 Pressure Test of Leak Trapping Devices

Each trapping device shall be tested as follows.

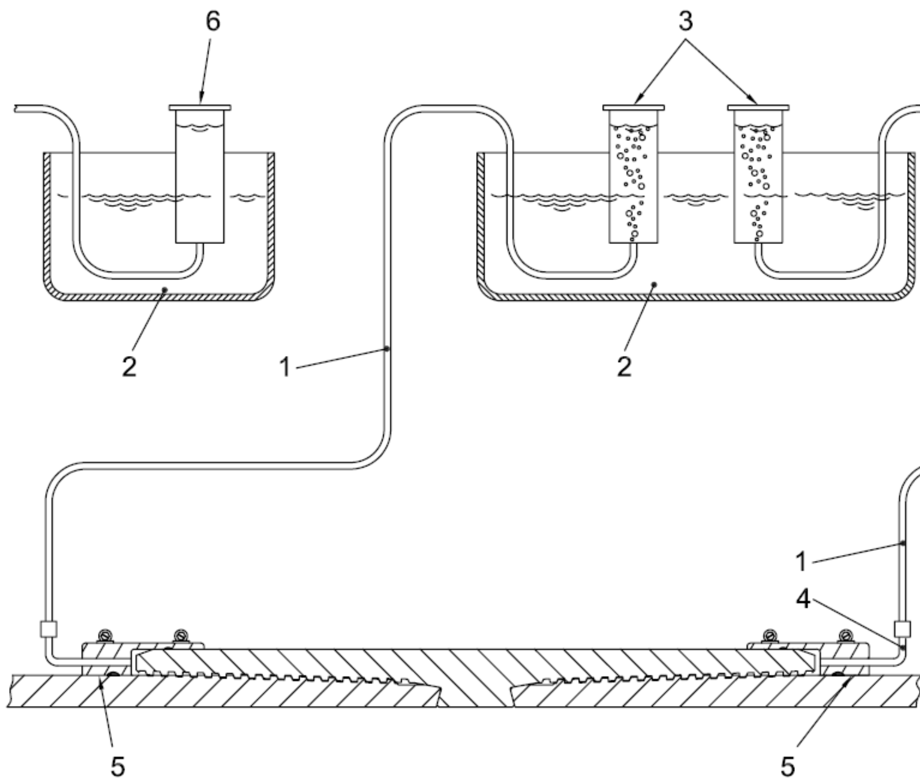
a) Check sealant and fitting for leaks by attaching a hose to a pressure supply at the beginning and end of the test:

   1) apply a gas pressure of 1 psig to 2 psig air or nitrogen,

   2) close off from supply and observe pressure gauge for a decrease in pressure.

b) Tighten or repair trapping device as necessary.

c) Periodically remove fitting, clean hole as necessary, and re-pressure test system as above.



Key

1 flexible hose (heat resistant for elevated temperature tests)

2 water tank

3 graduated cylinders

4 heat-resistant tube

5 leak trap devices

6 dummy graduated cylinder (same size and height above top of water as cylinders, see key item 3)

Figure 11—Example Configuration of Internal Pressure Leak Detection by Bubble Method

5.7.6.3 System Verification for Bubble Method

The following concern system verification for the bubble method.

a) Verify internal pressure leak detection systems prior to a test program and after completing the test program by testing for leaks and assessing sensitivity. In the event that leakage is discovered in the leak detection system after a test is conducted, tests conducted since the last leak detection system evaluation shall be repeated.

b) Test the system for leaks by applying 1 psig to 2 psig air or nitrogen gas pressure. When the pressure stabilizes, close off the gas supply. Observe the pressure gauge for 2 minutes for stability. Any drop in pressure indicates a system leak. Locate and repair any system leaks. This sensitivity efficiency shall be reported and may be used to evaluate indications. Note that sensitivity of the system may be improved by minimizing hose length.

c) Determine the sensitivity efficiency of the bubble leak detection system by introducing air and measuring the output air in each bubble tube. Inject the air in 1 cm^3 increments up to at least 10 cm^3. Determine the average relationship of output volume to input volume by plotting the data as shown in Figure 12. The initial amount of input air required to start output air in the bubble tube (pre-charge) shall be recorded, but does not affect the calculated leak rate and is therefore not considered in this sensitivity efficiency.

The sensitivity efficiency shall be at least 70 %; if less than 70 %, reconfigure the system to increase sensitivity. This sensitivity efficiency shall be used to correct observed leak rates and volumes during test execution according to the following:

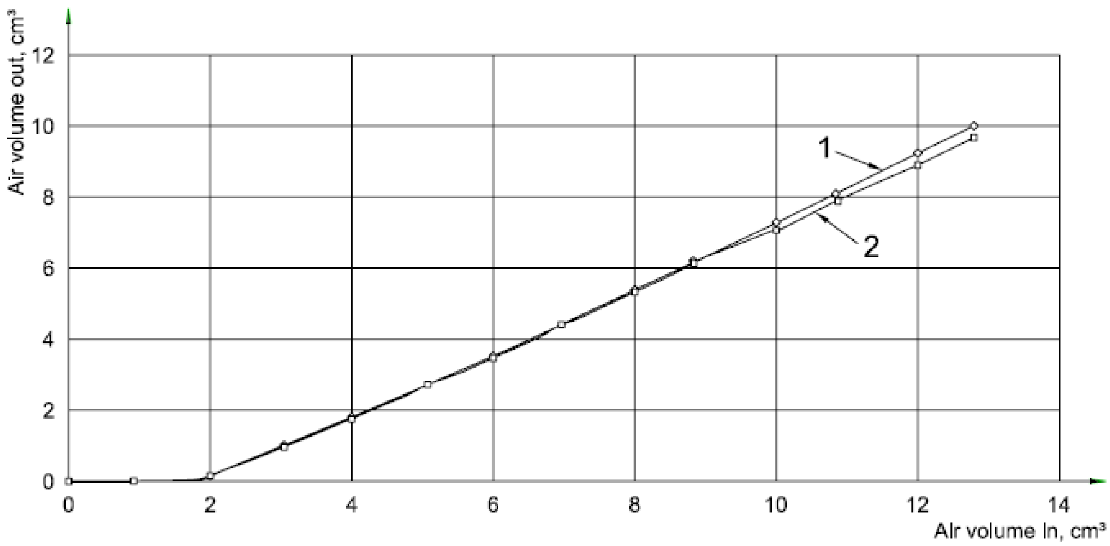
$$q_{ac} = \frac{q_o}{\eta_{lds}} \tag{3}$$

where

q_{ac} is the actual leak rate to be reported;

q_o is the observed leak rate;

η_{lds} is the leak detection system efficiency (slope of the lines in Figure 12).



Key

1 specimen end A

2 specimen end B

Figure 12—Example of a Plot for Determining Leak Detection Sensitivity

5.7.6.4 Start of Test

Before starting internal pressure tests, pre-charge each leak detection system by injecting air into the system near the box thread until a small amount of air collects in the bubble tube. Record this volume as the initial amount of gas that is subtracted from any additional gas collected in the tube. This pre-charge volume shall be sufficient to lower the water level to the scales on the graduated cylinder prior to the initiation of the test sequences and to demonstrate that the lines are not plugged.

5.7.7 Internal Pressure Leak Detection by Helium Mass Spectrometer Method

5.7.7.1 Principle

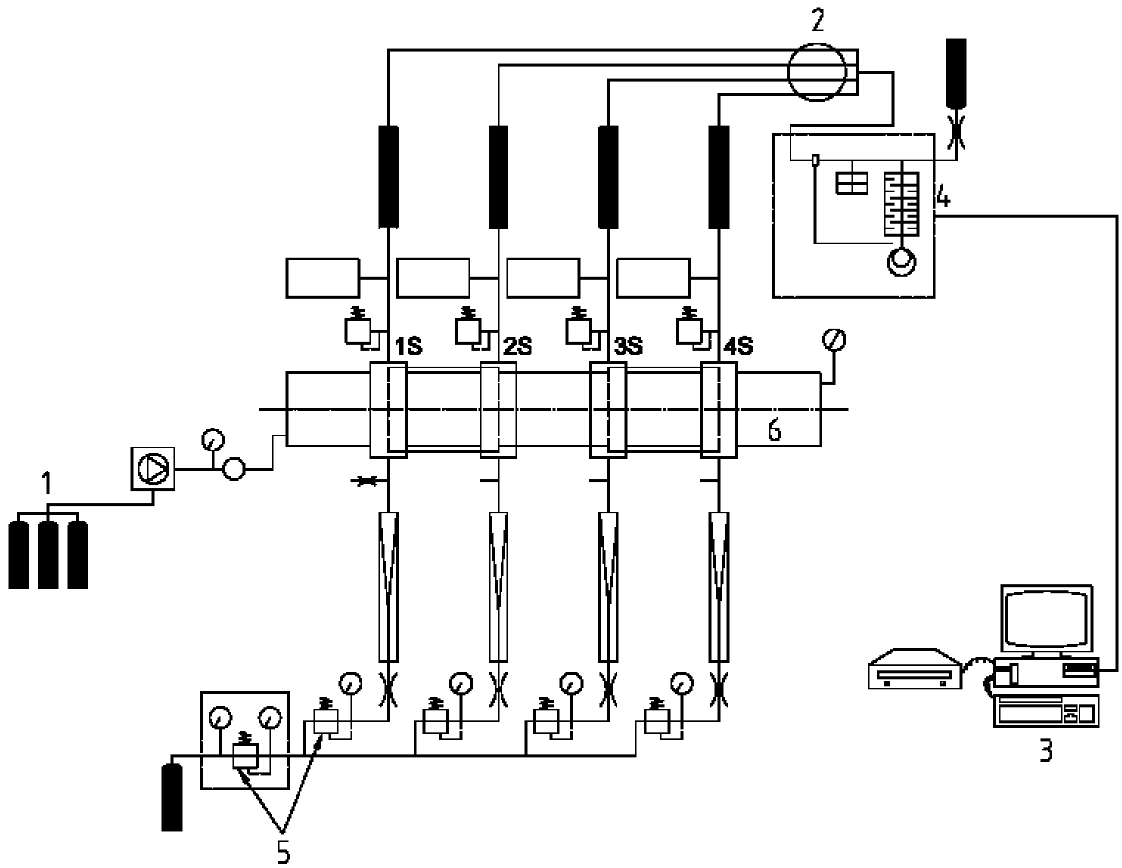
A leak detection system using a helium mass spectrometer (see Figure 13) includes the following:

a) a means of trapping the gas;

b) a tube or flexible hose connecting the leak trap device to a carrier gas line;

c) a pure nitrogen carrier gas line that connects to a mass spectrometer;

d) a helium mass spectrometer (where the mass spectrometer uses a sniffing method of leak measurement, special care is necessary to ensure the sniffer is working properly at atmospheric pressure).



Key

1 internal pressure source

2 sampling valve

3 data logger

4 mass spectrometer detector

5 carrier gas regulators

6 test specimen (shown with two couplings and four connections: 1S, 2S, 3S, and 4S)

Figure 13—Example Configuration of Leak Detection by Helium Mass Spectrometer Method

5.7.7.2 System Accuracy

The helium leak measuring system shall be capable of measuring a total effective leak rate of 1×10^{-4} cm^3/s under standard conditions or lower leakage rate.

5.7.7.3 Calibration

The complete system shall be calibrated to the equipment supplier's recommendation and at least once annually using a certified calibrated leak source. The calibrated leak source shall be used in place of a test specimen with each component of the leak detection system in place.

5.7.7.4 Multiple Specimen Leak Measurement

A manifold scanner can be used to test multiple connections or specimens. Minimum required sniffing time varies with equipment and shall be determined and demonstrated before starting the test. Each line shall be sniffed no less than once per minute.

5.7.7.5 System Verification

Before each test, flush the system with nitrogen. Inject a documented amount of helium at or near the leak trap device to ensure the detector is finding the helium. Sniff for helium through the complete line and leak trap device. Check for proper helium content of the gas, demonstrating that the lines are not plugged. Finally, flush the lines again to ensure that the test is starting with a non-contaminated system.

5.8 Leak Detection for TS-A Setup

5.8.1 Tests Performed at Ambient Temperature

5.8.1.1 Principle

The casing and tubing connections shall be subjected to internal and external pressure at ambient temperature within a system capable of detecting the internal and external pressure leakage. External pressure leak detection is recognized as more difficult and less accurate than internal pressure leak detection.

Though it is desirable to utilize leak detection methods similar to 5.7.6 and 5.7.7, these methods are not possible due to the presence of the external pressure vessel. As a result, TS-A leak detection at ambient temperature for internal pressuring testing shall be performed in accordance with 5.8.1 if the vessel remains on the specimen during internal pressure testing or 5.7 if the vessel is removed.

Displacements during load changes shall be recorded and reported; however, these displacements are not considered as a connection leak. Pressure sealing acceptance criteria is in accordance with 8.3. Connection leaks shall be identified on the pressure plots.

To validate suspected leaks, perform additional tests to confirm the rate and source. In the case of a suspected internal pressure leak, the external pressure chamber should be removed so that each connection in the test specimen assembly can be evaluated separately. In these cases, displacements observed with the external pressure chamber shall be recorded, but only the results without the external pressure chamber shall be used to evaluate a load point with a suspected leak.

In the context of the leak verification without the external pressure chamber, the load point(s) with a suspected leak shall be retested arriving to the load point from the same direction (CCW or CW) as the previous evaluation performed with the external pressure chamber. In case a load point showed suspected leaks in both directions during the previous testing sequence, leak verification without the external pressure chamber shall be performed for the previous load point from both directions. The hold period for leak verification shall be the longest hold period for that particular load point during that particular test sequence.

For practical reasons, in the case of a suspected leak with the external pressure chamber, it is allowed to continue the test with the external pressure chamber until the test sequence is completed, and perform the leak verification without the external pressure chamber thereafter.

The evaluation performed without the external pressure chamber shall be considered as part of the test and not a deviation.

5.8.1.2 Pressurization Media

Reference 5.7.2 for pressurization media.

External pressure tests performed at ambient temperature shall be conducted with water or an appropriate pressurization medium.

5.8.1.3 Internal and External Pressure Leak Detection Sensitivity and Verification

For TS-A tests at ambient temperature, the leak detection sensitivity for internal and external pressure testing shall follow 5.7.6.3, when calibrating the chamber and sample, respectively. The sensitivity shall be recorded and documented in accordance with 5.7.6.3.

To assist with leak detection, tracer dyes may be used in the fluid or the coupling may be ported in the area between the metal seal and the first thread start on the pin. Another option is to measure the length of time required for fluid to broach a thread seal. This length of time would then be used to determine the minimum hold times for current 1-hour holds performed after any external pressure tests.

5.8.1.4 Ported End Caps

Connection test specimen end caps should have holes that allow the inside of the specimen to be filled with liquid. These holes should have high-pressure fittings able to contain internal pressure during internal pressure tests. Normally, two holes are required, i.e. one for water inlet and one for air exit (air bleed). The air bleed hole should be at the opposite end of the specimen from the water inlet hole. The bleed hole should be located in the end cap to allow the removal of air from the inside of the specimen. If the air is not removed from the external pressure chamber, it may result in long stabilization periods and/or faulty results with regard to sealing of the connection. Therefore, efforts shall be taken to remove air from the external pressure chamber, from the test specimen, and from leak detection lines. Having the inlet and outlet ports in the proper locations, tilting the specimen during filling the specimen or external pressure chamber with water, use of wetting agents, etc., are examples of techniques to remove air from the test specimen. The ports shall also be located in such a manner as to allow removal of the water from the specimen for subsequent internal gas tests.

5.8.1.5 Setup for TS-A

An example setup for TS-A is shown in Figure 14. The port identified as key item 3 in Figure 14 shall be at the top of the external pressure chamber during setup and stabilization to remove air from the chamber. Then rotate the assembly around its longitudinal axis so that this port is as close as possible to 20° off vertical for leak detection or connect the leak detection hose to alternative port location, for example bottom (180°) or side (90°) of the chamber, to prevent any remaining air from entering the leak detection tube. The port identified as key item 11 in Figure 14 shall line up with the test specimen internal diameter or below.

5.8.1.6 Leak Detection and Measurement by Water Level

For internal pressure tests at ambient temperature, the chamber and leak detection lines shall be filled with water as described in 5.8.1.4. As described in 5.8.1.5, the flexible hose shall be connected to the leak detection system as shown in key items 3 and 12 in Figure 14 and item 8 in Figure 15.

For external pressure tests at ambient temperature, the specimen and leak detection lines shall be filled with water as described in 5.8.1.4. As described in 5.8.1.5, the flexible hose shall be connected to the leak detection system as shown in key items 8 and 12 in Figure 14 and item 8 in Figure 15.

During TS-A pressure testing, a chamber encloses the test connection and some portion of the pipe on both sides of the connection. During the pressure testing, it has been observed that immediately after reaching full pressure and axial load, there may be significant (greater than 0.9 cm^3/15 minute) water displacement. This displacement usually exhibits a decreasing trend that requires a stabilization period that shall be performed before starting the required hold period. In view of this test behavior, the following criteria should be used for TS-A pressure tests.

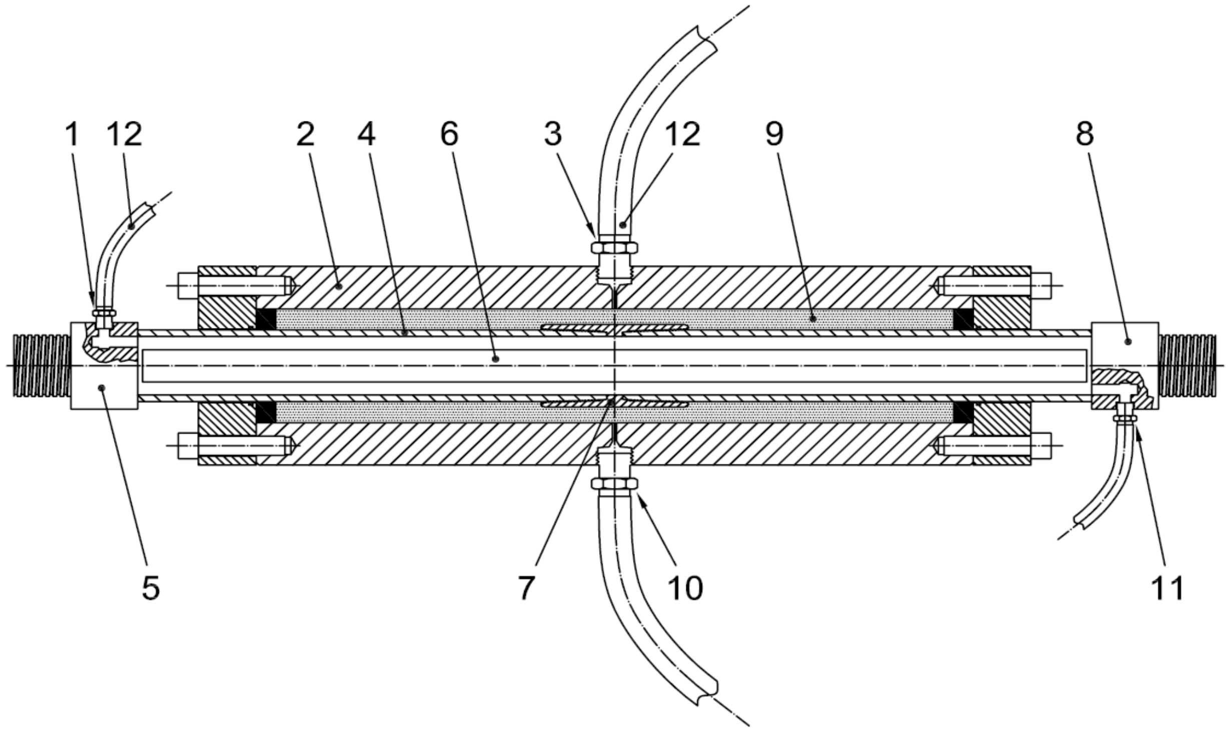
a) Apply the full required internal or external test pressure and close the pressure line valves from the pressurizing pump.

b) Small pressure increases may be necessary immediately after closing the valves in order to maintain the required pressure.

c) Begin recording the frame loads, pressures, and graduated cylinder water level readings shortly after closing the valves (after target loads are applied and the leak detection system is stabilized).

d) Record the frame loads, pressures, and graduated cylinder water level readings as described in 8.3.

e) Document the leak rate and note the trend of leakage in the bubble tube—pressure sealing acceptance criteria are stated in 8.3.



Key

1 port for pressure transducer for internal gas test, leak detection for external pressure test, shop air inlet to drain water after external pressure test

2 external pressure chamber

3 hole, equipped with flexible hose to leak detection for internal pressure test or pressure transducer for external pressure test

4 test pipe

5 end cap, containing top internal port, see key item 1

6 internal filler bar, for safety

7 test connection

8 end cap containing bottom internal port, see key item 11

9 chamber, fully filled with water

10 hole, for water pressure inlet to chamber

11 port for gas pressure inlet, water fill for external pressure test, water drain after external pressure test

12 flexible hose that attaches to leak detection system (see key item 8 in Figure 15)

Figure 14—Example Setup for TS-A

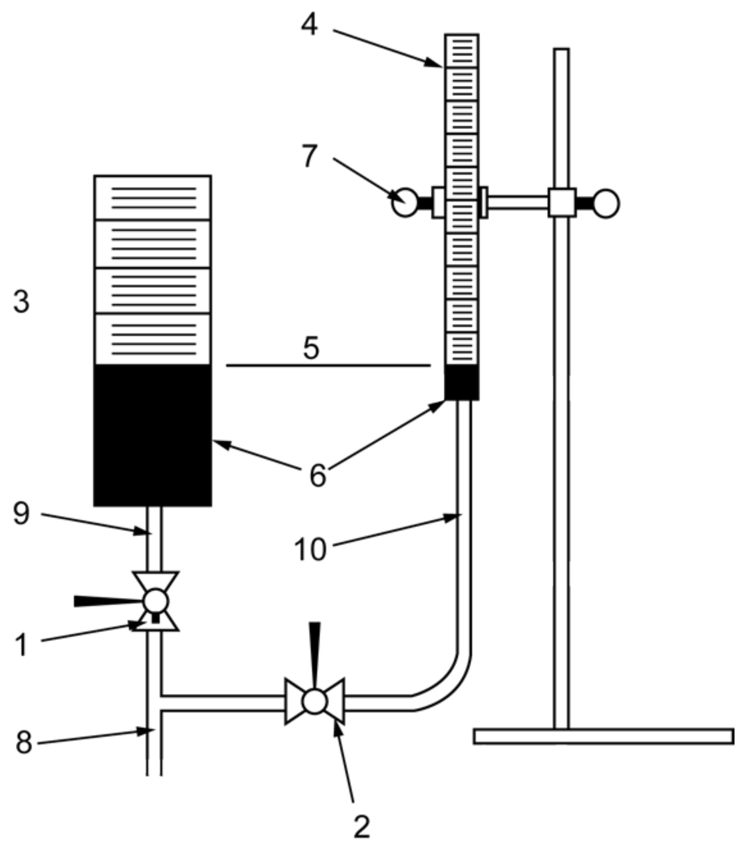
For both internal and external tests, at the start of the test, the large graduated cylinder shown in Figure 15 is approximately half filled with fluid. Before test loads are applied and adjusted, the large valve (see key item 1 in Figure 15) is opened and the small valve (see key item 2 in Figure 15) is closed. The fluid level inside the large cylinder will rise or fall with the applied test loads. At the start of a hold period, the small valve (see key item 2 in Figure 15) is opened and the position of the small graduated cylinder is adjusted up or down so that the fluid level in the small cylinder is near the bottom of the cylinder. The large valve (see key item 1 in Figure 15) is then closed. If a connection leak occurs, the fluid level in the small cylinder will rise and can be observed and measured in time to give a leak rate. A coloring agent should be added to the fluid inside the cylinders for ease of viewing the water level.

The fluid level in the small cylinder shall be recorded at the start and end of each hold period and at the intervals stated in 8.3.2 when a connection leak occurs to determine the leak characteristic.

5.8.2 Tests Performed at Elevated Temperature

5.8.2.1 Principle

Due to the difficulty of performing external pressure tests at elevated temperature with an accurate leak detection system, the principle is to exercise the connection at elevated temperature and the leak detection system is used to detect connection leaks for information purposes only.



Key

1 valve to large graduated cylinder

2 valve to small graduated cylinder

3 large graduated cylinder with open top (approximately 100 cm^3 to 200 cm^3)

4 small graduated cylinder with 0.1 cm^3 graduations with open top (approximately 25 cm^3)

5 water level

6 colored water

7 adjustable cylinder support to allow bottom of cylinder to be located at 100 cm^3 to 200 cm^3 water level at start of each hold period

8 flexible hose attached to top of chamber for internal gas tests and top port at one of end caps for external tests

9 flexible hose to large cylinder

10 flexible hose to small cylinder

Figure 15—Example of Leak Detection System for TS-A with External Pressure Chamber on Specimen for Ambient Internal and External Pressure Testing

Caution—The setup in Figure 15 should not to be used for elevated temperature testing.

TS-A leak detection at elevated temperature shall be performed by pressure drop method. If the external pressure vessel is removed, internal pressure at elevated temperature shall be performed in accordance with 5.7. Leaks, regardless of detection method (pressure, volume, or rate), shall be reported.

For the TS-A elevated temperature testing, the requirements in 5.10 apply.

5.8.2.2 Pressurization Media

Internal pressure testing shall be conducted with dry nitrogen. External pressure tests shall be conducted with an appropriate liquid that remains in a liquid state at a temperature above the test temperature.

5.8.2.3 TS-A leak Detection Sensitivity and Verification

For TS-A tests at elevated temperature, leak detection sensitivity equal to internal pressure leak detection sensitivity (see 5.7.3) is not possible due to the difficulty, accuracy, and safety concerns. For leak detection at elevated temperature under TS-A conditions, pressure drop (see 5.8.2.4) shall be used. As a result, the sensitivity of the leak detection is equal to the sensitivity of the pressure transducer. Results shall be recorded and documented.

5.8.2.4 Leak Detection and Measurement by Pressure Drop Method

Leak detection by pressure drop may be used for TS-A testing at elevated temperature. Pressure changes during load changes shall be recorded and reported; however, these pressure changes are not considered as a connection leak. Pressure sealing acceptance criteria is in accordance with 8.3. Connection leaks shall be identified on the pressure plots.

During internal pressure testing, the external pressure vessel is filled with appropriate pressurization media; and the port identified as key item 10 in Figure 16 is closed while a pressure transducer is used to monitor the pressure within the external pressure vessel at the port identified as key item 3 in Figure 16. The pressure within the external pressure vessel shall be maintained at less than 1.4 MPa (200 psi). During internal pressure hold periods, a reduction of internal pressure that is accompanied by an increase in external pressure is an indication of a possible connection internal pressure leak.

During external pressure testing, the specimen is filled with gas or liquid media. The end cap port identified as key item 11 in Figure 17 is closed while a pressure transducer is used to monitor the pressure within the specimen at the port identified as key item 1 in Figure 17. The pressure within the specimen shall be maintained at less than 1.4 MPa (200 psi). During external pressure hold periods, a reduction of external pressure that is accompanied by an increase in internal pressure is an indication of a possible connection external pressure leak. The pressure increase in the specimen will not be one-to-one with the pressure loss from the vessel. Based on the appropriate pressurization media being used as the external pressure medium, it can take a sizable enough volumetric leak to increase the internal pressure in order to recognize the leak.

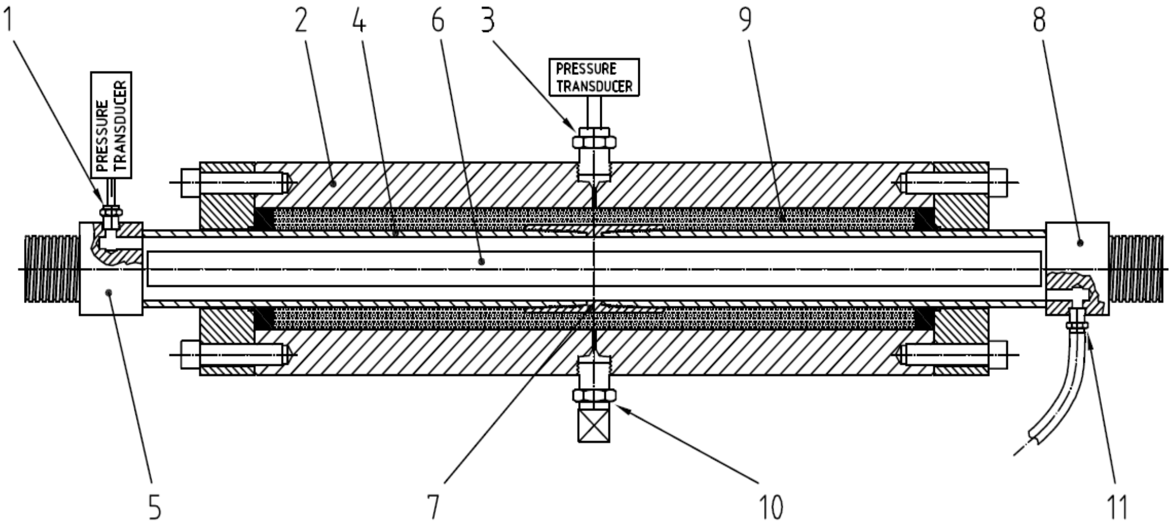
For TS-A at elevated temperature, leak detection shall be by monitoring the applied pressure for indications of a possible connection leak. Record the rate of pressure loss (psi/min) in 5-minute increments, the trend in the pressure loss rate, and the number of times pressure is increased during the hold. Sustained pressure loss or an increasing rate of pressure loss may be an indication of a possible connection leak. Pressure sealing acceptance criteria are stated in 8.3.

To validate suspected leaks, perform additional tests to confirm the leak rate and source. In the case of a suspected internal pressure leak, the external pressure chamber should be removed and the internal pressure testing repeated so that each connection in the specimen assembly can be evaluated separately with leak detection and measurement by the bubble method (see 5.7.7) or the helium mass spectrometer method (see 5.7.8). In case of a suspected external pressure leak, and based on agreement between manufacturer and user, elevated test may be completed and use TS-A ambient test at the 90 % level to confirm the leak or attribute it to the difficulty of elevated temperature detection. Alternatively, without agreement between the parties, the specimen should be cooled to ambient temperature and the external pressure testing repeated at ambient temperature loads at the 90 % level with leak detection and measurement by the water method (see 5.8.1.6).

5.9 Data Acquisition and Test Methods

5.9.1 General

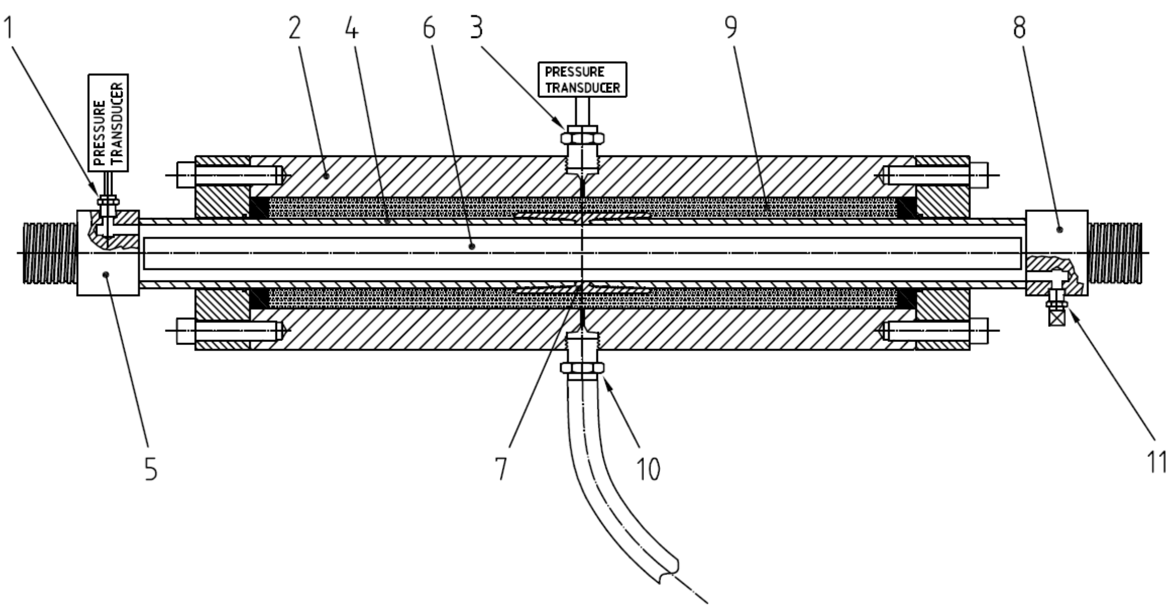
Correct and adequate recording of data is fundamental to the testing program. Without adequate records, it is not possible to provide the objective evidence of the performance verification of a connection.



Key

1 port for pressure transducer for internal gas pressure test
2 external pressure chamber
3 hole equipped with pressure transducer for internal gas pressure test
4 test pipe
5 end cap, containing top internal port, see key item 1
6 internal filler bar, for safety
7 test connection
8 end cap containing bottom internal port, see key item 11
9 chamber, fully filled with fluid
10 hole, for fluid inlet to chamber, closed off for internal gas pressure test
11 port for gas pressure inlet

Figure 16—Example Setup for Elevated TS-A (Internal Pressure)



Key

1 port for pressure transducer for external pressure test, shop air inlet to drain fluid after external pressure test
2 external pressure chamber
3 hole, equipped with pressure transducer for external pressure test
4 test pipe
5 end cap, containing top internal port, see key item 1
6 internal filler bar, for safety
7 test connection
8 end cap containing bottom internal port, see key item 11
9 chamber, fully filled with fluid
10 hole, for fluid pressure inlet to chamber
11 port for fluid fill for external pressure test, fluid drain after external pressure test

Figure 17—Example Setup for Elevated TS-A (External Pressure)

5.9.2 Principle

Test specimens are subject to a combination of applied loads, including axial, pressure, bending, and temperature. Proper measurement and control of these loads are vital to conducting the test program. For load points without intentional bending, bending loads may be induced by variations in pipe or alignment of specimen elements and the frame. Specimen support with anti-buckling fixtures is recommended. Test labs shall maintain processes to manage specimen bending.

Monitoring strain data during tests can provide insight into the connection’s response to test conditions and can confirm that planned loads are properly applied by the test equipment. Strain gauges may be applied to the connection (coupling/integral box OD and pin ID) and/or to the pipe body.

5.9.3 Procedure

5.9.3.1 General

The internal or external pressure, frame load, bending load, and temperature that are applied to the specimen shall be monitored and recorded. For each test, record the pressure, axial load, and temperature continuously versus time. These data shall be recorded digitally. The data acquisition rate should be appropriate for the expected load and pressure changes but shall not be less than one scan of each channel at 15 second intervals. For limit load tests, a faster scan rate is recommended.

5.9.3.2 Pressure and/or Axial Frame Loads

Connect a pressure transducer to the internal or external pressure cavity of the specimen. Locate the pressure transducer at the air bleed hole and not at the pressure inlet hole.

Load each specimen at an axial stress rate of 105 MPa/min (15,000 psi/min) or less. Load each specimen with pressure at a rate of 105 MPa/min (15,000 psi/min) or less. Loading the specimens may be performed continuously or intermittently. However, in the case of intermittent loading, the rates for axial load and pressure increments shall not exceed the maximum rates. There is no maximum or minimum rate for removing pressure or axial loads.

NOTE These rates are specified to ensure that accurate sealing and structural performance data are recorded in the tests.

During hold periods, the pressure and/or axial frame loads should be maintained above the target load. During hold periods, pressure loads shall be maintained between the target pressure ±1.4 MPa (200 psi) or ±1 %, whichever is greater. During hold periods, the axial frame load shall be maintained between the target axial frame load ±0.5 % or ±22 kN (5 kips), whichever is greater.

Adding or removing axial, pressure, or bending loads is acceptable during hold periods in order to maintain loads within the required tolerance range. Excursions below the lower tolerance limit for axial frame load, pressure, bending, or temperature do not compromise the hold; however, the hold shall be extended to meet the cumulative total hold time with loads within the tolerance range. Excursions above the upper tolerance limit for a given hold period should be avoided. If they occur, they shall be reported.

5.9.3.3 Use of Connection-mounted Strain Gauges During Make-Break Testing

Strain gauges may be used during make-break testing. When used, the test specimen should be instrumented for strain monitoring before initial assembly if data are to be collected during make and breaks. If strain data from the pipe body are to be collected during make-break testing, bi-axial, or tri-axial strain gauges shall be used.

NOTE Bi-axial strain gauges will measure principal strains during combined load testing; however, tri-axial gauges may be more appropriate during make-break testing since the principal pipe strain during makeup and breakout will be torsional in nature.

Various axial locations may be used for strain gauge placement. At a minimum, the number of strain gauges used at each axial location shall be as follows.

a) For pipe sizes ≤4 in., the minimum number of gauges shall be three at equally spaced circumferential locations (every 120°).

b) For pipe sizes >4 in., the minimum number of gauges shall be four at equally spaced circumferential locations (every 90°).

For make and breaks, strain gauges may be installed inside the pin and outside the coupling (for IJ connections, outside the box) opposite any metal-to-metal seal areas. If there are multiple metal-to-metal seals, the strain gauges may be placed opposite each seal. The strain gauges should be placed as close to the middle of the seal area as possible. The inside and outside strain gauges should be placed at matching axial locations (i.e. the axial location of the inside and outside strain gauges should match when the connection is made up). The circumferential locations need not match.

For each makeup, the strain gauge readings should be recorded with the (1) pin and coupling (box) separate, (2) connection assembled hand-tight and/or strap-tight, and (3) connection fully made up.

The use of strain gauges to collect data during specimen assembly is strongly suggested for retest specimens when the first specimen failed because of galling.

The strain gauges shall be zeroed and shunt-calibrated before the initial makeup. For multiple make and breaks, the strain gauge's calibration and zero position shall not be adjusted between make-and-break cycles (i.e. re-zeroing is not allowed). Internal strain gauges and associated wires shall be disconnected and removed after the FMU.

5.9.3.4 Use of Strain Gauges to Measure Bending

5.9.3.4.1 General

For TS-B with bending, the use of pipe body strain gauges is required. Strain gauges may be used to monitor for unintentional bending in other tests series.

The bending equivalent axial force in the reference pipe body for the target bending shall be determined by:

$$F_b = 2.284566\ x10^{-8} * \left(t_{avg} D_{avg}^2 - t_{avg}^2 D_{avg}\right) * E * D_{leg} \tag{4}$$

where

F_b bending equivalent axial force (kips);

t_{avg} average wall thickness of test specimen pipe body based on actual measurements (inches);

D_{avg} maximum average OD of test specimen pipe body based on actual measurements (inches);

D_{leg} effective dogleg severity (deg°/100 ft);

E elastic modulus of the pipe body material (psi) (see 5.5.2).

The constant 2.284566×10^{-8} is based on unit conversions and geometric constants considering the stress at the outer fiber of the pipe OD in the plane of bending. Equation (4) is derived by setting the plane stress equal to the outer fiber bending stress and solving for the axial load. Details on the equation and contact derivation are shown in D.6.2.2.

5.9.3.4.2 Strain Gauge Position and Orientation

When measuring bending using strain gauges, place the four uni-axial strain gauges on both pup joints in the same equally spaced 90° planes and at a distance of at least $3\sqrt{(D * t)}$ from the connection and any end cap or gripping fixture. If it is desirable to gather hoop strain data with these strain gauges as well, bi-axial strain gauges may be used. It is recommended that the 0° strain gauge be aligned with the specimen's thinnest wall location. The position/orientation of each gauge shall be documented.

Two methods are presented for the control of applied bending: bending moment based control (D_{leg}) and equivalent stress based control. In both cases, strain gauges are used to control the applied bending. The test laboratory shall select one method and use it throughout the entire test.

A strain gauge's calibration and zero position shall not be adjusted within any test series (i.e. re-zeroing is not allowed); any residual bending is part of the total applied bending moment. However, if at the end of TS-B ambient without bending, the sample is shown to be sufficiently straight (demonstrated by other means), then re-zeroing is allowed (while the sample is at elevated temperature) since the residual strains (resulting in calculated bending) are not believed to be the result of bending, but of non-uniform strain hardening of the pipe body material. In the event that a strain gauge needs to be replaced or re-zeroed, parties shall agree to the procedure and the impact on the testing.

5.9.3.4.3 Bending Moment Based Curvature Control

For bending moment based control (D_{leg}), apply and control bending at the connection to at least the minimum bending moment for deliberate bending tests as determined by measured strains from the pipe body strain gauges. For each pup joint, the bending is calculated in the horizontal and vertical planes. The bending is calculated for each plane and the two planes are combined vectorially to determine the bending moment. Apply the bending moment until the greater of the two pup joint readings reaches the target value. Monitor the pipe body strain gauges, calculate the bending stress, moment, and dogleg, and continuously record the dogleg.

During hold periods, the applied bending load shall be maintained between the target bending load as a minimum and the target bending load plus the tolerance specified below as a maximum. Excursions below the target bending load do not compromise the hold; however, the hold shall be extended to meet the cumulative total hold time with the bending load within the tolerance range. Excursions above the upper tolerance limit for a given hold period should be avoided. If they occur, they shall be reported.

a) For pipe sizes $\leq 2^7/_8$ in., a maximum bending tolerance of 3.0°/100 ft.

b) For pipe sizes $>2^7/_8$ in. to 4 in., a maximum bending tolerance of 2.0°/100 ft.

c) For pipe sizes >4 in. to $5^1/_2$ in., a maximum bending tolerance of 1.5°/100 ft.

d) For pipe sizes $>5^1/_2$ in. to 10 in., a maximum bending tolerance of 1.0°/100 ft.

e) For pipe sizes >10 in., a maximum bending tolerance of 0.5°/100 ft.

5.9.3.4.4 Equivalent Stress Based Curvature Control

For equivalent stress based control, each bending load point is associated with a non-bending load point at the same targeted stress level. The objective is to replace a portion of the axial load with a bending load so that the stress level before and after applying the bend are equivalent. This method may only be used for connections that are transparent to the pipe body in bending, e.g. 100 % bending efficient connections (see 5.9.3.4).

Bending shall be applied and controlled in one plane. Proper fixturing should be installed to restrict out-of-plane bend; out-of-plane bend shall be monitored. QI bend shall be controlled by the strain gauge on the tension side of the pipe, and QII bend shall be controlled by the strain gauge on the compression side of the pipe.

First apply the loads for the non-bend step and record the strain indicated by the controlling strain gauge on each pup. The order of the load points with and without bending may be switched so that the uni-axial load point may be applied before application of bending. Reduce the axial load by the calculated value and apply the bending load until the controlling strain gauge returns to the last value recorded at the previous non-bend load step. The target bend has now been achieved and the hold period may be started. Note that the strain gage may creep during the hold due to the material being loaded beyond its proportional limit. Bending load may be reduced to maintain the strain within the tolerance specified below.

The applied bending load tolerance is 2 % of elastic yield strain based on the elastic modulus as determined above and SMYS or 50 microstrain, whichever is larger.

5.9.3.4.5 Bending Measurement

The strain gauges used to measure bending should not be larger than 0.25 in. The axial location of the strain gauges is dependent on the method used to apply bending, as described below. Alternate dogleg measurement techniques (e.g. video, laser, and photogrammetric techniques) may be used to monitor bending. Alternative measurement methods shall be documented to demonstrate that the required minimum bending is achieved for each bending load point.

Two load methods for deliberate bending are recognized.

a) Four-point bending fixture.

   Locate both bending load cylinders at equal distances from the end reaction points and ensure they impose equal load. The strain gauges used for bending control shall be located on the pipe body between the two bending cylinders, provided the requirements in 5.9.3.4.2 are met.

b) Uniform bending from rotating end fixtures.

   The applied bending moment shall be the same on both ends. The location of the strain gauges may be anywhere along the length of the pipe, provided the requirements in 5.9.3.4.2 are met.

5.9.3.5 Limit Load Tests

Monitor and record the internal or external pressure and axial load that is applied to the specimen.

For each limit load test, photograph the specimen after failure and show the location and mode of failure. Record major loads and dimensions on Figure B.7. Report and include test data in the test reports (see Section 9 and Annex C). See 7.4.2 for termination of tests.

5.10 Elevated Temperature Tests

5.10.1 General

The purpose of mechanical cycling between ambient and elevated temperature (TS-A and B) and thermal cycling (TS-C) is to approximate service conditions and accelerate potential leakage by applying these tests while the connection is subjected to axial tension, compression, bending, and internal pressure loads. For the last set of ambient mechanical cycles in TS-A, TS-B, and TS-C, the temperature of the test specimen (pipe and connection) shall be ≤95 °F (35 °C).

5.10.2 Apparatus

The temperature changes for the mechanical and thermal cycling tests may be produced by any means capable of uniformly changing the temperature of the connection within the temperature limits of the test. The apparatus should avoid subjecting the test specimens to a substantially higher temperature than required by the test procedure.

The applied heating and cooling shall be uniformly distributed over the coupling or connection, as applicable.

A minimum of two thermocouples shall be used on each specimen. Both thermocouples shall be in the center of the coupling for threaded and coupled (T&C) connections and in the center of the connection for integral connections. The thermocouples shall be located 180° apart (at the top and bottom for horizontally oriented testing). Ensure that the temperature measured is not affected by local temperature variations in the vicinity of the thermocouple and that the temperature measured is representative of the connection's temperature. Additional thermocouples may be used at the discretion of the user or manufacturer. The additional thermocouples may be used for measurement, control or informational measurement purposes.

In TS-A, TS-B, and TS-C, during elevated temperature test holds, thermocouple readings shall be within ±27 °F (±15 °C) of the specified elevated test temperature for the specified connection application level. Temporary excursions below this range are allowable (especially when increasing or decreasing the pressure); however, hold times shall not be initiated until temperature readings reach the acceptable range. If the temporary excursions below the range occur when hold period has been started, the hold shall be extended to meet the cumulative total hold time with the temperatures within the range. Excursions above the specified temperature may affect the connection performance. If there is an accidental excursion above the maximum temperature tolerance, it shall be recorded and the appropriate parties contacted for guidance. The test specimen temperature is the average of the connection thermocouple readings. At elevated temperature the test specimen temperature shall be at least 275 °F (135 °C) for CAL II and at least 356 °F (180 °C) for CAL III and CAL IV tests.

In TS-C, the minimum temperature for each thermal cycle is the average of the two thermocouples and the minimum temperature shall be no greater than 125 °F (52 °C) for each application level, with no limit on the lower bound. Thermocouples for each of the five pressure/tension cycles at the end of TS-C (key item 10 in Figure 31) shall not exceed 95 °F (35 °C).

Thermal and mechanical cycles may be continuous or interrupted as required for overnight shutdown or equipment repair.

Leak detection for TS-B and TS-C shall be in accordance with 5.7. Leak detection for TS-A testing shall be in accordance with 5.8. During the elevated temperature cycling tests, there may be small changes in the fluid level in the graduated cylinders. Variations occur randomly and might not be related to a connection leak, as rapid thermal changes and barometric pressure changes may be the cause of these fluid level variations.

The pressure sealing acceptance criteria are shown in 8.3.

6 Test Specimen Preparation

6.1 General Test Objectives

Control and definition of the test specimens is critical since this testing method is based on extreme tolerance/worst-case connection configuration evaluation and not random sampling of a population. Extreme tolerance evaluation addresses performance parameters of dimensions, makeup torque, and the type and amount of thread compound. Product tolerances are based on performance, manufacturing capabilities, and cost of manufacture. It is important to recognize that this test procedure does not provide the statistical basis for risk analysis nor does it give specific guidance on connection usage.

Manufacture and test the full-scale test specimens at the worst-case performance extremes of the connection that can be produced according to the drawings, quality plan, running (including thread compound application) procedures, and makeup torques described in the connection geometry and performance data test sheets and quality control procedures. Table 2 gives general connection test specimen objectives for each specimen. Table 3 gives guidance for selecting specimens for testing a metal-to-metal sealing, tapered thread connection. The test specimen extremes shall conform to these test objectives. For connections with attributes different from those in Table 3, worst-case extremes shall be determined, documented, and used in the tests.

Table 2—Test Specimen Objectives for CALs

Specimen Number	Makeup Objective	Test Load Objective	Limit Load Testing		Test Path Number [a]			
			Testing Objective	Test Reference (Section)	CAL I	CAL II	CAL III	CAL IV
1	Thread galling	Minimum leak integrity [b]	Tension with internal pressure increasing to failure	7.5.6	LL5	LL5	LL5	LL5
2	Thread galling	Minimum leak integrity [b]	Internal pressure with compression increasing to failure	7.5.5			LL4	LL4
3	Worst–seal galling tendency [b]	Minimum leak integrity	High internal pressure with tension increasing to failure	7.5.2			LL1	LL1
4	Pin maximum axial stress	Leak resistance at maximum makeup tightness [b]	Internal pressure with compression increasing to failure (CAL II) or compression with external pressure increasing to failure (CAL III & IV)	7.5.5 (CAL II) or 7.5.3 (CAL III & IV)		LL4	LL2	LL2
5	Maximum box hoop stress	Maximum makeup tightness [b]	Tension increasing to failure	7.5.4	LL3	LL3	LL3	LL3

[a] Test path numbers refer to failure tests shown in Figure 35 or Figure 36.

[b] Primary test objective.

Table 3—Guidelines for Selecting Test Specimens for Testing a Metal-to-Metal Sealing, Tapered Thread Connection

Specimen Number	Summary of Objectives	Made-up Condition	Thread Interference	Seal Interference	Pin Thread Taper	Box Thread Taper	Final Torque
1	Thread galling and sealing	Minimum seal interference	Extreme high	Extreme low	Slow	Fast	Minimum
2	Sealing	Minimum seal interference	Extreme high	Extreme low	Slow	Fast	Minimum
3	Seal galling and sealing	Maximum seal interference	Low	High	Fast	Slow	Maximum
4	Sealing	Maximum torque into shoulder	Low	Low	Slow	Fast	Maximum
5	Galling	Maximum overall tightness	High	High	Fast	Slow	Maximum

6.2 Test Specimen Identification and Marking

Identify each test specimen by marking with the following information (see Figure 18).

a) The test specimen number (i.e. 1, 2, 3, 4, or 5) shall be placed on both pups and the couplings (as applicable).

b) The pup joint designation (A or B) shall be placed after the specimen number.

c) The coupling side designation (A or B) shall be placed at the appropriate end of the coupling. The coupling manufacturer identification may differ from the required identification of the specimen; however, the manufacturer shall provide a document that links their identification to the required specimen identification.

d) Identify replacement and/or re-machined connections with an “R1” after the “A” or “B” identification the first time they are reworked, an “R2” the second time they are reworked, etc.

6.3 Test Specimen Preparation

6.3.1 Additional and Unsupported Pipe Lengths

Prepare test specimens such that for each specimen, each pipe length has a minimum unsupported pup joint length L_{pj} (see Figure 18) that is calculated from:

$$L_{pj} \geq D + 6\sqrt{(D * t)} \tag{5}$$

where

D is the specified pipe OD;

t is the specified wall thickness.

Additional length for gripping and/or end caps shall be provided.

Mark specimens to allow wall and diameter measurements at appropriate lengths along L_A, L_B, and L_C (see Figure B.2) and record them on the datasheet in Figure B.5.

6.3.2 Pipe and Coupling Stock

Test specimens should be machined on pipe and coupling stock that is manufactured consistent with standard mill/thread practices as follows:

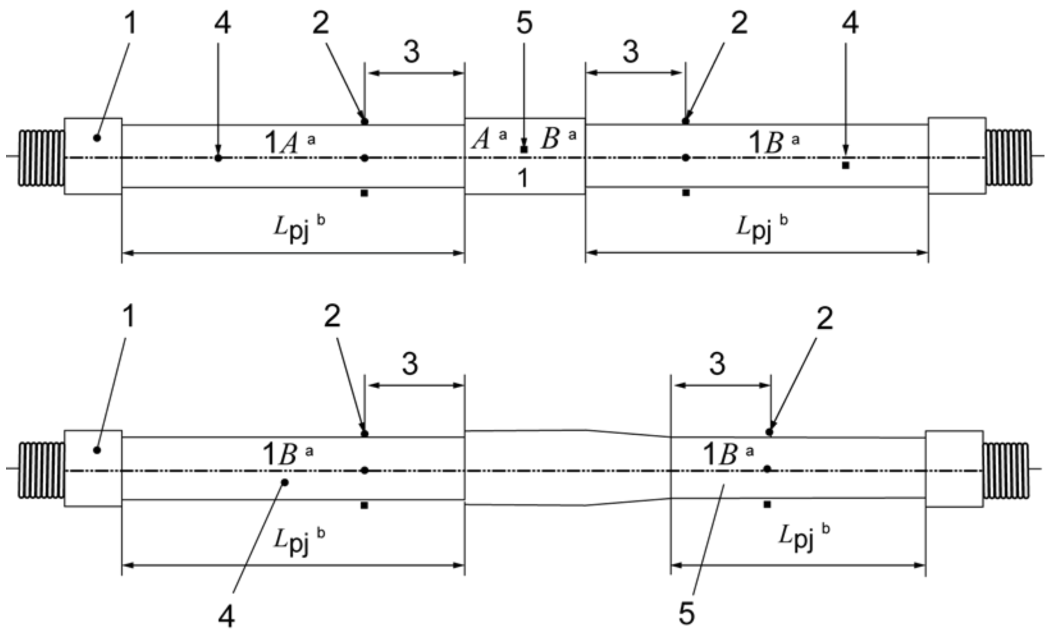
a) machine connections for upset pipe on upset pipe,

b) machine connections for swaged pipe on swaged pipe,

c) machine flush connections for plain-end pipe on plain-end pipe, and

d) stress-relieve pin and/or box ends prior to threading if it is part of the manufacturer’s process for production manufacturing.

It is acceptable, but less desirable, to manufacture test specimens from material stock by machining external upsets to replicate the product configuration. If the upsets are machined, the configuration that is not normally machined, and the length shall be to the minimum allowed by the manufacturer. The test reports shall indicate that the test specimens are machined from thick wall cylinders, when applicable.



Key

1 end fixture

2 strain gauges for measuring bending

3 minimum distance of $3\sqrt{(D*t)}$ between strain gauges and connection (leaving a minimum distance of $D+3\sqrt{(D*t)}$ between strain gauges and the end fixtures)

4 pin

5 box

[a] Full-scale test specimen number is designated by 1, 2, 3, etc., and A and B are pup joint and coupling side designations.

[b] L_{pj} is the minimum unsupported pup joint length ($D+6\sqrt{(D*t)}$); see 6.3.1.

NOTE It is not necessary that the pup joint lengths be the same length.

Figure 18—Test Specimen Nomenclature and Unsupported Length

6.3.3 Material Requirements

For each set of test specimens:

a) A end and B end pups should come from one mother joint;

b) coupling stock should come from one lot;

c) material properties (mechanical properties and dimensional measurements) of each test specimen pup shall be determined in accordance with 5.5;

d) all material shall be in compliance with a specified material specification;

e) total range of measured yield strength at ambient temperature for each mother pipe should be less than or equal to 105 MPa (15 ksi);

f) average coupling stock mother tube yield strength at ambient temperature should not exceed the minimum average pin mother pipe yield strength by more than 70 MPa (10 ksi);

g) if the pipe and coupling are not from the same specified grade, the difference between yield strengths shall be by agreement between user and manufacturer.

6.3.4 Recording of Data

All appropriate data shall be recorded on Figure B.3, Figure B.5, and Figure B.6.

6.4 Test Specimen Machining

Manufacture test specimens as specified by the connection manufacturer's process control plan. The tolerances shall be as specified in 6.5.

The first article contour tracings, or equivalent (such as impression molds), at minimum magnification of X20 shall meet the applicable machine drawing dimensions of the specimen being threaded. The piece representing the start of the thread lot shall be verified to meet the applicable machine drawing requirements prior to machining the test specimens. The contour tracings, or equivalent, shall be part of the connection manufacturer's full test report.

In the sealing area measure the surface roughness in accordance with the surface roughness specifications of the product drawing and record in the test report. The measurement shall be taken after machining and before surface treatment and shall be within the surface roughness specifications of the product drawing.

The selected surface treatment of each pin and box shall be consistent with the surface treatment applied to production components. The manufacturer shall establish, especially on gall sensitive materials, surface treatment of pin and box that should be at minimum (or maximum) of the tolerance range, depending on which is deemed most severe for the connection. Report the actual thickness of the surface treatment.

If a test specimen is damaged before testing is completed, manufacture a replacement specimen. This replacement specimen shall be machined and assembled to the same tolerances as the damaged specimen, and all testing required for the original specimen shall be repeated. Identify replacement and/or re-machined connections with an "R1" after the "A" or "B" identification the first time they are reworked, an "R2" the second time they are reworked, etc.

All proprietary data that are to be reported on Figure B.6 may be reported as a percent of tolerance range of the measured dimension (i.e. 0 % represents the minimum value of the tolerance range of the measured dimension and 100 % represents the maximum value of the tolerance range of the measured value). If using percentage of tolerance range, the measured value shall be retained in the thread manufacturer's files. Note that 50 % represents the middle of the tolerance range. Connection primary seal ovality shall be reported as a percentage.

6.5 Machining Tolerances

6.5.1 Worst-case Performance Objectives

The specific machining dimensions will depend on the type of connection. For connections with attributes other than covered by Table 3 or if different machining tolerances are recommended, then the manufacturer shall use analytical, computational [such as finite element analysis (FEA)], and/or experimental techniques (such as strain gauge testing) to provide objective evidence that the extreme dimensional configurations of the product resulting in worst-case performance are tested. To select worst-case performance objectives, the manufacturer shall take into account the minimum and maximum extremes of local seal contact pressure, total seal contact load, and total active seal contact length as influenced by machining parameters. For T&C connections, side A and side B shall be machined to identical dimensional objectives.

Table 2 shows full-scale test specimen objectives for CALs. Table 3 shows guidelines for selecting test specimens for testing a metal-to-metal sealing, tapered thread connection. Table 4 shows tolerance limits on machining objectives for the metal seal and thread interferences, and Table 5 shows thread taper tolerance limits. Figure 19 provides a schematic description of test specimen interference ranges.

Machining tolerances, which may be relevant to worst-case performance, include, but may not be limited to, the following:

a) seal diameters,

b) thread tapers,

c) pin nose thickness,

d) thread diameters,

e) surface roughness.

The extreme connection tolerances applied to the test specimen create inherent conservatism in the testing program and may be evaluated along with the probability of those events occurring. Quantitative risk-assessment methods may be applied to estimate probabilities of events associated with the testing conditions.

6.5.2 Example Machining Tolerances

As an example, for metal-to-metal sealing, tapered thread connections with pin-nose torque shoulders, Table 3 shows combinations of seal and thread diameters, thread tapers, and FMU torques that have been found to provide the worst-case performance extremes corresponding to the test objectives in Table 2. For this type of connection, the manufacturer shall machine the full-scale test specimens to the extremes in Table 3 unless the attributes described in 6.5.1 indicate other tolerances should be tested. For each pin/box assembly and each interference location (thread or seal), at least one of the diameters of elements of individual connection members (pin or box) shall be within its design tolerances. In addition, that element shall be within 25 % of the design tolerance range at the intended target extreme. The other diameter may be outside of the design tolerances, if necessary, as long as the interference of the assembly satisfies the interference target of the combination of pin and box (see Table 4).

Table 4—Tolerance Limits on Machining Objectives

Item [a]	Allowable Interference Range	
	Minimum	**Maximum**
Maximum specimen interference (H)	$I_{max} - \max\begin{bmatrix} 0.002 \text{ in.} \\ 25\ \% \times I_{range} \end{bmatrix}$	No limit
Extreme maximum specimen interference (XH)	$I_{max} - \max\begin{bmatrix} 0.001 \text{ in.} \\ 5\ \% \times I_{range} \end{bmatrix}$	No limit
Minimum specimen interference (L)	No limit	$I_{min} + \max\begin{bmatrix} 0.002 \text{ in.} \\ 25\ \% \times I_{range} \end{bmatrix}$
Extreme minimum specimen interference (XL)	No limit	$I_{min} + \max\begin{bmatrix} 0.001 \text{ in.} \\ 5\ \% \times I_{range} \end{bmatrix}$

[a] The same principle applies to seal and thread interferences.

Table 5—Thread Taper Tolerance Limits [a]

Thread Tapers	Plus (+) Tolerance	Minus (−) Tolerance
Maximum (fast)	No limit	0.001 in./in.
Minimum (slow)	0.001 in./in.	No limit

[a] Taper tolerances shall apply to incremental measurements of taper along the length of the thread.

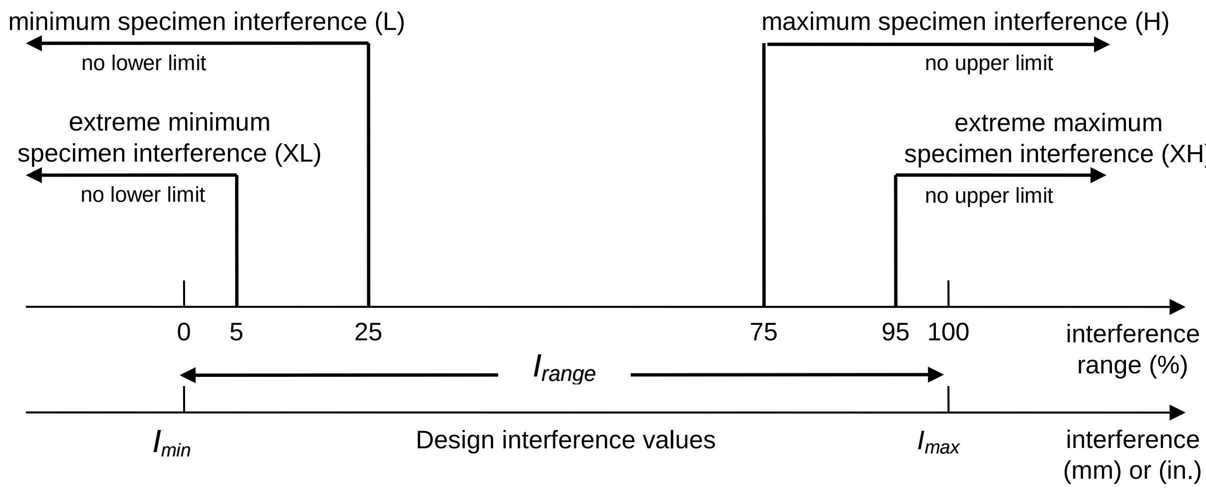


Figure 19—Schematic Description of Test Specimen Interference Ranges

6.6 Grooved Torque Shoulder

For connection types with a torque shoulder on the front of the pin, the A ends (B ends for integral connections) of specimens shall have torque shoulders grooved as shown in Figure 20 to simulate possible handling damage that could be sustained by connections in the field. Grooves shall be applied any time before FMU. Other specimen ends in the test may have the torque shoulder grooved.

Inclusion of the torque shoulder pressure-bypassing groove for other connection seal types should be by agreement between the user and manufacturer. Justification for omitting the pressure-bypassing groove shall be included in the full test report specified in Annex C. However, if any field dressing of the torque shoulder is allowed, the groove shall be included in the connection test configuration.

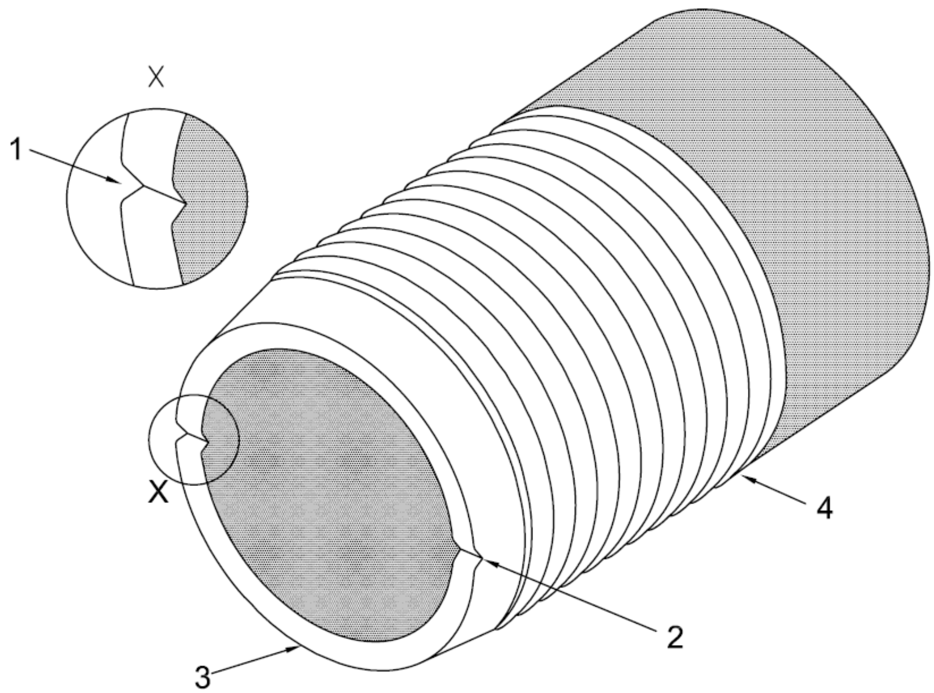
For Figure 20, corners at grooves 1 and 2 should be rounded to prevent possible galling. Bypass grooves shall not traverse into the pin nose metal seal.

7 Test Procedures

7.1 Principle

The procedures subject the worst-case connection configurations to test envelope loads and limit loads of the pipe body or connection (whichever is less).

In accordance with the connection test specimen objectives (see Table 2), Table 6 provides a summary of test procedures for each specimen according to seal interference condition, makeup/breakout condition and testing to Series A, B, or C and LL (limit loads to failure). Table 3 provides further information for selecting connection test specimens for a metal-seal connection.



Key

1 groove 0.008 in. (0.2 mm) deep, minimum

2 groove 0.008 in. (0.2 mm) deep, minimum, and located as close as possible to 180° from key item 1

3 torque shoulder

4 threads

Figure 20—Torque Shoulder Pressure-bypassing Grooves

7.2 Makeup/Breakout Tests

7.2.1 Principle

An objective of the overall program is to evaluate galling sensitivity of the connection design. Another program objective is to conduct sealing tests on specimen ends that have been assembled one time and other specimen ends that have been subjected to makeup and breakout cycles. Thus, some specimen ends receive makeup and breakout testing as specified in 7.2.2 (MBG) followed by an FMU as specified in 7.2.3. Other specimen ends receive only one makeup (FMU) as specified in 7.2.3.

All initial and intermediate connection makeups for MBG shall be to maximum makeup torque with the minimum amount of thread compound. The FMU prior to TLE testing shall have the maximum amount of thread compound applied to each connection, and torque shall be in accordance with Table 6. For thread-sealing connections, FMU prior to TLE testing shall have the minimum amount of thread compound and minimum or maximum amount of torque in accordance with Figures 4 through 7 and Table 6.

A galling evaluation shall be part of the final report, including photographs of the galled surfaces before and after repair from the first galling event, the repaired surfaces after the next breakout, and the final breakout.

For connection types not included in Table 6, the manufacturer shall provide thread compound and torque values to meet the objectives of Figures 4 through 7. Thread-sealing connection and large diameter connection types may follow Table 6 when the applicable columns are used.

Table 6—Test Specimen Description and Summary of Test Series for a Metal-to-Metal Sealing, Tapered Thread Connection

Specimen Description [c]			Thread Compound		Torque		Make / Breaks	CAL IV				CAL III				CAL II			CAL I		
Specimen No.	Interference						A and B ends	Test Series				Test Series				Test Series			Test Series		
	Thread	Seal [d]	MBG	FMU	MBG	FMU	MBG	A	B	C	LL	A[a]	B	C	LL	A	B	LL	A	B	LL
			A or B end		A or B end		A / B end														
1	XH	XL	L	H	H	L	N / Y	A	B	C	LL 5	A	B	C	LL 5	A	B	LL 5	A	B	LL5
2	XH	XL	—	H	—	L	N / N	A	B	C	LL 4		B		LL 4						
3	L	H	L	H	H	H	Y / N	A	B	C	LL 1		B		LL 1						
4	L	L	L	H	H	H	N / Y	A	B	C	LL 2	A	B	C	LL 2		B	LL 4			
5	H	H	L	H	H	H	Y / Y				LL 3				LL 3			LL 3			LL 3

MU and BO Cycles for each Full-Scale Test Specimen											
Specimen No.	Casing End A	Casing End B	Tubing End A	Tubing End B	Sum of specimen A and B ends for each make/break condition						
1	–	2	–	9		Make/break galling – A ends	MBG	T&C – 2 Integral – N/A	T&C – 2 Integral – N/A	T&C – 1 Integral - N/A	T&C – 1 Integral - N/A
2	–	–	–	–		Make/break galling – B ends	MBG	T&C – 3 Integral – 3	T&C – 3 Integral – 3	T&C – 3 Integral – 3	T&C – 2 Integral – 2
3	2	–	9	–							
4	–	2	–	9		Final make-up – A and B ends	FMU	T&C – 10 Integral – 5	T&C – 10 Integral – 5	T&C – 6 Integral – 3	T&C – 4 Integral – 2
5	2	2	9	9							
Total number of specimens for each test class								5	5	3	2

Y Yes

N No

MBG Make/break limit galling test (see 7.2.2)

FMU Final make-up (see 7.2 3)

H Manufacturer's recommended maximum value [b]

XH Manufacturer's recommended extreme maximum value [b]

a For CAL III, Test Series A is performed at ambient and elevated with no QI–QIII Cycling.

b Tolerances on specimen interference are provided in 6.5.2 and Tables 4 and 5; tolerances on thread compound are provided in 5.6.2; tolerances on make-up torque are provided in 5.6.3.

L Manufacturer's recommended minimum [b]

XL Manufacturer's recommended extreme minimum [b]

LL Limit load (failure) tests (see 7.4 and Table 2)

c For T&C connections, A ends shall be configured the same as the B ends described above.

d Seal interference condition determined by local seal contact pressure or total seal contact load, i.e., the integral of contact pressure

NOTE All threads on integral joint connections are identified as B end threads.

7.2.2 Makeup/Breakout Test for Galling Resistance (MBG) (A and B Ends)

Prior to starting makeup/breakout tests, rehearsal makeup tests may be used to calibrate dump valve settings on the makeup equipment. This will increase the odds that the desired final torque will be achieved during makeup/breakout testing. Higher RPM used in the connection makeup may increase the range of error around the target torque.

Makeup and breakout of connection test specimen ends shall be in accordance with the following procedure:

a) refer to 5.6 for general makeup/breakout procedures;

b) record connection geometry data on Figure B.6;

c) connections shall be clean and dry, and the mass of thread compound applied shall be recorded;

d) makeup assemblies as shown in Table 6 with the indicated amount of thread compound and makeup torque;

e) after each breakout, clean, examine, and photograph the pin and box end in accordance with 5.6; and

f) see 7.2.3 for FMU.

NOTE All integral connections are “B” assemblies and do not have “A” ends.

7.2.3 Final Makeup (A and B Ends)

FMU of test specimens shall be in accordance with the following procedure:

a) refer to 5.6 for general makeup/breakout procedures;

b) record connection geometry data on Figure B.6;

c) connections shall be clean and dry, and the quantity of thread compound applied shall be recorded;

d) makeup assemblies as shown in Table 6 with the indicated amount of thread compound and makeup torque; and

e) report results on Figure B.4 and Figure B.6.

7.3 Test Load Envelope Tests

7.3.1 Test Load Envelope Calculation

7.3.1.1 General

In the calculation of the CEEs, it is the intent of this RP to test the specimens to as high a load or combination of loads as is safely practical. In view of this objective, the following variable definitions for load shall be applied to each specimen.

If the CEE of coupled connections is less than the pipe body reference envelope due to a factor other than actual material yield strength (see 7.3.1.3), then the TLE shall be 100 % of the CEE. In case of integral connections, maximum axial loads are limited by critical sections (not pipe body), then if the CEE is defined as 100 % of critical section times actual yield the 90 % limitation in axial loads applies; however if the CEE is limited in axial loads due to a factor other than actual material yield strength and critical section (see 7.3.1.3), then the TLE shall be 100 % of the CEE.

7.3.1.2 Test Specimen Pipe Body Reference Envelope (Ambient and Elevated Temperature)

7.3.1.2.1 General

The calculation of the ambient temperature pipe body reference envelope is required for each test specimen as stated in 4.2 and is used in Figures 21 through 32. In order to determine the pipe body reference envelope at ambient temperature, a series of axial load vs pressure reference curves shall be calculated. The pipe body reference envelope at ambient temperature for each test specimen is derived from the actual API VME curve and a combination of the reference curves for external pressure. To simplify the process, reference curves that apply for external pressure shall be placed on the pipe body reference envelope in their entirety.

Refer also to D.3.1 to D.3.5 (Curves 1[a] through 5[a]) for the methodology in using the API 5C3 equations for the purposes of this RP.

7.3.1.2.2 Pipe Body Reference Curves Based on API Specified Input Parameters

The first three of the reference curves do not change between test specimens, as they are a function of API specified or nominal input parameters. These reference curves are calculated as specified below.

a) Nominal VME curve at ambient temperature (Curve 1[a])—Use API 5C3 to calculate this curve. The input parameters for this equation are SMYS, specified OD, specified wall, and 87.5 % of specified wall (for minimum wall). The nominal VME curve at ambient temperature shall be shown as a continuous VME envelope.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *triaxial yield of pipe body*.

b) Nominal API collapse curve at ambient temperature (Curve 2[a])—Use API 5C3 to calculate this curve by using SMYS, specified OD, and specified wall as input parameters.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *external pressure resistance*.

c) Proprietary high collapse curve at ambient temperature (Curve 3[a])—This curve (if applicable) shall be uni-axially scaled out from the nominal API collapse curve at ambient temperature (Curve 2[a]) using the ratio between the uni-axial high collapse pressure at ambient temperature provided by the manufacturer and the uni-axial nominal API collapse pressure at ambient temperature as the scaling factor.

7.3.1.2.3 Pipe Body Reference Curves Based on Measured Input Parameters

The remaining two of the reference curves will change between test specimens, as they are a function of measured input parameters. These reference curves are calculated as specified below.

a) Actual VME curve at ambient temperature (Curve 4[a])—Use API 5C3 to calculate this curve for each test specimen using the minimum of each parameter between the two pups for the ambient temperature AMYS as established in 5.5.2.5, the minimum wall (for hoop stress) as established in 5.5.3.2, the minimum average wall (for axial loads) as established in 5.5.3.3, and the maximum of the parameter between the two pups for maximum average OD as established in 5.5.3.4. The actual VME curve at ambient temperature for each test specimen shall be shown as a continuous VME envelope.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *triaxial yield of pipe body*.

b) Actual API collapse curve at ambient temperature (Curve 5[a])—Use API 5C3 to calculate this curve for each test specimen by using the minimum parameter between the two pups for ambient temperature AMYS as established in 5.5.2.5, the minimum parameter between the two pups for minimum average wall as established in 5.5.3.3, and the maximum parameter between the two pups for maximum average OD as established in 5.5.3.4.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *external pressure resistance*.

7.3.1.2.4 Elevated Temperature Pipe Body Reference Envelope

Calculation of the elevated temperature pipe body reference envelope is required for each test specimen as stated in 4.2 and used in Figures 28 and 32. In order to determine the pipe body reference envelope at elevated temperature, a series of axial load vs pressure reference curves shall be calculated. The elevated temperature reference curves are not well established and are under investigation by the industry. For the purpose of this RP, they shall be scaled from their respective ambient temperature reference curve. However, alternative scaling methods can be used in the calculation of the pipe body reference envelopes at elevated temperature provided they are reported in API 5C3 or experimental evidence of these can be demonstrated and are included in detail in the test plan.

Since the scaling factor for each of the elevated temperature reference curves is a function of AMYS, these curves need to be calculated individually for each test specimen. The pipe body reference envelope at elevated temperature for each test specimen is derived from a combination of these reference curves. To simplify the process, reference curves that apply for external pressure shall be placed on the pipe body reference envelope in their entirety.

a) Nominal VME curve at elevated temperature (Curve 1^e)—This curve shall be bi-axially scaled-in from the nominal VME curve at ambient temperature (Curve 1^a) using the elevated temperature scaling factor (K_{temp}); see 5.5.2.6. The nominal VME curve at elevated temperature shall be shown as a continuous VME envelope.

b) Nominal API collapse curve at elevated temperature (Curve 2^e)—This curve shall be bi-axially scaled-in from the nominal API collapse curve at ambient temperature (Curve 2^a) using the elevated temperature scaling factor (K_{temp}); see 5.5.2.6.

c) Proprietary high collapse curve at elevated temperature (Curve 3^e)—This curve shall be defined by the manufacturer of the proprietary high collapse pipe. The final scaling factor from Curve 3^a shall be reported.

d) Actual VME curve at elevated temperature (Curve 4^e)—This curve shall be bi-axially scaled-in from the actual VME curve at ambient temperature (Curve 4^a) using the elevated temperature scaling factor (K_{temp}); see 5.5.2.6. The actual VME curve at elevated temperature shall be shown as a continuous VME envelope.

e) Actual API collapse curve at elevated temperature (Curve 5^e)—This curve shall be bi-axially scaled in from the actual API collapse curve at ambient temperature (Curve 5^a) using the elevated temperature scaling factor (K_{temp}); see 5.5.2.6.

7.3.1.3 Test Specimen CEE (Ambient and Elevated Temperature)

The calculation of the ambient and elevated temperature CEE is required for each test specimen as stated in 4.2.

The manufacturer is responsible for defining the ambient and elevated temperature CEE for each test specimen based on the connection design, measured dimensions, and material yield strength for each test specimen. The CEE may be limited by the pipe body or the connection performance properties. If the CEE is limited by the pipe body performance properties, then the CEE is based on material yield strength. If the CEE is less than the pipe body reference envelope, it needs to be disclosed by the manufacturer (for each CEE point defined in Table 7) whether the CEE limitation is based on material yield strength or some other factor. With this information about the CEE, the scaling factors for the TLE can now be determined.

The ambient and elevated temperature CEEs shall not exceed the ambient and elevated temperature actual VME curves (Curve 4^a and Curve 4^e), respectively, of the pipe body for each test specimen as defined in 7.3.1.3. The manufacturer may limit the CEE based on the pipe body reference collapse curves for each test specimen as described in 7.3.1.3. If the ambient temperature CEE^a is determined by the nominal API collapse curve at ambient temperature (Curve 2^a) or the proprietary high collapse curve at ambient temperature (Curve 3^a), the manufacturer may limit the ambient temperature CEE^a compression load in QIII to the pipe body compression rating based on specified minimum material yield strength, specified wall, and specified OD.

7.3.1.4 Test Specimen Test Load Envelope (Ambient and Elevated Temperature)

Calculation of the TLE at both ambient and elevated temperature is required for each test specimen as stated in 4.2.

Caution should be taken as the assumptions for elevated temperature API collapse and actual API collapse are outside the scope of API 5C3.

For the ambient temperature load points defined in Table 7 requiring 80 % bi-axial scaling, the CEE scaling factor remains at 80 % regardless of whether the CEE is limited by material yield strength or some other factor. For each of the internal pressure load points defined in Table 7, if the CEE is a function of material yield strength, the TLE for both ambient and elevated temperature shall be bi-axially scaled in as a percentage (90 % or 95 %, whichever applies) of the CEE for both ambient and elevated temperature. However, axial loads (tension and compression) shall be capped at 90 % of the CEE.

For each of the load points defined in Table 7, if the CEE is not a function of material yield strength, the TLE at ambient and elevated temperature shall be 100 % of the CEE at ambient and elevated temperature with the exception of the load points scaled to 80 % of the CEE that shall also remain scaled to 80 %.

For each of the external pressure load points defined in Table 7, if the CEE is a function of material yield strength, the ambient and elevated temperature TLEs shall be bi-axially scaled in as a percentage (90 %, 95 %, or 100 %, whichever applies) of the ambient and elevated temperature CEEs. However, axial loads (tension and compression) shall be capped at 90 % of the CEE. For each CEE point defined in Table 7, if the external pressure is determined by the actual API collapse curve or the actual VME curve, then the bi-axial scaling factor shall be 90 % or 95 % (whichever applies). For each CEE point defined in Table 7, if the external pressure is determined by the nominal API collapse curve or the proprietary high collapse curve, then the bi-axial scaling factor shall be 100 % (no scaling). Multiple reference curves may need to be evaluated for each CEE point defined in Table 7 in order to determine which reference curve generates the highest TLE load point.

If the ambient temperature CEE[a] is determined by the nominal API collapse curve (Curve 2[a]) or the ambient temperature proprietary high collapse curve (Curve 3[a]), and the manufacturer chooses to limit the CEE[a] compression load in QIII to the pipe body compression rating based on specified minimum material yield strength, specified wall, and specified OD, then the TLE compression load shall be 100 % of the CEE[a] compression load.

Refer to Figures 4 through 7 for the test sequence.

Each TLE shall include as a minimum the relative load points for ambient and elevated temperature for each test series as specified in Table 7. Separate TLE diagrams shall be provided for each test specimen for both ambient and elevated temperatures for each test series.

Each test specimen shall be tested to 100 % of the loads shown in the TLE. See 5.3.2 for assessment of the test results.

Figures 21 through 24 are examples of two different types of generic TLEs. Figures 25 through 32 illustrate some examples of TLEs for TS-A and TS-B at ambient and elevated temperatures. These examples are not meant to be all-inclusive and other types of TLEs are possible and acceptable. The TLE diagrams shall be displayed on a plot of the tri-axial yield of the pipe body of the test specimens calculated in accordance with API 5C3, not to any percentage of minimum specified uni-axial capacities. The user is responsible for appropriate interpretation of the test data and determination of their minimum connection performance envelope.

NOTE For the reference to API 5C3, the appropriate section that applies addresses the *triaxial yield of pipe body*.

7.3.2 Principle and Guidelines

7.3.2.1 Principle

The connection design has satisfied the requirements of this RP for the TLE for the specified CAL when all the test specimens complete the load steps with no connection leak for the prescribed TS-A, TS-B, TS-C, and limit load tests as defined for the specified CAL.

If each of the tests conducted at the 90 % level pass, but the following tests conducted at the 95 % level fail, the connection has conformed to the stated assessment level at the 90 % level. If each of the tests conducted at the 90 % level and 95 % level pass, the connection has conformed to the stated assessment level at the 95 % level. See Figures 4 through 7 for the test requirements and test sequence. If a failed 95 %

level test specimen does not allow continuing to the limit load test, a replacement test specimen shall be manufactured to complete the limit load test. For the replacement test specimen, use the specified FMU and bake-out for that specimen; however, sealability testing is not required prior to the limit load test.

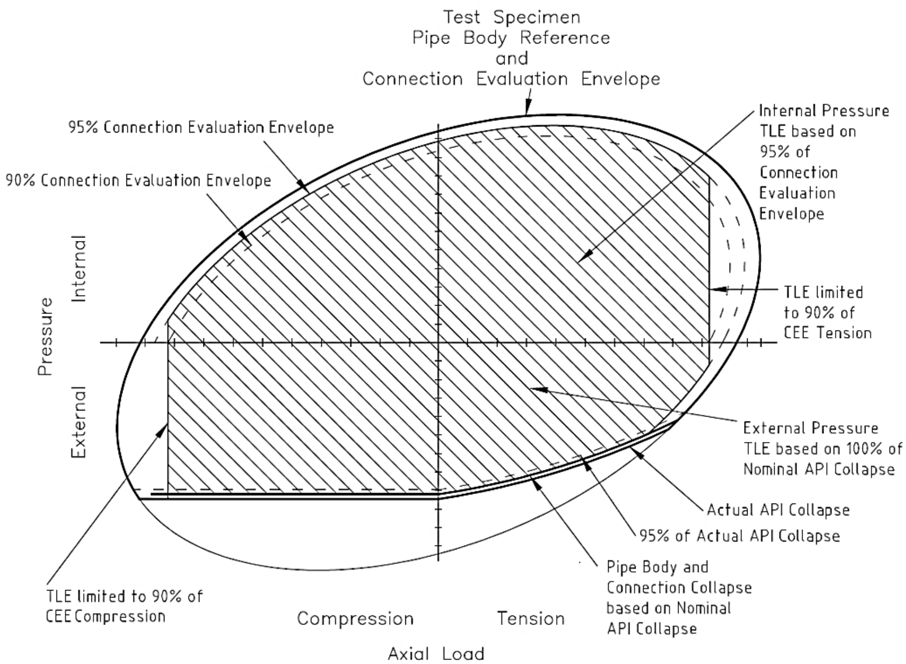


Figure 21—Example of a Test Load Envelope Where Pipe Body Reference Envelope and Connection Evaluation Envelope Are the Same and TLE Based on 95 % of CEE for Internal Pressure and 100 % of Nominal API Collapse for External Pressure

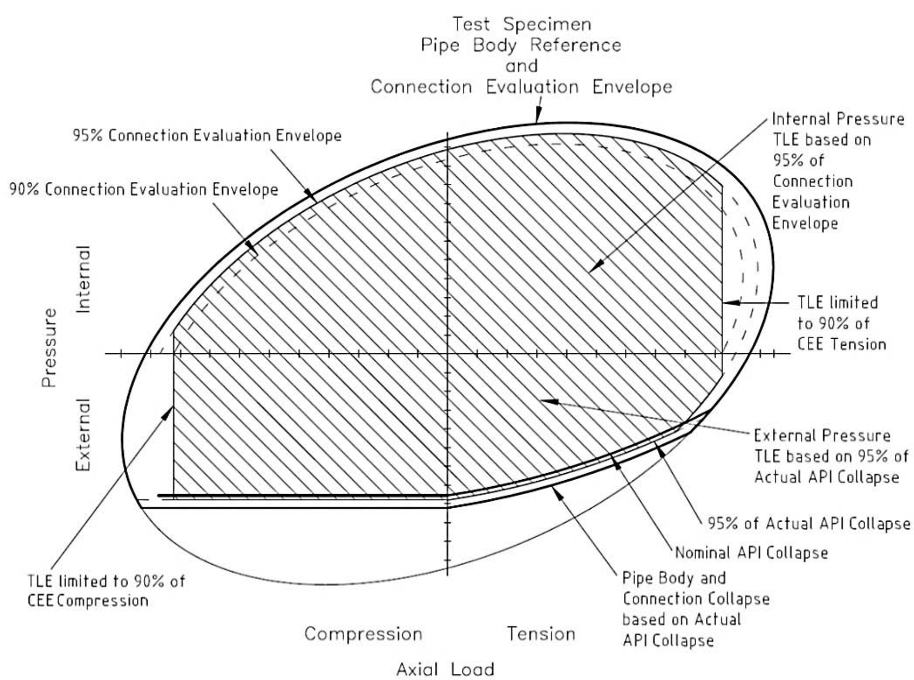


Figure 22—Example of a Test Load Envelope Where Pipe Body Reference Envelope and Connection Evaluation Envelope Are the Same and TLE Based on 95 % of CEE for Internal Pressure and 95 % of Actual API Collapse for External Pressure

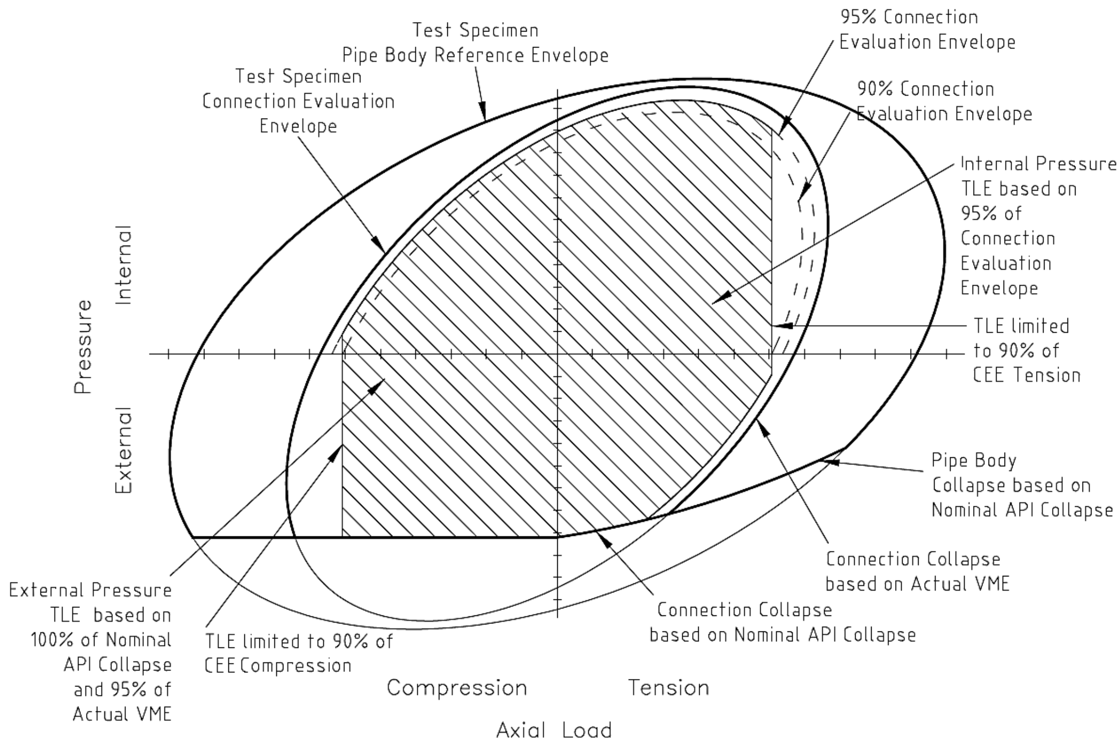


Figure 23—Example of a Test Load Envelope Where Pipe Body Reference Envelope and Connection Evaluation Envelope Are Not the Same and TLE Based on 95 % of CEE for Internal Pressure and a Combination of 100 % of Nominal API Collapse and 95 % of Actual VME for External Pressure

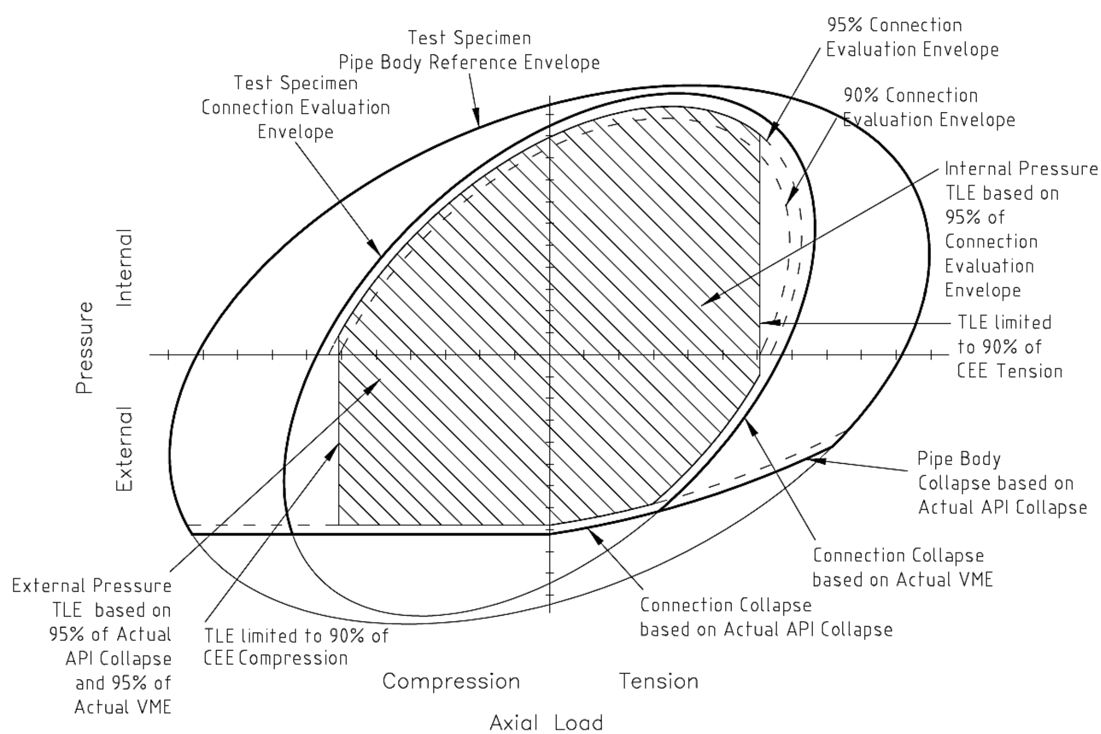


Figure 24—Example of a Test Load Envelope Where the Pipe Body Reference Envelope and the Connection Evaluation Envelope Are Not the Same and TLE Based on 95 % of CEE for Internal Pressure and a Combination of 95 % of Actual API Collapse and 95 % of Actual VME for External Pressure

7.3.2.2 Test Guidelines

The test loads shall be 100 % of the TLE. It is the responsibility of the manufacturer to fully define the CEEs for their product(s). Table 7 provides load point definitions that shall be used to create a test load table for each test series. Annex D may also be referenced to calculate the pipe body reference envelopes.

In combined load testing, the total axial load, F_a, is the sum of the load frame axial load, F_f, plus the bending equivalent axial load, F_b, plus the pressure-induced axial load (if any). In addition to the data required herein, the manufacturer shall record and report other data the manufacturer considers pertinent to these tests. Use Figure B.8 and Figure B.9 to record any leakage during the tests.

A test series shall be accomplished by sequentially progressing row by row through the load steps specified for the test series based on the CAL being conducted and maintaining each load point for the specified hold time. Load points with pressure are intended to validate sealability, so the test hold time begins when specified load, pressure, and temperature have been reached and displacement remains stable throughout the hold period. Load points without pressure and load points with 2-minute holds are considered structural holds; therefore, displacement stabilization is not required. Annex D provides examples of various load schedules for each test series. Pressure sealing acceptance criteria are stated in 8.3.

Testing may be occasionally interrupted at any point in the procedure by removing loads and temperature, for example, an overnight shutdown or equipment repair. Testing shall then resume at the next load step in the procedure after the last successfully completed load step.

Multiple specimens in series may only be tested simultaneously during test series C. When testing in series, the applied axial loads shall be the largest required for each specimen in the series. Calculated pressures shall be applied independently to each specimen based on the axial load applied to achieve the appropriate stress level on each specimen.

Testing shall not be conducted on multiple specimens in series for TS-A and B, as both test series require compressive loads during which it has been demonstrated that connections can be easily overstressed or even destroyed.

Testing in quadrants II and III can require special fixturing to prevent buckling due to potentially high compressive loading.

7.3.2.3 Test Specimen Bake-out

Prior to sealability testing, test specimens shall be subjected to a bake-out at a minimum temperature as specified in Table 1. It is not intended in this RP to perform elevated temperature testing after ambient temperature external pressure testing. However, if any ambient temperature external pressure testing occurs after the initial bake-out, to be followed by additional elevated temperature testing, the test specimen should be subjected to an additional bake-out.

The test specimen shall have thermocouples placed on it as required in 5.10.2. Thermocouples used during the bake-out shall meet or exceed the temperature specified in Table 1. The average temperature shall meet or exceed the temperature specified in Table 1; thermocouples shall be within the specified tolerance band.

Bake-out requirements are as follows.

a) Test specimens on pipe size less than $9^5/_8$ in. OD shall be subjected to a bake-out for a cumulative minimum of 12 hours.

b) Test specimens on pipe size $9^5/_8$ in. OD and larger shall be subjected to a bake-out for a cumulative minimum of 24 hours.

This procedure reduces thread compound de-gassing later that can appear to be a leak and provides worst-case thread compound performance.

For Table 7, if LP 14_a90 TLE^a exceeds 90 % of CEE^a, internal pressure shall be limited to 90 % of CEE^a.

Table 7—Load Point Definitions

Load Point	Test Series			Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Bend	Temp	Test Level
	A	B	C	Axial Point F_a	Pressure Point p_i or p_o	Axial Load F_a	Pressure Load p_i or p_o			
Zero	●	●	●	0	0	0	0		Amb	All
1_a80		●		min(F_t^a,CEE$^a t$)	0	0.67 × LP 1_a80 CEE^a F_a	0		Amb	
2_a80		●				0.80 × LP 4_a80 CEE^a F_a	0.25 × 0.80 × LP 4_a80 CEE^a p_i		Amb	
3_a80		●				0.80 × LP 4_a80 CEE^a F_a	0.50 × 0.80 × LP 4_a80 CEE^a p_i		Amb	
4_a80		●		0.67/0.80 × min(F_t^a,CEE$^a t$)	100 % CEE^a p_i	0.80 × LP 4_a80 CEE^a F_a	0.80 × LP 4_a80 CEE^a p_i		Amb	
5_a80		●		F_{CEPL}	100 % CEE^a p_i	0.80 × LP 5_a80 CEE^a F_a	0.80 × LP 5_a80 CEE^a p_i		Amb	80 %
6_a80		●		0	100 % CEE^a p_i	0	0.80 × LP 6_a80 CEE^a p_i		Amb	
7_a80		●		0.50/0.80 × min(F_c^a,CEE$^a c$)	100 % CEE^a p_i	0.80 × LP 7_a80 CEE^a F_a	0.80 × LP 7_a80 CEE^a p_i		Amb	
8_a80		●				0.80 × LP 7_a80 CEE^a F_a	0.50 × 0.80 × LP 7_a80 CEE^a p_i		Amb	
9_a80		●		min(F_c^a,CEE$^a c$)	0	0.50 × LP 9_a80 CEE^a F_a	0		Amb	
10_a95	●	●		min(F_t^a,CEE$^a t$)	0	0.90 × LP 10_a95 CEE^a F_a	0		Amb	
11_a95		●				0.95 × LP 13_a95 CEE^a F_a	0.25 × 0.95 × LP 13_a95 CEE^a p_i		Amb	
12_a95	●	●				0.95 × LP 13_a95 CEE^a F_a	0.50 × 0.95 × LP 13_a95 CEE^a p_i		Amb	
13_a95	●	●		0.90/0.95 × min(F_t^a,CEE$^a t$)	100 % CEE^a p_i	0.95 × LP 13_a95 CEE^a F_a	0.95 × LP 13_a95 CEE^a p_i	Yes	Amb	
14_a95	●	●		0.80/0.95 × min(F_t^a,CEE$^a t$)	100 % CEE^a p_i	0.95 × LP 14_a95 CEE^a F_a	0.95 × LP 14_a95 CEE^a p_i	Yes	Amb	
15_a95	●	●		F_{CEPL}	100 % CEE^a p_i	0.95 × LP 15_a95 CEE^a F_a	0.95 × LP 15_a95 CEE^a p_i		Amb	
16_a95	●	●		0	100 % CEE^a p_i	0	0.95 × LP 16_a95 CEE^a p_i	Yes	Amb	95 %
17_a95	●	●		0.25/0.95 × min(F_c^a,CEE$^a c$)	100 % CEE^a p_i	0.95 × LP 17_a95 CEE^a F_a	0.95 × LP 17_a95 CEE^a p_i	Yes	Amb	
18_a95	●	●		0.50/0.95 × min(F_c^a,CEE$^a c$)	100 % CEE^a p_i	0.95 × LP 18_a95 CEE^a F_a	0.95 × LP 18_a95 CEE^a p_i	Yes	Amb	
19_a95	●	●		0.75/0.95 × min(F_c^a,CEE$^a c$)	100 % CEE^a p_i	0.95 × LP 19_a95 CEE^a F_a	0.95 × LP 19_a95 CEE^a p_i	Yes	Amb	
20_a95	●	●		0.90/0.95 × min(F_c^a,CEE$^a c$)	100 % CEE^a p_i	0.95 × LP 20_a95 CEE^a F_a	0.95 × LP 20_a95 CEE^a p_i	Yes	Amb	
21_a95	●	●		min(F_c^a,CEE$^a c$)	0	0.90 × LP 21_a95 CEE^a F_a	0		Amb	
22_a95	●			(1) 0.90/A × min(F_c^a,CEE$^a c$)	100 % CEE^a p_o	(1) A × LP 22_a95 CEE^a F_a	(1) A × LP 22_a95 CEE^a p_o		Amb	

Table 7—Load Point Definitions (Continued)

Load Point	Test Series			Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Bend	Temp	Test Level
	A	B	C	Axial Point F_a	Pressure Point p_i or p_o	Axial Load F_a	Pressure Load p_i or p_o			
23_a95	●			(1) 0.50/A × min(F_c ^a^,CEE^a^c)	100 % CEE^a^ p_o	(1) A × LP 23_a95 CEE^a^ F_a	(1) A × LP 23_a95 CEE^a^ p_o		Amb	95 %
24_a95	●			0	100 % CEE^a^ p_o	0	(1) A × LP 24_a95 CEE^a^ p_o		Amb	
25_a95	●			(1) 0.33/A × min(F_t ^a^,CEE^a^t)	100 % CEE^a^ p_o	(1) A × LP 25_a95 CEE^a^ F_a	(1) A × LP 25_a95 CEE^a^ p_o		Amb	
26_a95	●			(1) 0.67/A × min(F_t ^a^,CEE^a^t)	100 % CEE^a^ p_o	(1) A × LP 26_a95 CEE^a^ F_a	(1) A × LP 26_a95 CEE^a^ p_o		Amb	
27_a95	●			(1) 0.90/A × min(F_t ^a^,CEE^a^t)	100 % CEE^a^ p_o	(1) A × LP 27_a95 CEE^a^ F_a	(1) A × LP 27_a95 CEE^a^ p_o		Amb	
10_a90	●	●		min(F_t ^a^,CEE^a^t)	0	0.90 × LP 10_a90 CEE^a^ F_a	0		Amb	90 %
11_a90		●				0.90 × LP 13_a90 CEE^a^ F_a	0.25 × 0.90 × LP 13_a90 CEE^a^ p_i		Amb	
12_a90	●	●				0.90 × LP 13_a90 CEE^a^ F_a	0.50 × 0.90 × LP 13_a90 CEE^a^ p_i		Amb	
13_a90	●	●		0.90/0.90 × min(F_t ^a^,CEE^a^t)	100 % CEE^a^ p_i	0.90 × LP 13_a90 CEE^a^ F_a	0.90 × LP 13_a90 CEE^a^ p_i	Yes	Amb	
14_a90	●	●	●	0.80/0.90 × min(F_t ^a^,CEE^a^t)	100 % CEE^a^ p_i	0.90 × LP 14_a90 CEE^a^ F_a	0.90 × LP 14_a90 CEE^a^ p_i	Yes	Amb	
15_a90	●	●		F_{CEPL}	100 % CEE^a^ p_i	F_{CEPL}	0.90 × LP 15_a90 CEE^a^ p_i		Amb	
16_a90	●	●		0	100 % CEE^a^ p_i	0	0.90 × LP 16_a90 CEE^a^ p_i	Yes	Amb	
17_a90	●	●		0.25/0.90 × min(F_c ^a^,CEE^a^c)	100 % CEE^a^ p_i	0.90 × LP 17_a90 CEE^a^ F_a	0.90 × LP 17_a90 CEE^a^ p_i	Yes	Amb	
18_a90	●	●		0.50/0.90 × min(F_c ^a^,CEE^a^c)	100 % CEE^a^ p_i	0.90 × LP 18_a90 CEE^a^ F_a	0.90 × LP 18_a90 CEE^a^ p_i	Yes	Amb	
19_a90	●	●		0.75/0.90 × min(F_c ^a^,CEE^a^c)	100 % CEE^a^ p_i	0.90 × LP 19_a90 CEE^a^ F_a	0.90 × LP 19_a90 CEE^a^ p_i	Yes	Amb	
20_a90	●	●		0.90/0.90 × min(F_c ^a^,CEE^a^c)	100 % CEE^a^ p_i	0.90 × LP 20_a90 CEE^a^ F_a	0.90 × LP 20_a90 CEE^a^ p_i	Yes	Amb	
21_a90	●	●		min(F_c ^a^,CEE^a^c)	0	0.90 × LP 21_a90 CEE^a^ F_a	0		Amb	
22_a90	●			(2) 0.90/B × min(F_c ^a^,CEE^a^c)	100 % CEE^a^ p_o	(2) B × LP 22_a90 CEE^a^ F_a	(2) B × LP 22_a90 CEE^a^ p_o		Amb	
23_a90	●			(2) 0.50/B × min(F_c ^a^,CEE^a^c)	100 % CEE^a^ p_o	(2) B × LP 23_a90 CEE^a^ F_a	(2) B × LP 23_a90 CEE^a^ p_o		Amb	
24_a90	●			0	100 % CEE^a^ p_o	0	(2) B × LP 24_a90 CEE^a^ p_o		Amb	
25_a90	●			(2) 0.33/B × min(F_t ^a^,CEE^a^t)	100 % CEE^a^ p_o	(2) B × LP 25_a90 CEE^a^ F_a	(2) B × LP 25_a90 CEE^a^ p_o		Amb	
26_a90	●			(2) 0.67/B × min(F_t ^a^,CEE^a^t)	100 % CEE^a^ p_o	(2) B × LP 26_a90 CEE^a^ F_a	(2) B × LP 26_a90 CEE^a^ p_o		Amb	

Table 7—Load Point Definitions (Continued)

Load Point	Test Series			Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Bend	Temp	Test Level
	A	B	C	Axial Point F_a	Pressure Point p_i or p_o	Axial Load F_a	Pressure Load p_i or p_o			
27_a90	●			(2) 0.90/B × min(F_t^a,CEE$^a t$)	100 % CEE^a p_o	(2) B × LP 27_a90 CEE^a F_a	(2) B × LP 27_a90 CEE^a p_o		Amb	
28_a90			●			LP 14_a90 TLE^a F_a – LP 14_a90 F_{CEPL}	0		Amb	
29_a90			●			LP 28_a90 TLE^a F_a + F_{CEPL}	0.20 × LP 14_a90 TLE^a p_i		Amb	
30_a90			●			0.05 × LP 28_a90 TLE^a F_a + F_{CEPL}	(3) LP 14_a90 TLE^a p_i		Amb	
31_a90			●			0.05 × LP 28_a90 TLE^a F_a + F_{CEPL}	0.20 × LP 14_a90 TLE^a p_i		Amb	
13_{Cycle}	●					LP 13_e90 TLE^e F_a + $(K_{150°} – K_{temp})/(1 – K_{temp})$ × (LP 13_a90 TLE^a F_a − LP 13_e90 TLE^e F_a)	LP 13_e90 TLE^e p_i + $(K_{150°} – K_{temp})/(1 – K_{temp})$ × (LP 13_a90 TLE^a p_i − LP 13_e90 TLE^e p_i)		150 °F (65 °C)	
10_e	●	●		min(F_t^e,CEE$^e t$)	0	0.90 × LP 10_e CEE^e F_a	0		Elev	
11_e		●				0.90 × LP 13_e CEE^e F_a	0.25 × 0.90 × LP 13_e CEE^e p_i		Elev	
12_e	●	●				0.90 × LP 13_e CEE^e F_a	0.50 × 0.90 × LP 13_e CEE^e p_i		Elev	90 %
13_e	●	●		0.90/0.90 × min(F_t^e,CEE$^e t$)	100 % CEE^e p_i	0.90 × LP 13_e CEE^e F_a	0.90 × LP 13_e CEE^e p_i	Yes	Elev	
14_e	●	●	●	0.80/0.90 × min(F_t^e,CEE$^e t$)	100 % CEE^e p_i	0.90 × LP 14_e CEE^e F_a	0.90 × LP 14_e CEE^e p_i	Yes	Elev	
15_e	●	●		F_{CEPL}	100 % CEE^e p_i	F_{CEPL}	0.90 × LP 15_e CEE^e p_i		Elev	
16_e	●	●		0	100 % CEE^e p_i	0	0.90 × LP 16_e CEE^e p_i	Yes	Elev	
17_e	●	●		0.25/0.90 × min(F_c^e,CEE$^e c$)	100 % CEE^e p_i	0.90 x LP 17_e CEE^e F_a	0.90 × LP 17_e CEE^e p_i	Yes	Elev	
18_e	●	●		0.50/0.90 × min(F_c^e,CEE$^e c$)	100 % CEE^e p_i	0.90 × LP 18_e CEE^e F_a	0.90 × LP 18_e CEE^e p_i	Yes	Elev	
19_e	●	●		0.75/0.90 × min(F_c^e,CEE$^e c$)	100 % CEE^e p_i	0.90 × LP 19_e CEE^e F_a	0.90 × LP 19_e CEE^e p_i	Yes	Elev	
20_e	●	●		0.90/0.90 × min(F_c^e,CEE$^e c$)	100 % CEE^e p_i	0.90 × LP 20_e CEE^e F_a	0.90 × LP 20_e CEE^e p_i	Yes	Elev	
21_e	●	●		min(F_c^e,CEE$^e c$)	0	0.90 × LP 21_e CEE^e F_a	0		Elev	
22_e	●			(2) 0.90/B × min(F_c^e,CEE$^e c$)	100 % CEE^e p_o	(2) B × LP 22_e CEE^e F_a	(2) B × LP 22_e CEE^e p_o		Elev	

Table 7—Load Point Definitions (Continued)

Load Point	Test Series			Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Bend	Temp	Test Level
	A	B	C	Axial Point F_a	Pressure Point p_i or p_o	Axial Load F_a	Pressure Load p_i or p_o			
23_e	●			(2) 0.50/B × min(F_c^e,CEE$^e c$)	100 % CEE^e p_o	(2) B × LP 23_e CEE^e F_a	(2) B × LP 23_e CEE^e p_o		Elev	
24_e	●			0	100 % CEE^e p_o	0	(2) B × LP 24_e CEE^e p_o		Elev	
25_e	●			(2) 0.33/B × min(F_t^e,CEE$^e t$)	100 % CEE^e p_o	(2) B × LP 25_e CEE^e F_a	(2) B × LP 25_e CEE^e p_o		Elev	90 %
26_e	●			(2) 0.67/B × min(F_t^e,CEE$^e t$)	100 % CEE^e p_o	(2) B × LP 26_e CEE^e F_a	(2) B × LP 26_e CEE^e p_o		Elev	
27_e	●			(2) 0.90/B × min(F_t^e,CEE$^e t$)	100 % CEE^e p_o	(2) B× LP 27_e CEE^e F_a	(2) B × LP 27_e CEE^e p_o		Elev	

NOTE 1 If the external pressure for the CEE^a is determined by the actual API collapse envelope or the external pressure portion of the actual VME envelope, A = 95 %. If the external pressure for the CEE^a is determined by the nominal API collapse envelope or the proprietary high collapse envelope, A = 100 % (no scaling).

NOTE 2 If the external pressure for the CEE^e is determined by the actual API collapse envelope or the external pressure portion of the actual VME envelope, B = 90 %. If the external pressure for the CEE^e is determined by the nominal API collapse envelope or the proprietary high collapse envelope, B = 100 % (no scaling).

7.3.3 TS-A—Tension/Compression and Internal/External Pressure

7.3.3.1 General

The purpose of TS-A is to approximate maximum service conditions and accelerate potential leakage by applying external or internal pressure, and tension or compression. Loading for CAL I and CAL II is at ambient temperature; however, loading is at both ambient and elevated temperature for CAL III and CAL IV.

NOTE Applied bending is not a component of this test series.

7.3.3.2 Principle

TS-A is divided into three parts: (1) elevated temperature (at 90 % level), (2) QI-QIII cycles (at 90 % level), and (3) ambient temperature (at 90 % and/or 95 % level). Testing to the three TS-A parts depends on the CAL selected. For TS-A elevated-temperature testing, load combinations of internal pressure/axial load and external pressure/axial load are applied clockwise and counter-clockwise around the TLE in each of the four quadrants. For TS-A QI-QIII cycle testing, the loads are cycled between QI load point 13_{cycle} at ≤150 °F (65 °C) and QIII load point 22_e at elevated temperature. For TS-A elevated-temperature and QI-QIII cycle testing, ambient methods of leak detection may not be suitable; therefore, pressure drop across the sealing feature is used as the leak-detection method. Ambient temperature leak-detection methods used for TS-A ambient-temperature testing provide the accuracy required to validate sealability, especially post-elevated temperature testing (for CAL III and IV). For TS-A ambient-temperature testing, load combinations of internal pressure/axial load and external pressure/axial load are applied clockwise and counter-clockwise around the TLE in each of the four quadrants.

7.3.3.3 Calculating Test Loads

7.3.3.3.1 Refer to Table 1 and Figures 4 through 7 to determine test specimens requiring TS-A testing. Refer to Table 7 for load point definitions. For CAL III, and CAL IV load steps, refer to Table 8. For CAL I and CAL II load steps, refer to Table 9. Refer to Annex D for an example load schedule. TS-A for CAL I and CAL II has a reduced number of cycles (see Figures 4 and 5, respectively).

7.3.3.3.2 Submit the test specimens to the test procedure below.

a) Determine the TS-A loads at ambient and elevated temperature in accordance with Table 7.

b) Using the calculations in Annex D as an example, determine the axial loads and internal pressure loads for the load points shown in Figure 25 for the 95 % level at ambient temperature, Figure 27 for the 90 % level at ambient temperature, Figure 28 for the 90 % level at elevated temperature, and in Annex D.

c) Perform the tests according to instructions in 5.8 and 5.10, and as shown in Table 8 for CAL III and CAL IV, or Table 9 for CAL I and CAL II, and in Annex D.

d) In CAL IV, when cycling between QIII and QI, the stabilized temperature in QIII shall be 356 °F (180 °C), and the temperature in QI shall be stabilized at no higher than 150 °F (65 °C) and each thermocouple shall be less than 150 °F (65 °C). The QI temperature shall be reported, and the QI loading shall take due account of the effect of the temperature on the yield stress in calculating applied load. If yield stress measurement was not conducted at the stabilized QI temperature, then linear interpolation of yield stress between the values measured at ambient and elevated temperatures is permitted.

e) Report results on Figure B.8, connection sealability test log sheet for TS-A.

f) Evaluate the TS-A TLE by applying the load points represented below and in Figure 25 for the 95 % level at ambient temperature, Figure 27 for the 90 % level at ambient temperature, and Figure 28 for the 90 % level at elevated temperature.

7.3.3.3.3 For Table 8, the following apply.

a) If LP 15_e total tension exceeds LP 14_e total tension, LP 14_e shall be used instead.

b) If LP 15_a90 total tension exceeds LP 14_a90 total tension, LP 14_a90 shall be used instead.

c) If LP15_a95 total tension exceeds LP 14_a95 total tension, LP 14_a95 shall be used instead.

7.3.3.3.4 For Table 9, the following apply.

a) If LP 15_a90 total tension exceeds LP 14_a90 total tension, LP 14_a90 shall be used instead.

b) If LP 15_a95 total tension exceeds LP 14_a95 total tension, LP 14_a95 shall be used instead.

7.3.3.3.5 In Figures 25 to 28, the tension and pressure load combinations that define each numbered load point are defined in Table 7. The order in which the load points are applied during the test and the number of times each load point is applied can be determined from Tables 8 or 9 for a TS-A.

7.3.4 TS-B—Tension/Compression and Internal Pressure

7.3.4.1 General

The purpose of TS-B is to approximate maximum service conditions and accelerate potential leakage by applying internal pressure and tension or compression at elevated and/or ambient temperature, with and without applied bending. Applied bending is planar and results in maximum VME fiber stress bounded by the TLE.

7.3.4.2 Principle

TS-B testing is divided in three parts: (1) ambient temperature without bending (at 80 % and/or 95 % level), (2) elevated temperature with bending (at 90 % level), and (3) ambient temperature with bending (at 90 % and/or 95 % level). Testing to the three TS-B parts depends on the CAL selected. For TS-B, load combinations of internal pressure/axial load are applied clockwise and counter-clockwise around the TLE in QI and QII. Prior to applying bending, the axial load is reduced by a load equivalent to the pipe OD bending stress corresponding to the planned bend load such that the stress levels before and after bending is applied are equivalent.

Table 8—TS-A for CAL III [a] and CAL IV

Load Step	Load Point	Temperature	Hold Time (min)	Direction
1	Zero	Heat-up	—	—
2	10_e	356 °F (180 °C)	2	CCW See Figure 28 (90 % Level)
3	12_e	356 °F (180 °C)	10	
4	13_e	356 °F (180 °C)	10	
5	14_e	356 °F (180 °C)	10	
6	15_e	356 °F (180 °C)	10	
7	16_e	356 °F (180 °C)	60	
8	17_e	356 °F (180 °C)	10	
9	18_e	356 °F (180 °C)	10	
10	19_e	356 °F (180 °C)	10	
11	20_e	356 °F (180 °C)	10[b]	
12	21_e	356 °F (180 °C)	2	
13	Zero	356 °F (180 °C)	—	
Switch from internal pressure to external pressure				
14	21_e	356 °F (180 °C)	2	CCW See Figure 28 (90 % Level)
15	22_e	356 °F (180 °C)	60	
16	23_e	356 °F (180 °C)	10	
17	24_e	356 °F (180 °C)	10	
18	25_e	356 °F (180 °C)	10	
19	26_e	356 °F (180 °C)	10	
20	27_e	356 °F (180 °C)	2	
21	26_e	356 °F (180 °C)	10	CW See Figure 28 (90 % Level)
22	25_e	356 °F (180 °C)	10	
23	24_e	356 °F (180 °C)	60	
24	23_e	356 °F (180 °C)	10	
25	22_e	356 °F (180 °C)	10	
26	21_e	356 °F (180 °C)	2	
27	Zero	356 °F (180 °C)	—	
Switch from external pressure to internal pressure				
28	21_e	356 °F (180 °C)	2	CW See Figure 28 (90 % Level)
29	20_e	356 °F (180 °C)	10[b]	
30	19_e	356 °F (180 °C)	10	
31	18_e	356 °F (180 °C)	60	
32	17_e	356 °F (180 °C)	10	
33	16_e	356 °F (180 °C)	10	
34	15_e	356 °F (180 °C)	10	
35	14_e	356 °F (180 °C)	60	
36	13_e	356 °F (180 °C)	10	
37	12_e	356 °F (180 °C)	10	
38	10_e	356 °F (180 °C)	2	
39	Zero	356 °F (180 °C)	—	

Table 8—TS-A for CAL III [a] and CAL IV (Continued)

Load Step	Load Point	Temperature	Hold Time (min)	Direction
QI-QIII Cycles [a]				
40	13_{Cycle}	≤150 °F (65 °C)	15	Cycle [a] (90 % Level)
41	22_{e}	356 °F (180 °C)	15	
42	13_{Cycle}	≤150 °F (65 °C)	15	
43	22_{e}	356 °F (180 °C)	15	
44	13_{Cycle}	≤150 °F (65 °C)	15	
45	22_{e}	356 °F (180 °C)	15	
46	13_{Cycle}	≤150 °F (65 °C)	15	
47	22_{e}	356 °F (180 °C)	15	
48	13_{Cycle}	≤150 °F (65 °C)	15	
49	22_{e}	356 °F (180 °C)	15	
50	Zero	356 °F (180 °C)	—	
End of QI-QIII Cycles				
51	Zero	Cooldown	—	—
52	$10_{a}90$	Ambient	2	CCW See Figure 27 (90 % Level)
53	$12_{a}90$	Ambient	10	
54	$13_{a}90$	Ambient	10	
55	$14_{a}90$	Ambient	10	
56	$15_{a}90$	Ambient	10	
57	$16_{a}90$	Ambient	60	
58	$17_{a}90$	Ambient	10	
59	$18_{a}90$	Ambient	10	
60	$19_{a}90$	Ambient	10	
61	$20_{a}90$	Ambient	10[b]	
62	$21_{a}90$	Ambient	2	
63	Zero	Ambient	—	
Switch from internal pressure to external pressure				
64	$21_{a}90$	Ambient	2	CCW See Figure 27 (90 % Level)
65	$22_{a}90$	Ambient	60	
66	$23_{a}90$	Ambient	10	
67	$24_{a}90$	Ambient	10	
68	$25_{a}90$	Ambient	10	
69	$26_{a}90$	Ambient	10	
70	$27_{a}90$	Ambient	2	
71	$26_{a}90$	Ambient	10	CW See Figure 27 (90 % Level)
72	$25_{a}90$	Ambient	10	
73	$24_{a}90$	Ambient	60	
74	$23_{a}90$	Ambient	10	
75	$22_{a}90$	Ambient	10	
76	$21_{a}90$	Ambient	2	
77	Zero	Ambient	—	

Table 8—TS-A for CAL III[a] and CAL IV (Continued)

Load Step	Load Point	Temperature	Hold Time (min)	Direction
Switch from external pressure to internal pressure				
78	21_a90	Ambient	2	CW See Figure 27 (90 % Level)
79	20_a90	Ambient	10[b]	
80	19_a90	Ambient	10	
81	18_a90	Ambient	60	
82	17_a90	Ambient	10	
83	16_a90	Ambient	10	
84	15_a90	Ambient	10	
85	14_a90	Ambient	60	
86	13_a90	Ambient	10	
87	12_a90	Ambient	10	
88	10_a90	Ambient	2	
89	Zero	Ambient	—	
90	10_a95	Ambient	2	CCW See Figure 25 (95 % Level)
91	12_a95	Ambient	10	
92	13_a95	Ambient	10	
93	14_a95	Ambient	10	
94	15_a95	Ambient	10	
95	16_a95	Ambient	60	
96	17_a95	Ambient	10	
97	18_a95	Ambient	10	
98	19_a95	Ambient	10	
99	20_a95	Ambient	10	
100	21_a95	Ambient	2	
101	Zero	Ambient	—	
Switch from internal pressure to external pressure				
102	21_a95	Ambient	2	CCW See Figure 25 (95 % Level)
103	22_a95	Ambient	60	
104	23_a95	Ambient	10	
105	24_a95	Ambient	10	
106	25_a95	Ambient	10	
107	26_a95	Ambient	10	
108	27_a95	Ambient	2	
109	26_a95	Ambient	10	CW See Figure 25 (95 % Level)
110	25_a95	Ambient	10	
111	24_a95	Ambient	60	
112	23_a95	Ambient	10	
113	22_a95	Ambient	10	
114	21_a95	Ambient	2	
115	Zero	Ambient	—	

Table 8—TS-A for CAL III [a] and CAL IV (Continued)

Load Step	Load Point	Temperature	Hold Time (min)	Direction
Switch from external pressure to internal pressure				
116	$21_{a}95$	Ambient	2	CW See Figure 25 (95 % Level)
117	$20_{a}95$	Ambient	10	
118	$19_{a}95$	Ambient	10	
119	$18_{a}95$	Ambient	60	
120	$17_{a}95$	Ambient	10	
121	$16_{a}95$	Ambient	10	
122	$15_{a}95$	Ambient	10	
123	$14_{a}95$	Ambient	60	
124	$13_{a}95$	Ambient	10	
125	$12_{a}95$	Ambient	10	
126	$10_{a}95$	Ambient	2	
127	Zero	Ambient	—	

[a] For CAL III, load steps 40 to 50 are not performed.

[b] If there is no pressure for this Load Point, the hold time may be reduced to 2 minutes.

Table 9—TS-A for CAL I [a] and II

Load Step	Load Point	Temperature	Hold Time (min)	Direction
1	Zero	Ambient	—	CCW [a] See Figure 27 (90 % Level)
2	$10_{a}90$	Ambient	2	
3	$12_{a}90$	Ambient	10	
4	$13_{a}90$	Ambient	10	
5	$14_{a}90$	Ambient	60	
6	$15_{a}90$	Ambient	10	
7	$16_{a}90$	Ambient	10	
8	$17_{a}90$	Ambient	10	
9	$18_{a}90$	Ambient	30	
10	$19_{a}90$	Ambient	10	
11	$20_{a}90$	Ambient	10 [b]	
12	$21_{a}90$	Ambient	2	
13	Zero	Ambient	—	
Switch from internal pressure to external				
14	$21_{a}90$	Ambient	2	CCW [a] See Figure 27 (90 % Level)
15	$22_{a}90$	Ambient	30	
16	$23_{a}90$	Ambient	10	
17	$24_{a}90$	Ambient	10	
18	$25_{a}90$	Ambient	10	
19	$26_{a}90$	Ambient	10	
20	$27_{a}90$	Ambient	2	

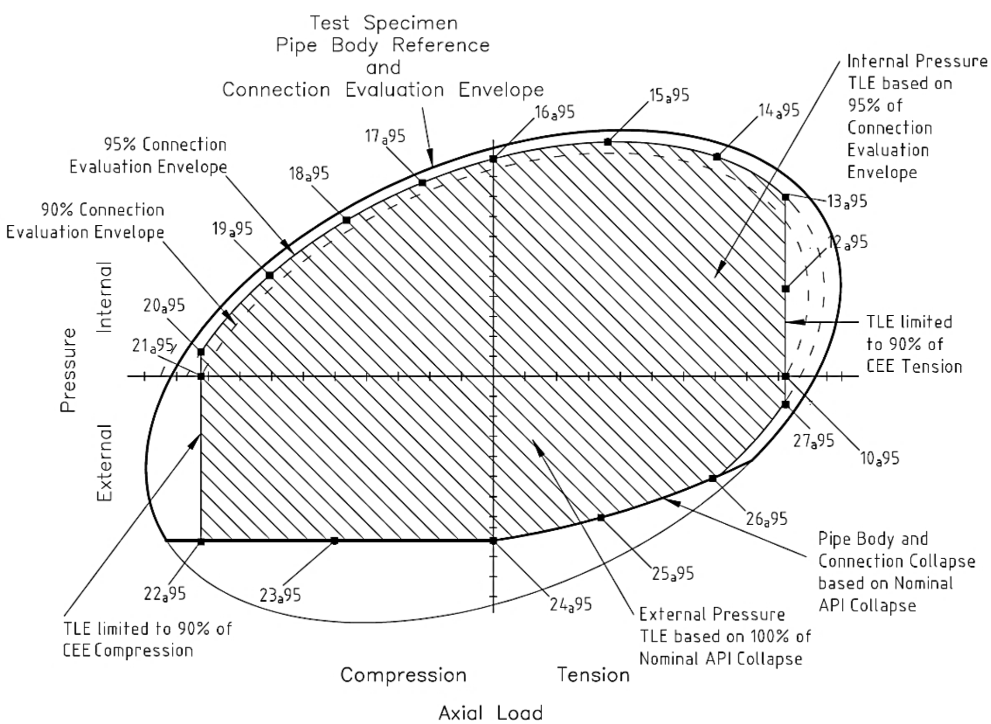
Table 9—TS-A for CAL I [a] and II (Continued)

Load Step	Load Point	Temperature	Hold Time (min)	Direction
21	26_a90	Ambient	15	CW [a] See Figure 27 (90 % Level)
22	25_a90	Ambient	15	
23	24_a90	Ambient	60	
24	23_a90	Ambient	15	
25	22_a90	Ambient	15	
26	21_a90	Ambient	2	
27	Zero	Ambient	—	
Switch from external pressure to internal				
28	21_a90	Ambient	2	CW [a] See Figure 27 (90 % Level)
29	20_a90	Ambient	10 [b]	
30	19_a90	Ambient	10	
31	18_a90	Ambient	60	
32	17_a90	Ambient	10	
33	16_a90	Ambient	10	
34	15_a90	Ambient	10	
35	14_a90	Ambient	60	
36	13_a90	Ambient	10	
37	12_a90	Ambient	10	
38	10_a90	Ambient	2	
39	Zero	Ambient	—	
40	10_a95	Ambient	2	CCW See Figure 25 (95 % Level)
41	12_a95	Ambient	10	
42	13_a95	Ambient	10	
43	14_a95	Ambient	60	
44	15_a95	Ambient	10	
45	16_a95	Ambient	10	
46	17_a95	Ambient	10	
47	18_a95	Ambient	30	
48	19_a95	Ambient	10	
49	20_a95	Ambient	10	
50	21_a95	Ambient	2	
51	Zero	Ambient	—	
Switch from internal pressure to external				
52	21_a95	Ambient	2	CCW See Figure 25 (95 % Level)
53	22_a95	Ambient	30	
54	23_a95	Ambient	10	
55	24_a95	Ambient	10	
56	25_a95	Ambient	10	
57	26_a95	Ambient	10	
58	27_a95	Ambient	2	

Table 9—TS-A for CAL I [a] and II (Continued)

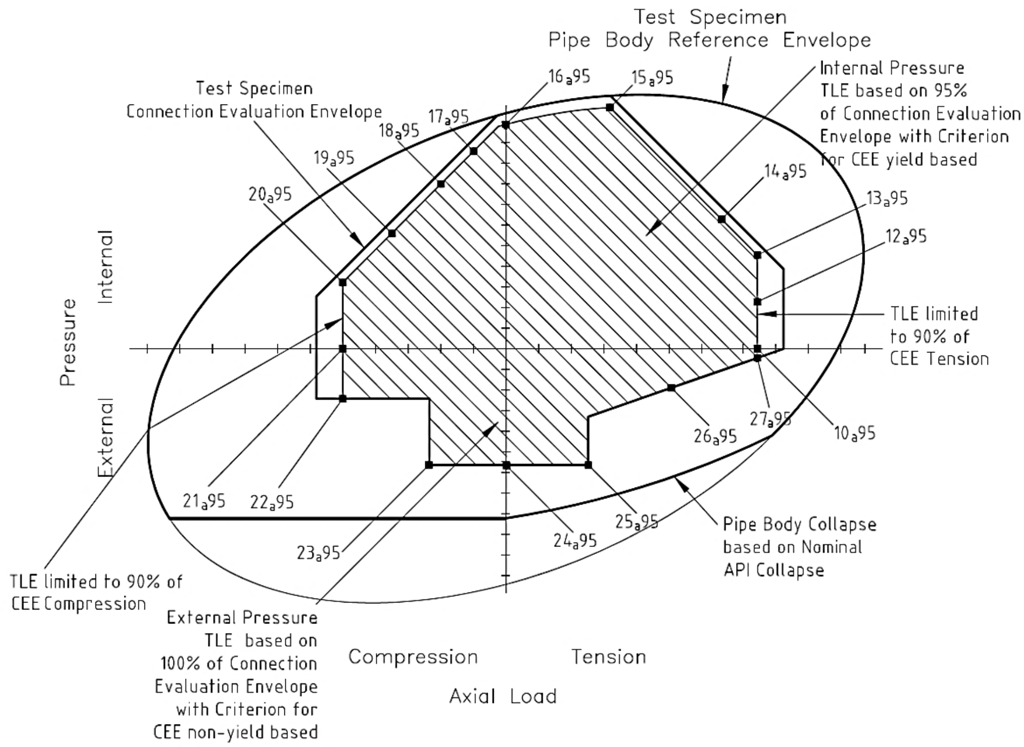
Load Step	Load Point	Temperature	Hold Time (min)	Direction
59	26_a95	Ambient	15	CW See Figure 25 (95 % Level)
60	25_a95	Ambient	15	
61	24_a95	Ambient	60	
62	23_a95	Ambient	15	
63	22_a95	Ambient	15	
64	21_a95	Ambient	2	
65	Zero	Ambient	—	
Switch from external pressure to internal				
66	21_a95	Ambient	2	CW See Figure 25 (95 % Level)
67	20_a95	Ambient	10	
68	19_a95	Ambient	10	
69	18_a95	Ambient	60	
70	17_a95	Ambient	10	
71	16_a95	Ambient	10	
72	15_a95	Ambient	10	
73	14_a95	Ambient	60	
74	13_a95	Ambient	10	
75	12_a95	Ambient	10	
76	10_a95	Ambient	2	
77	Zero	Ambient	—	

a Load steps 1 to 39 are not performed for CAL I.
b If there is no pressure for this load point, the hold time may be reduced to 2 minutes.



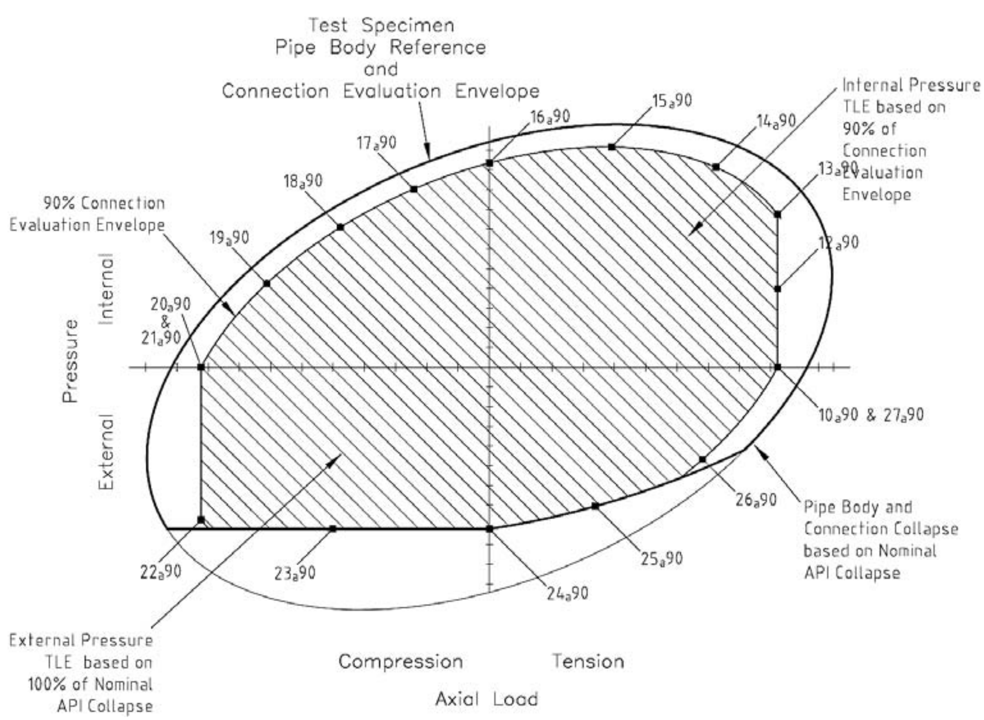
NOTE See Table 8, load steps 90 to 127 and Table 9, load steps 40 to 77.

Figure 25—Example of Ambient Temperature TS-A Load Points at 95 % of the CEE Where the Pipe Body Reference Envelope and Connection Evaluation Envelope Are the Same, with Tension and Compression Limited to 90 % of the CEE



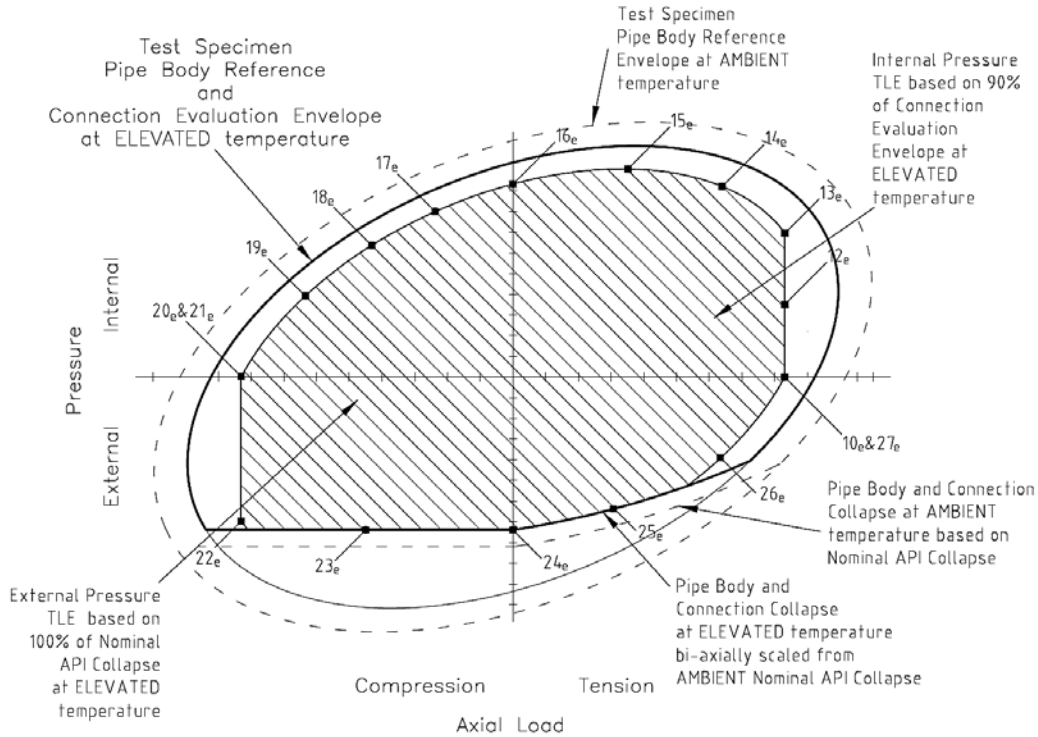
NOTE See Table 8, load steps 90 to 127 and Table 9, load steps 40 to 77.

Figure 26—Example of Ambient Temperature TS-A Load Points at 95 % of the CEE for Internal Pressure and 100 % of the CEE for External Pressure Where the Pipe Body Reference Envelope and Connection Evaluation Envelope Are Not the Same, with Tension and Compression Limited to 90 % of the CEE



NOTE See Table 8, load steps 51 to 89 and Table 9, load steps 1 to 39.

Figure 27—Example of Ambient Temperature TS-A Load Points at 90 % of the CEE Where the Pipe Body Reference Envelope and Connection Evaluation Envelope Are the Same



NOTE See Table 8, load steps 1 to 39.

Figure 28—Example of Elevated Temperature TS-A Load Points at 90 % of the CEE Where the Pipe Body Reference Envelope and Connection Evaluation Envelope Are the Same

7.3.4.3 Calculating Test Loads

7.3.4.3.1 General

Submit the connection test specimens to the procedure below. Refer to Table 1 and Figures 4 through 7 for test specimens requiring TS-B testing. Refer to Table 7 for load point definitions. For TS-B CAL II, CAL III, and CAL IV load steps, refer to Table 10. For TS-B CAL I load steps, refer to Table 11. For test specimens in CAL II, CAL III, and CAL IV that do not require TS-A, refer to Table 12 for additional TS-B load steps. Refer to Annex D for an example load schedule. Note that for CAL I, CAL II, CAL III, and CAL IV, bending is normative.

a) Determine the TS-B loads at ambient and at elevated temperature in accordance with Table 7 above.

   Determine the equivalent axial tension and compression loads due to bending. Reduce frame load for the load point by the equivalent axial tension or compression load prior to applying the bending. The sum of the applied loads (pressure end load F_{CEPL}, bend load F_b, and frame load F_i) shall equal the desired load, F_a, for the load point. Reduce the bend to zero prior to moving to the next load point. Verify VME stress at the inner and outer fiber. In the event the VME stress exceeds 90 % or 95 % (whichever applies) of the applicable material yield strength, reduce bending or axial loads to obtain a stress equal to 90 % or 95 % (whichever applies) of the applicable material yield strength. When bending is used, use the lesser of:

   1) a dogleg of 20°/100 ft,

   2) 40 % of the pipe body bending yield strength,

   3) 40 % of the connection bending yield strength, or

4) total VME stress not to exceed 90 % or 95 % (whichever applies) of the applicable material yield strength in accordance with 5.5.2.

b) For CAL I, using the calculations in Annex D as an example, determine the axial loads and internal pressure loads for the load points shown in Figures 29 and 30 for the 95 % level at ambient temperature.

c) For CAL II, CAL III, and CAL IV, using the calculations in Annex D as an example, determine the axial loads and internal pressure loads for the load points shown in Figures 29 and 30 for the 95 % level at ambient temperature, Figure 31 for the 90 % level at ambient temperature, and Figure 32 for the 90 % level at elevated temperature.

d) Perform the tests according to instructions in 5.7 and 5.10, and control bending with selected method indicated in 5.9.3.4 and as shown in Table 10 for CAL II, CAL III, and CAL IV, Table 11 for CAL I, and Table 12 for CAL II and CAL III (for test specimens that do not require TS-A).

e) Report results on Figure B.8, connection sealability test log sheet for TS-B.

NOTE Pipe sizes >$9^5/_8$ in. (244.48 mm) may be limited by the 40 % of connection yield strength criteria.

7.3.4.3.2 For Table 10, the following apply.

a) If LP 5_a80 total tension exceeds LP 4_a80 total tension, LP 4_a80 shall be used instead.

b) If LP 15_a95 total tension exceeds LP 14_a95 total tension, LP 14_a95 shall be used instead.

c) If LP 15_e total tension exceeds LP 14_e total tension, LP 14_e shall be used instead.

d) If LP 15_a90 total tension exceeds LP 14_a90 total tension, LP 14_a90 shall be used instead.

7.3.4.3.3 For Table 11, the following apply.

a) If LP 5_a80 total tension exceeds LP 4_a80 total tension, LP 4_a80 shall be used instead.

b) If LP 15_a95 total tension exceeds LP 14_a95 total tension, LP 14_a95 shall be used instead.

c) If LP 15_e total tension exceeds LP 14_e total tension, LP 14_e shall be used instead.

d) If LP 15_a90 total tension exceeds LP 14_a90 total tension, LP 14_a90 shall be used instead.

7.3.4.3.4 For Table 12, the following apply.

a) If LP 15_a95 total tension exceeds LP 14_a95 total tension, LP 14_a95 shall be used instead.

b) If LP 15_e total tension exceeds LP 14_e total tension, LP 14_e shall be used instead.

c) If LP 15_a90 total tension exceeds LP 14_a90 total tension, LP 14_a90 shall be used instead.

7.3.4.3.5 In Figures 29 to 32, the tension and pressure load combinations that define each numbered load point are defined in Table 7. The order in which the load points are applied during the test and the number of times each load point is applied can be determined from Tables 11, 12, or 13 for a TS-B.

Table 10—TS-B—CAL II, CAL III, and CAL IV

Load Step	Load Point	Bending	Temperature		Hold Time (min)	Direction
			CAL II	CAL III & IV		
1	1_a80	—	Ambient	Ambient	2	CCW See Figure 29 (80 % Level)
2	2_a80	—	Ambient	Ambient	2	
3	3_a80	—	Ambient	Ambient	2	
4	4_a80	—	Ambient	Ambient	2	
5	5_a80	—	Ambient	Ambient	2	
6	6_a80	—	Ambient	Ambient	2	
7	7_a80	—	Ambient	Ambient	2	
8	8_a80	—	Ambient	Ambient	2	
9	9_a80	—	Ambient	Ambient	2	
10	Zero	—	Ambient	Ambient	—	
11	10_a95	—	Ambient	Ambient	2	CCW See Figure 29 (95 % Level)
12	11_a95	—	Ambient	Ambient	5	
13	12_a95	—	Ambient	Ambient	5	
14	13_a95	—	Ambient	Ambient	5	
15	14_a95	—	Ambient	Ambient	5	
16	15_a95	—	Ambient	Ambient	5	
17	16_a95	—	Ambient	Ambient	5	
18	17_a95	—	Ambient	Ambient	5	
19	18_a95	—	Ambient	Ambient	5	
20	19_a95	—	Ambient	Ambient	5	
21	20_a95	—	Ambient	Ambient	5	
22	21_a95	—	Ambient	Ambient	2	
23	20_a95	—	Ambient	Ambient	5	CW See Figure 29 (95 % Level)
24	19_a95	—	Ambient	Ambient	5	
25	18_a95	—	Ambient	Ambient	5	
26	17_a95	—	Ambient	Ambient	5	
27	16_a95	—	Ambient	Ambient	5	
28	15_a95	—	Ambient	Ambient	5	
29	14_a95	—	Ambient	Ambient	5	
30	13_a95	—	Ambient	Ambient	5	
31	12_a95	—	Ambient	Ambient	5	
32	11_a95	—	Ambient	Ambient	5	
33	10_a95	—	Ambient	Ambient	2	

Table 10—TS-B—CAL II, CAL III, and CAL IV (Continued)

Load Step	Load Point	Bending	Temperature		Hold Time (min)	Direction
			CAL II	CAL III & IV		
34	Zero	—	Heat-up		—	—
35	10_e	—	275 °F (135 °C)	356 °F (180 °C)	2	CCW See Figure 32 (90 % Level)
36	11_e	—	275 °F (135 °C)	356 °F (180 °C)	5	
37	12_e	—	275 °F (135 °C)	356 °F (180 °C)	5	
38	13_e	—	275 °F (135 °C)	356 °F (180 °C)	15	
39	$13b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	15	
40	14_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
41	$14b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	60	
42	15_e	—	275 °F (135 °C)	356 °F (180 °C)	15	
43	16_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
44	$16b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10	
45	17_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
46	$17b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10	
47	18_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
48	$18b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10	
49	19_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
50	$19b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10	
51	20_e	—	275 °F (135 °C)	356 °F (180 °C)	10[a]	
52	$20b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10[b]	
53	21_e	—	275 °F (135 °C)	356 °F (180 °C)	2	
54	$20b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10[b]	CW See Figure 32 (90 % Level)
55	20_e	—	275 °F (135 °C)	356 °F (180 °C)	10[a]	
56	$19b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10	
57	19_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
58	$18b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	60	
59	18_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
60	$17b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10	
61	17_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
62	$16b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10	
63	16_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
64	15_e	—	275 °F (135 °C)	356 °F (180 °C)	15	
65	$14b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	10	
66	14_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
67	$13b_e$	Yes	275 °F (135 °C)	356 °F (180 °C)	60	
68	13_e	—	275 °F (135 °C)	356 °F (180 °C)	10	
69	12_e	—	275 °F (135 °C)	356 °F (180 °C)	5	
70	11_e	—	275 °F (135 °C)	356 °F (180 °C)	5	
71	10_e	—	275 °F (135 °C)	356 °F (180 °C)	2	

Table 10—TS-B—CAL II, CAL III, and CAL IV (Continued)

Load Step	Load Point	Bending	Temperature		Hold Time (min)	Direction
			CAL II	CAL III & IV		
72	Zero	—	Cooldown		—	
73	10_a90	—	Ambient	Ambient	2	CCW See Figure 31 (90 % Level)
74	11_a90	—	Ambient	Ambient	5	
75	12_a90	—	Ambient	Ambient	5	
76	13_a90	—	Ambient	Ambient	10	
77	$13b_a90$	Yes	Ambient	Ambient	10	
78	14_a90	—	Ambient	Ambient	10	
79	$14b_a90$	Yes	Ambient	Ambient	10	
80	15_a90	—	Ambient	Ambient	60	
81	16_a90	—	Ambient	Ambient	10	
82	$16b_a90$	Yes	Ambient	Ambient	10	
83	17_a90	—	Ambient	Ambient	10	
84	$17b_a90$	Yes	Ambient	Ambient	10	
85	18_a90	—	Ambient	Ambient	10	
86	$18b_a90$	Yes	Ambient	Ambient	10	
87	19_a90	—	Ambient	Ambient	10	
88	$19b_a90$	Yes	Ambient	Ambient	10	
89	20_a90	—	Ambient	Ambient	10[a]	
90	$20b_a90$	Yes	Ambient	Ambient	60[b]	
91	21_a90	—	Ambient	Ambient	2	
92	$20b_a90$	Yes	Ambient	Ambient	10[b]	
93	20_a90	—	Ambient	Ambient	10[a]	
94	$19b_a90$	Yes	Ambient	Ambient	10	CW See Figure 31 (90 % Level)
95	19_a90	—	Ambient	Ambient	10	
96	$18b_a90$	Yes	Ambient	Ambient	10	
97	18_a90	—	Ambient	Ambient	10	
98	$17b_a90$	Yes	Ambient	Ambient	10	
99	17_a90	—	Ambient	Ambient	10	
100	$16b_a90$	Yes	Ambient	Ambient	60	
101	16_a90	—	Ambient	Ambient	10	
102	15_a90	—	Ambient	Ambient	10	
103	$14b_a90$	Yes	Ambient	Ambient	10	
104	14_a90	—	Ambient	Ambient	10	
105	$13b_a90$	Yes	Ambient	Ambient	10	
106	13_a90	—	Ambient	Ambient	10	
107	12_a90	—	Ambient	Ambient	5	
108	11_a90	—	Ambient	Ambient	5	
109	10_a90	—	Ambient	Ambient	2	
110	Zero	—	Ambient	Ambient	—	

[a] If there is no pressure for this load point, the hold time may be reduced to 2 minutes.
[b] If there is no pressure for this load point, the hold time may be reduced to 5 minutes.
[c] The order of the load points with and without bending may be switched so that the uni-axial load point may be applied before application of bending.

Table 11—TS-B for CAL I

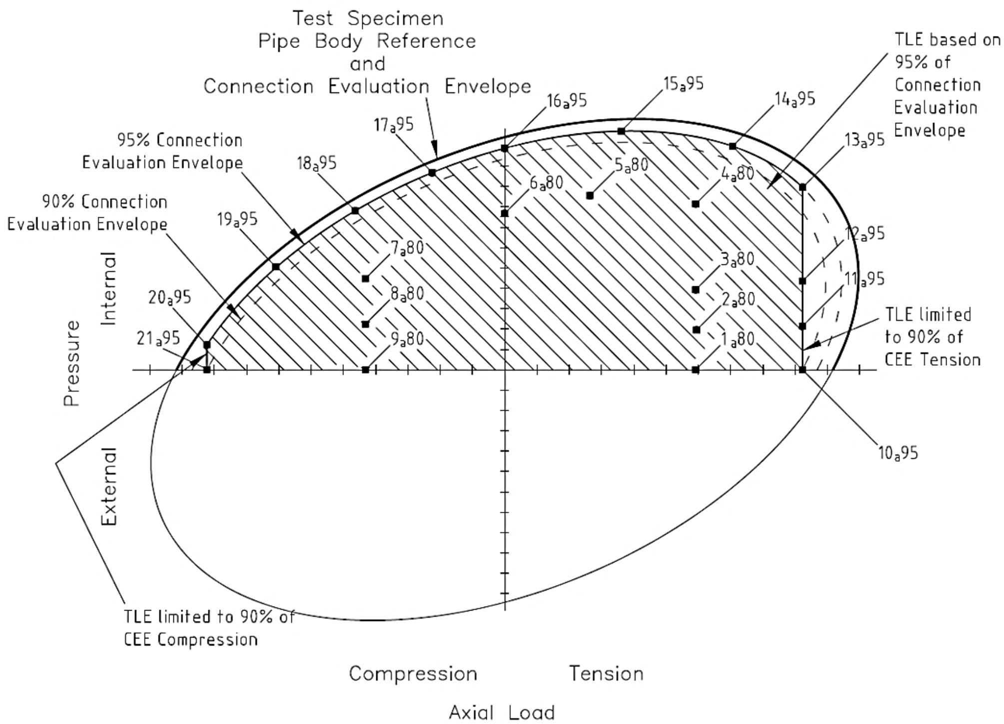
Load Step	Load Point	Bending	Temperature	Hold Time (min)	Direction
1	1_a80	—	Ambient	2	CCW See Figure 29 (80 % Level)
2	2_a80	—	Ambient	2	
3	3_a80	—	Ambient	2	
4	4_a80	—	Ambient	2	
5	5_a80	—	Ambient	2	
6	6_a80	—	Ambient	2	
7	7_a80	—	Ambient	2	
8	8_a80	—	Ambient	2	
9	9_a80	—	Ambient	2	
10	Zero	—	Ambient	—	
11	10_a95	—	Ambient	2	CCW See Figure 29 (95 % Level)
12	11_a95	—	Ambient	5	
13	12_a95	—	Ambient	5	
14	13_a95	—	Ambient	5	
15	14_a95	—	Ambient	5	
16	15_a95	—	Ambient	5	
17	16_a95	—	Ambient	5	
18	17_a95	—	Ambient	5	
19	18_a95	—	Ambient	5	
20	19_a95	—	Ambient	5	
21	20_a95	—	Ambient	5	
22	21_a95	—	Ambient	2	
23	20_a95	—	Ambient	5	CW See Figure 29 (95 % Level)
24	19_a95	—	Ambient	5	
25	18_a95	—	Ambient	5	
26	17_a95	—	Ambient	5	
27	16_a95	—	Ambient	5	
28	15_a95	—	Ambient	5	
29	14_a95	—	Ambient	5	
30	13_a95	—	Ambient	5	
31	12_a95	—	Ambient	5	
32	11_a95	—	Ambient	5	
33	10_a95	—	Ambient	2	
34	Zero	—	Ambient	—	

Table 11—TS-B for CAL I (Continued)

Load Step	Load Point	Bending	Temperature	Hold Time (min)	Direction
35	10$_a$95	—	Ambient	2	CCW See Figure 30 (95 % Level)
36	11$_a$95	—	Ambient	5	
37	12$_a$95	—	Ambient	5	
38	13$_a$95	—	Ambient	15	
39	13b$_a$95	Yes	Ambient	15	
40	14$_a$95	—	Ambient	10	
41	14b$_a$95	Yes	Ambient	60	
42	15$_a$95	—	Ambient	15	
43	16$_a$95	—	Ambient	10	
44	16b$_a$95	Yes	Ambient	10	
45	17$_a$95	--	Ambient	10	
46	17b$_a$95	Yes	Ambient	10	
47	18$_a$95	—	Ambient	10	CCW See Figure 30 (95 % Level)
48	18b$_a$95	Yes	Ambient	10	
49	19$_a$95	—	Ambient	10	
50	19b$_a$95	Yes	Ambient	10	
51	20$_a$95	—	Ambient	10	
52	20b$_a$95	Yes	Ambient	10	
53	21$_a$95	—	Ambient	2	
54	20b$_a$95	Yes	Ambient	10	CW See Figure 30 (95 % Level)
55	20$_a$95	—	Ambient	10	
56	19b$_a$95	Yes	Ambient	10	
57	19$_a$95	—	Ambient	10	
58	18b$_a$95	Yes	Ambient	60	
59	18$_a$95	—	Ambient	60	
60	17b$_a$95	Yes	Ambient	10	
61	17$_a$95	—	Ambient	10	
62	16b$_a$95	Yes	Ambient	10	
63	16$_a$95	—	Ambient	10	
64	15$_a$95	—	Ambient	10	
65	14b$_a$95	Yes	Ambient	10	
66	14$_a$95	—	Ambient	10	
67	13b$_a$95	Yes	Ambient	60	
68	13$_a$95	—	Ambient	10	
69	12$_a$95	—	Ambient	5	
70	11$_a$95	—	Ambient	5	
71	10$_a$95	—	Ambient	2	
72	Zero	—	Ambient	—	

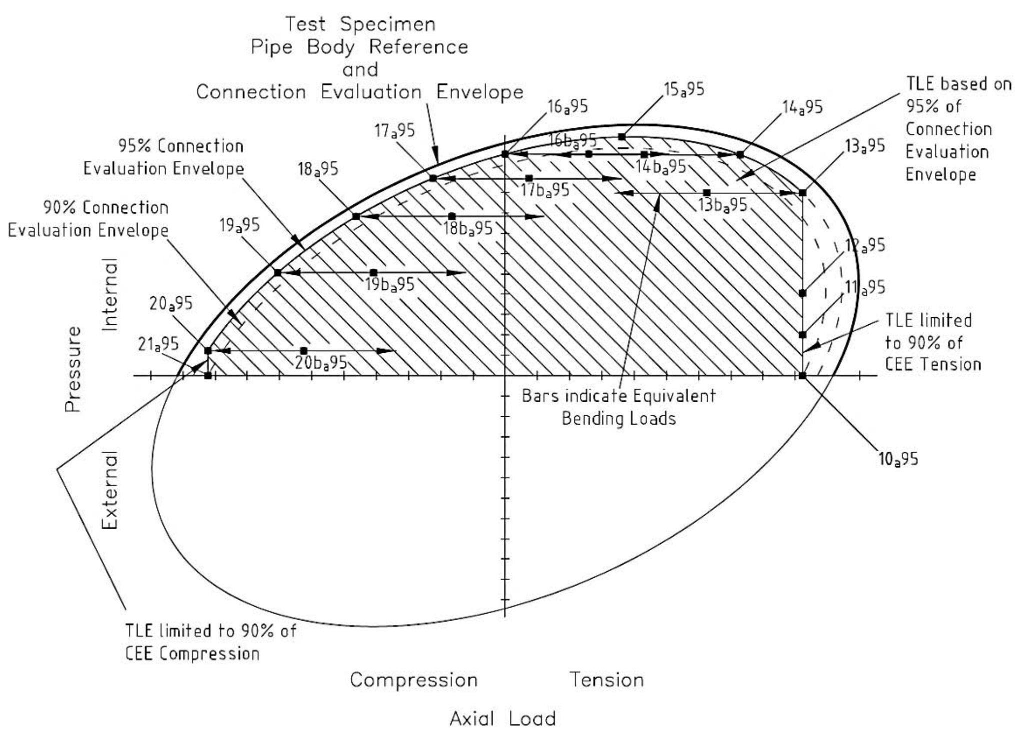
Table 12—TS-B Additional Requirements for CAL II and CAL III (for Test Specimens that Do Not Require TS-A)

Load Step	Load Point	Bending	Temperature	Hold Time (min)	Direction
1	10_a95	—	Ambient	2	CCW See Figure 30 (95 % Level)
2	11_a95	—	Ambient	5	
3	12_a95	—	Ambient	5	
4	13_a95	—	Ambient	15	
5	$13b_a95$	Yes	Ambient	15	
6	14_a95	—	Ambient	10	
7	$14b_a95$	Yes	Ambient	60	
8	15_a95	—	Ambient	15	
9	16_a95	—	Ambient	10	
10	$16b_a95$	Yes	Ambient	10	
11	17_a95	--	Ambient	10	
12	$17b_a95$	Yes	Ambient	10	
13	18_a95	—	Ambient	10	
14	$18b_a95$	Yes	Ambient	10	
15	19_a95	—	Ambient	10	
16	$19b_a95$	Yes	Ambient	10	
17	20_a95	—	Ambient	10	
18	$20b_a95$	Yes	Ambient	10	
19	21_a95	—	Ambient	2	
20	$20b_a95$	Yes	Ambient	10	CW See Figure 30 (95 % Level)
21	20_a95	—	Ambient	10	
22	$19b_a95$	Yes	Ambient	10	
23	19_a95	—	Ambient	10	
24	$18b_a95$	Yes	Ambient	60	
25	18_a95	—	Ambient	60	
26	$17b_a95$	Yes	Ambient	10	
27	17_a95	—	Ambient	10	
28	$16b_a95$	Yes	Ambient	10	
29	16_a95	—	Ambient	10	
30	15_a95	—	Ambient	10	
31	$14b_a95$	Yes	Ambient	10	
32	14_a95	—	Ambient	10	
33	$13b_a95$	Yes	Ambient	60	
34	13_a95	—	Ambient	10	
35	12_a95	—	Ambient	5	
36	11_a95	—	Ambient	5	
37	10_a95	—	Ambient	2	
38	Zero	—	Ambient	—	



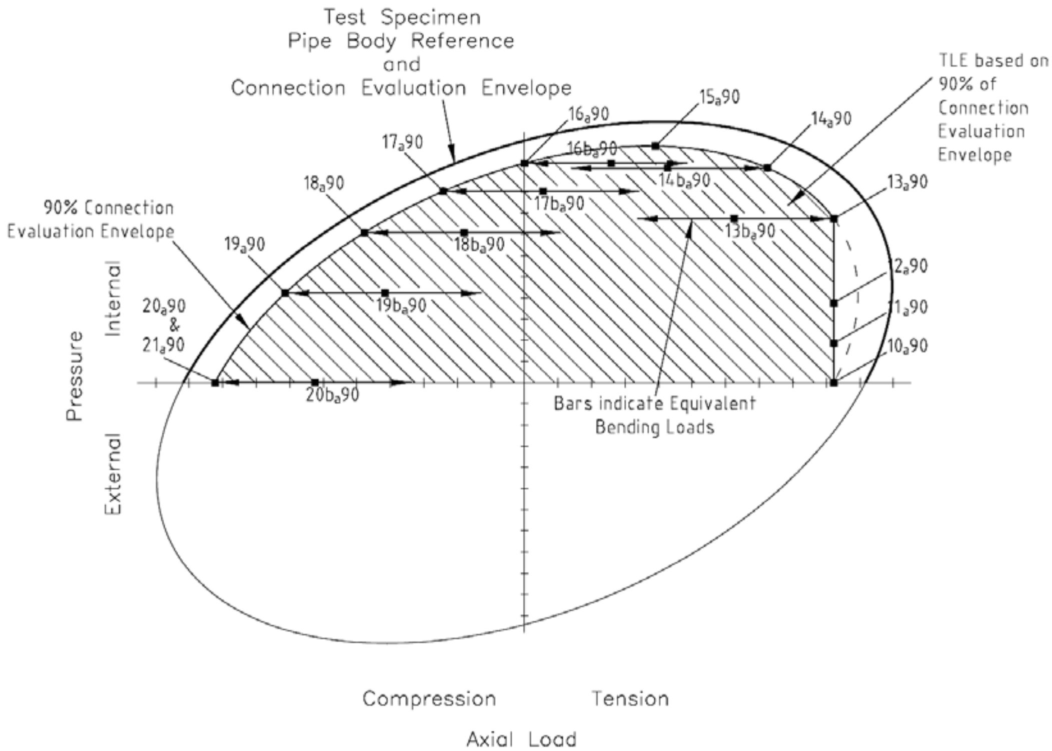
NOTE See Table 10, load steps 1 to 33 and Table 11, load steps 1 to 34.

Figure 29—Example of Ambient Temperature TS-B Load Points at 95 % of the CEE Where the Pipe Body Reference Envelope and Connection Evaluation Envelope Are the Same, with Tension and Compression Limited to 90 % of the CEE



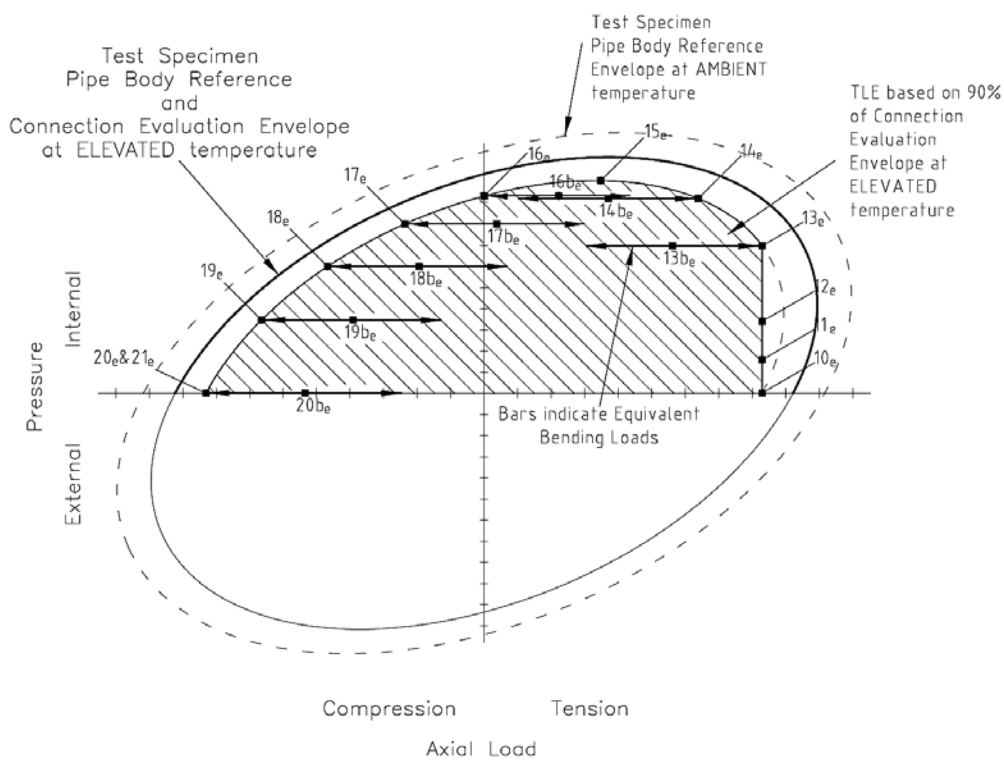
NOTE See Table 11, load steps 35 to 72 and Table 12, load steps 1 to 38.

Figure 30—Example of Ambient Temperature TS-B Load Points with Bending at 95 % of the CEE Where the Pipe Body Reference Envelope and Connection Evaluation Envelope Are the Same, with Tension and Compression Limited to 90 % of the CEE



NOTE See Table 10, load points 72 to 110.

Figure 31—Example of Ambient Temperature TS-B Load Points with Bending at 90 % of the CEE Where the Pipe Body Reference Envelope and Connection Evaluation Envelope Are the Same



NOTE See Table 10, load steps 34 to 71.

Figure 32—Example of Elevated Temperature TS-B Load Points with Bending at 90 % of the CEE Where the Pipe Body Reference Envelope and Connection Evaluation Envelope Are the Same

7.3.5 TS-C—Thermal Cycle Tests with Tension and Internal Pressure

7.3.5.1 General

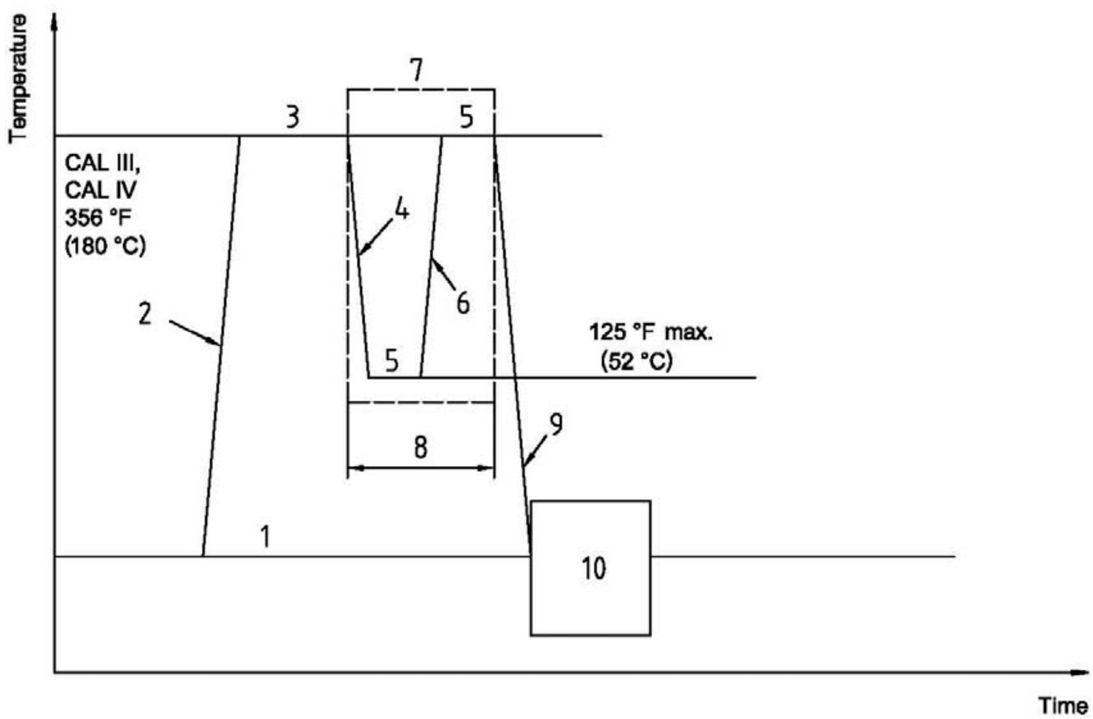
The purpose of thermal and ambient-temperature mechanical cycling is to approximate service conditions and accelerate potential leakage by applying thermal cycling while the connection is subject to axial tension and internal pressure loads.

7.3.5.2 Principle

TS-C testing begins with 10 thermal cycles and ends with 5 pressure/tension cycles at ≤95 °F (35 °C). A thermal cycle is a change from “maximum” temperature to “minimum” temperature and back to “maximum” temperature and is illustrated as key item 7 in Figure 33. A minimum time of 5 minutes shall elapse at or above the maximum temperature (but no greater than the maximum allowable tolerance in accordance with 5.10) and 5 minutes at or below the minimum temperature. Minimum time per thermal cycle is 30 minutes.

7.3.5.3 Calculating Test Loads

Refer to Table 7 for calculation of the load points and to D.5.3 for an example of a TS-C load schedule.



Key

1 ambient temperature
2 initial heat-up
3 minimum 60-minute hold at elevated temperature
4 cooldown
5 5-minute hold
6 heat-up
7 perform 10 thermal cycles for CAL III and CAL IV
8 typical thermal cycle (shall be at least 30 minutes)
9 final cooldown
10 five pressure/tension cycles performed at ≤95 °F (35 °C)

Figure 33—TS-C Thermal/Mechanical Cycles for CAL III and CAL IV

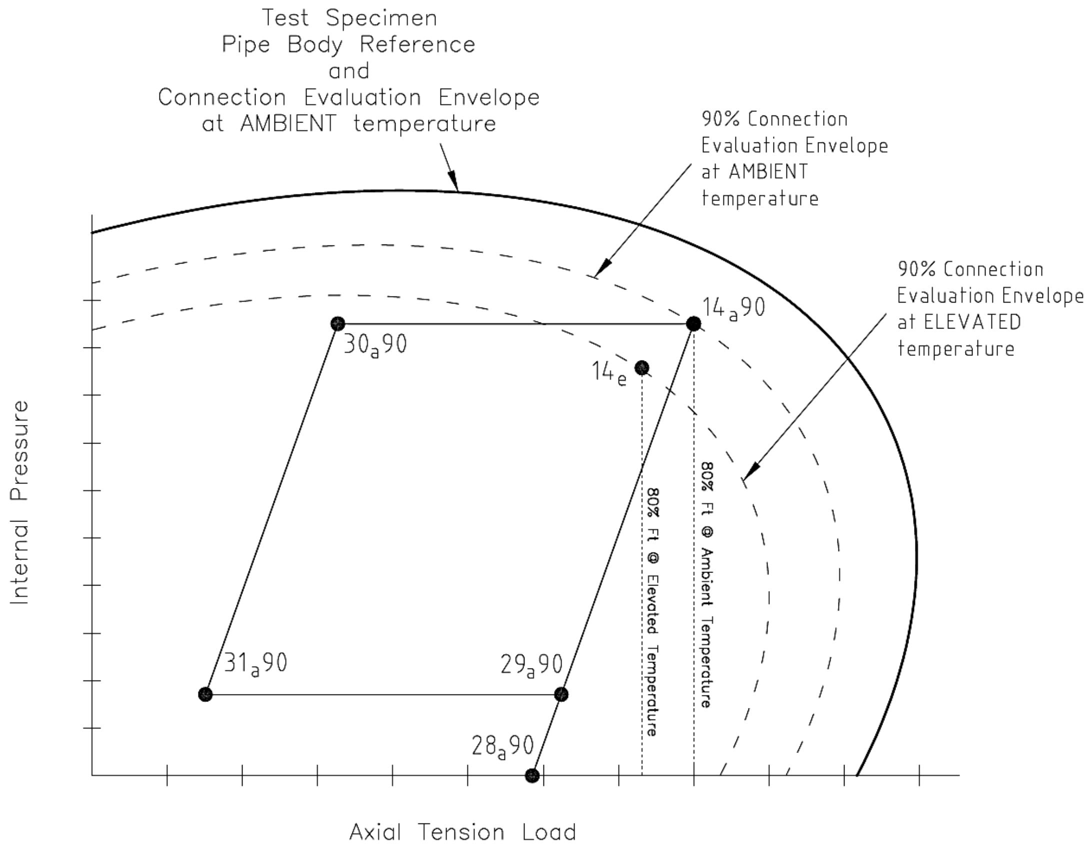


Figure 34—TS-C Load Path Calculation Procedure

Regarding Figure 34, the tension and pressure load combinations that define each numbered load point are defined in Table 7; the order in which the load points are applied during the test and the number of times each load point is applied can be determined from Table 13 for TS-C.

Submit the full-scale test specimens (see Table 1 and Figures 6 and 7) to the following procedure.

a) Determine the axial loads and internal pressures in accordance with Table 7.

b) Perform the test according to instructions herein and as shown in Figures 33 and 34.

   1) Leak detection and setup are in accordance with 5.10.

   2) Heat the specimens and monitor the temperature with thermocouples in accordance with 5.10 and Table 13.

   3) The pressure and axial loads may be applied at any time during the heat-up or the 60-minute thermal hold.

   4) After the 60-minute thermal hold (key item 3 in Figure 33), apply 10 thermal cycles.

   5) Apply five mechanical cycles.

      i) Remove loads.

      ii) Cool specimens to a temperature less than or equal to 95 °F (35 °C) (key item 9 in Figure 33).

      iii) Perform five ambient temperature mechanical cycles as specified in Table 13 (key item 10 in Figure 33) with the maximum temperature to be less than or equal to 95 °F (35 °C).

c) Monitor the temperature during testing with thermocouples in accordance with 5.10.

d) Report results on Figure B.9, connection sealability test log sheet for TS-C.

Table 13 shows the testing required for TS-C.

Table 13—TS-C

Load Step	Load Point	Load Step	Temperature	Hold Time (min)
1	Zero	—	Heat-up	—
2	14_e	—	356 °F (180 °C)	60
3	14_e	TC1	Cooldown	—
4	14_e		≤125 °F (52 °C)	5
5	14_e		Heat-up	—
6	14_e		356 °F (180 °C)	5
7	14_e	TC2	Cooldown	—
8	14_e		≤125 °F (52 °C)	5
9	14_e		Heat-up	—
10	14_e		356 °F (180 °C)	5
11	14_e	TC3	Cooldown	—
12	14_e		≤125 °F (52 °C)	5
13	14_e		Heat-up	—
14	14_e		356 °F (180 °C)	5
15	14_e	TC4	Cooldown	—
16	14_e		≤125 °F (52 °C)	5
17	14_e		Heat-up	—
18	14_e		356 °F (180 °C)	5
19	14_e	TC5	Cooldown	—
20	14_e		≤125 °F (52 °C)	5
21	14_e		Heat-up	—
22	14_e		356 °F (180 °C)	5
23	14_e	TC6	Cooldown	—
24	14_e		≤125 °F (52 °C)	5
25	14_e		Heat-up	—
26	14_e		356 °F (180 °C)	5
27	14_e	TC7	Cooldown	—
28	14_e		≤125 °F (52 °C)	5
29	14_e		Heat-up	—
30	14_e		356 °F (180 °C)	5
31	14_e	TC8	Cooldown	—
32	14_e		≤125 °F (52 °C)	5

Table 13—TS-C (Continued)

Load Step	Load Point	Load Step	Temperature	Hold Time (min)
33	14e		Heat-up	—
34	14e		356 °F (180 °C)	5
35	14e	TC9	Cooldown	—
36	14e		≤125 °F (52 °C)	5
37	14e		Heat-up	—
38	14e		356 °F (180 °C)	5
39	14e	TC10	Cooldown	—
40	14e		≤125 °F (52 °C)	5
41	14e		Heat-up	—
42	14e		356 °F (180 °C)	5
43	Zero	—	Cooldown	—
44	28a90	Transition	≤95 °F (35 °C)	—
45	14a90	—	≤95 °F (35 °C)	5
46	30a90	MC1	≤95 °F (35 °C)	2
47	31a90			2
48	29a90			2
48	14a90			5
50	30a90	MC2	≤95 °F (35 °C)	2
51	31a90			2
52	29a90			2
53	14a90			5
54	30a90	MC3	≤95 °F (35 °C)	2
55	31a90			2
56	29a90			2
57	14a90			5
58	30a90	MC4	≤95 °F (35 °C)	2
59	31a90			2
60	29a90			2
61	14a90			5
62	30a90	MC5	≤95 °F (35 °C)	2
63	31a90			2
64	29a90			2
65	14a90			5
66	Zero	—	≤95 °F (35 °C)	—

7.4 Limit Load Tests

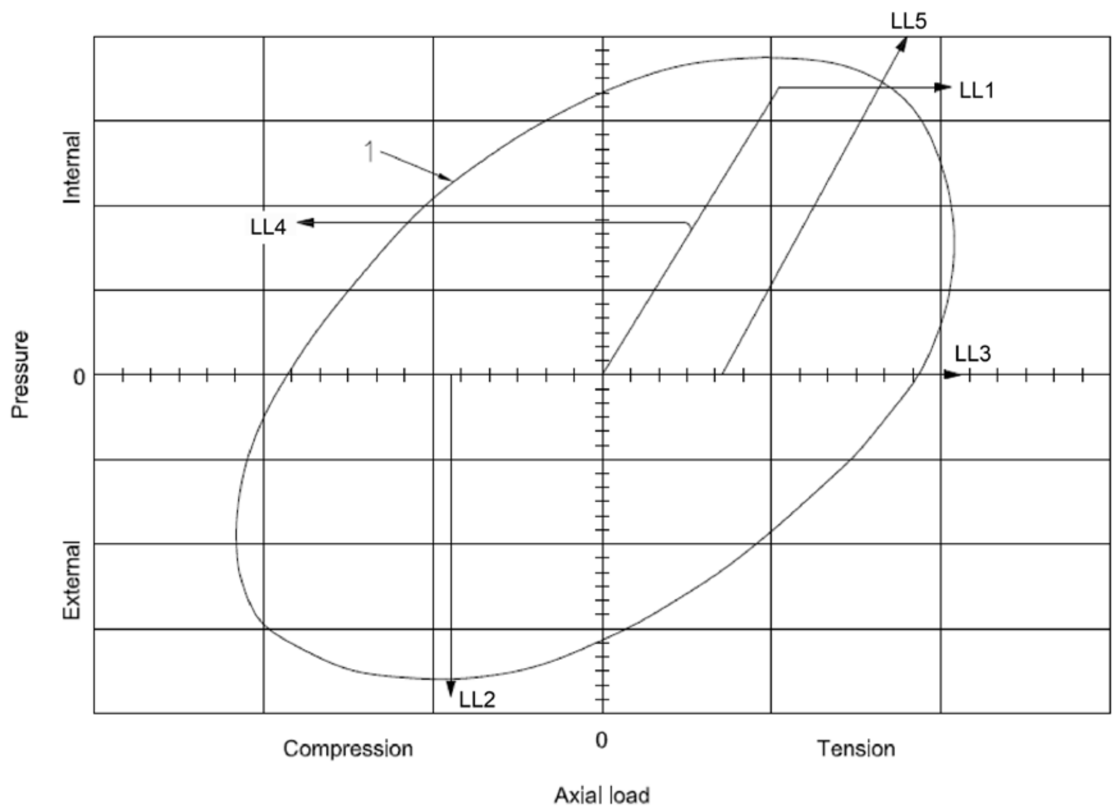
7.4.1 Principle

Limit load tests are conducted to establish the structural limits of the connection. Limit load tests are important for demonstrating connection structural performance beyond the CEE. Limit load tests may also be useful for correlating with FEA data. The results of the limit load tests are used to interpret the connection conformance to the requirements of this RP; however, the limit load results can necessitate a downward revision of the manufacturer's original limit loads (see 5.3.2). Specific test paths are specified in 7.5. Figures 35 and 36 are examples of limit load test paths.

Limit load pressure tests shall be conducted with a liquid medium. After termination of the limit load tests, measure and record lengths L_A, L_B, and L_C on Figure B.7.

The manufacturer's connection datasheet, specified in A.1.5 and Table A.1, should contain load limits based on SMYS and nominal connection dimensions. The manufacturer's test specimen datasheets, specified in Table A.2, should contain actual anticipated failure loads for each test specimen, based on AMYS and actual connection dimensions (see A.2.4). For direct comparison to measured failure loads, the nominal failure loads may be considered as normalized to actual anticipated failure loads by multiplication with two factors: (1) the ratio of actual test material strength to minimum material strength and (2) the ratio of actual to nominal dimensional parameter for the connection under the specific load.

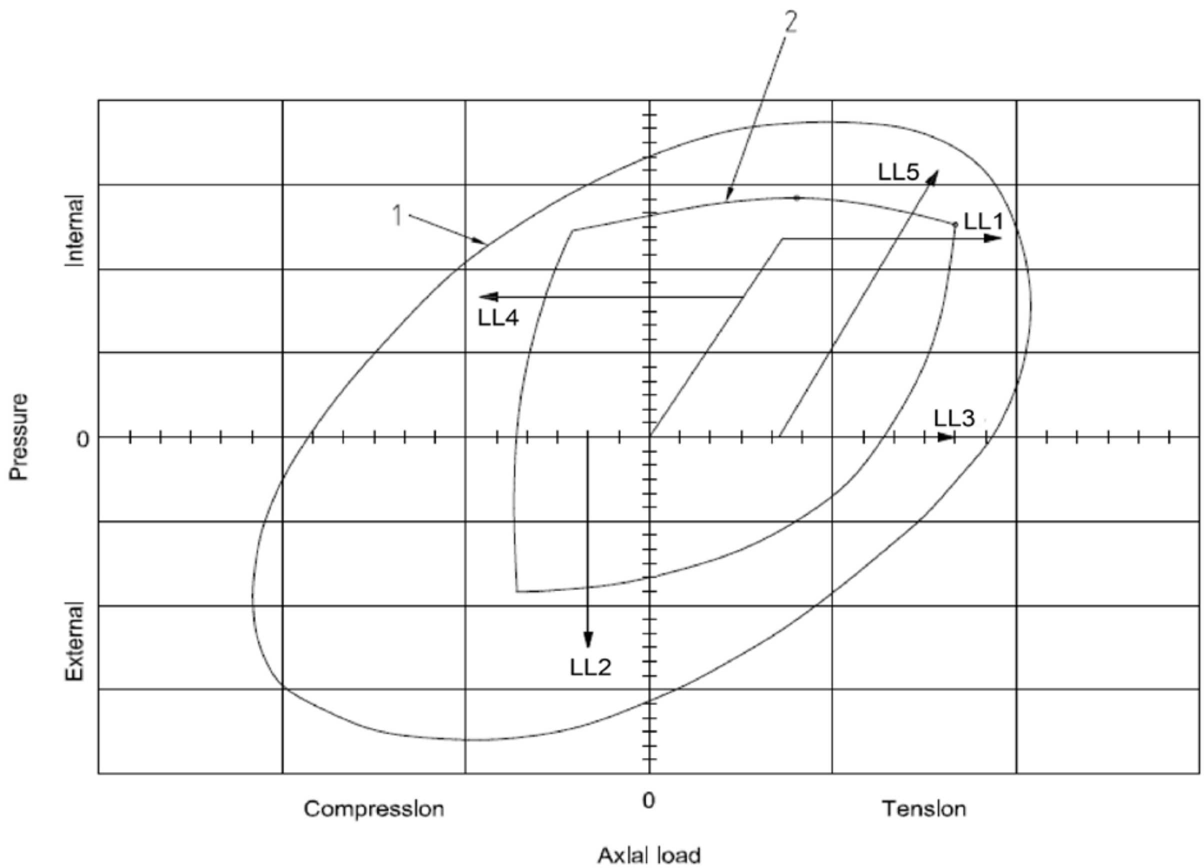
The dimensional parameter for tension and compression loads is the appropriate critical area. For pressure loads, the geometry dependent portion of the connection pressure resistance is the dimensional parameter.



Key

1 100 % VME pipe body yield envelope

Figure 35—Limit Load Test Paths (Example 1)



Key

1 100 % VME pipe body yield envelope

2 100 % connection evaluation envelope

Figure 36—Limit Load Test Paths (Example 2)

7.4.2 Termination of Limit Load Test

The test may be terminated when any of the following apply:

a) change in specimen length ($L_A + L_B + L_C$ in Figure B.4) exceeds 1.5 %;

b) specimen leaks continuously;

c) specimen load exceeds 120 % of CEE or 111 % of pipe body VME (Curve 4[a]).

The tests may be continued to structural failure, which shall be reported as the limit load except when leakage has occurred first. If the specimen leaks continuously, report the load at the beginning of leak as the limit load.

In a test with pressure, if a continuous leak occurs before structural failure, record the pressure and frame load, establish the leak rate in terms of volume or pressure loss per unit time. Structural or leakage failure at the end fixtures gripping the specimen invalidates the test, and the test shall be repeated unless the specimen was at imminent failure indicated by one of the above termination criteria, or sufficient gross deformation, or exceeding 120 % of the CEE. If the specimen is undamaged by failure of an end fixture, reuse the specimen and repeat the test. However, if the specimen is damaged by the failure of an end fixture, repeat the test with a new specimen. The new specimen shall be machined to the same conditions as specified in Section 6.

7.5 Limit Load Test Path

7.5.1 General

Limit load test paths are shown in Figures 35 and 36. These tests are performed as shown in Figures 4 through 7.

7.5.2 Test Path 1—High Internal Pressure with Tension Increasing to Failure Tests

The limit load is determined by test path 1 using the following procedure.

a) Use specimen number as specified in Table 6.

b) Monitor leakage in the same manner as TLE tests (see 5.7) or by appropriate visual means.

c) Apply an internal pressure to 100 % of LP 15_a90 pressure test load.

d) While maintaining internal pressure constant, apply increasing tension to specimen failure.

e) Report the results of each test on a separate datasheet (Figure B.7) and include representative photos of the failure in the connection test report.

7.5.3 Test Path 2—Compression with External Pressure Increasing to Failure Tests

The limit load is determined by test path 2 using the following procedure.

a) Use specimen number as specified in Table 6.

b) Monitoring of leakage is not required.

c) Apply a compressive axial load to 50 % of the uni-axial compression of the TLE at zero pressure load.

d) While maintaining frame compression load constant, apply increasing external pressure to specimen failure.

e) Report the results of each test on a separate datasheet (Figure B.7) and include representative photos of the failure in the connection test report.

7.5.4 Test Path 3—Tension Increasing to Failure Tests

The limit load is determined by test path 3 using the following procedure.

a) Use specimen number as specified in Table 6.

b) Hold pressure loads at zero, then apply increasing tension to failure.

c) Report the results of each test on a separate datasheet (Figure B.7) and include representative photos of the failure in the connection test report.

7.5.5 Test Path 4—Internal Pressure with Compression Increasing to Failure Tests

The limit load is determined by test path 4 using the following procedure.

a) Use specimen number as specified in Table 6.

b) Monitor leakage in the same manner as TLE tests (see 5.7) or by appropriate visual means.

c) Apply internal pressure to 70 % of LP 15_a95 pressure test load.

d) While maintaining internal pressure constant, apply increasing compression to specimen failure.

e) Report the results of each test on a separate datasheet (Figure B.7) and include representative photos of the failure in the connection test report.

7.5.6 Test Path 5—Tension with Internal Pressure Increasing to Failure Tests

The limit load is determined by test path 5 using the following procedure.

a) Use specimen number as specified in Table 6.

b) Monitor leakage in the same manner as TLE tests (see 5.7) or by appropriate visual means.

c) Apply a tensile axial load to 50 % of the uniaxial tension of the TLE at zero pressure load.

d) While maintaining machine tension load constant, apply increasing internal pressure to specimen failure.

e) Report the results of each test on a separate datasheet (Figure B.7) and include representative photos of the failure in the connection test report.

8 Acceptance Criteria

8.1 General

Completing the tests according to the requirements of this RP demonstrates validation of the CEE to a specified CAL. The user is responsible for appropriate interpretation of the test data and determination of their minimum connection performance envelope.

Test results may require a revision of the connection design or the connection validation envelope. In the first case (connection redesign), the testing shall be repeated. In the second case (connection validation envelope revision), the individual test specimens shall be retested unless the tested validation envelopes conform to the revised connection validation envelope.

8.2 Makeup and Breakout Tests

Makeup and breakout tests are considered acceptable if they comply with the following.

a) Makeup and breakout tests are considered successful if after completion of the required number of makeup and breakout tests at proper torque values no galling is observed or if repairable damage meeting the manufacturer's repair criteria is observed and repaired.

    1) Light and moderate galling on the threads within the scope of manufacturer’s field repair recommendations may be repaired in accordance with such recommendations and documented in accordance with 7.2.1. After such repair, testing may be continued.

    2) Except for light and moderate galling as discussed above, galling is not acceptable. Any severe galling shall be evaluated for its cause. It is necessary that the galling evaluation demonstrate that the cause of galling was other than from the design. If it can be proven that the cause was other than design, a minimum of two replacement specimens of the previous type shall be retested through the make-break sequence to confirm acceptance and a single specimen through sealing and limit load tests. If the galling problem cannot be resolved, testing shall be terminated.

b) Typically, in accordance with the manufacturer’s specifications, no galling is allowed on the metal seal; however, in the case where light galling is deemed repairable by the manufacturer, agreement shall be reached with the user as to documentation of galling repair procedures.

8.3 Test Load Envelope Tests

8.3.1 General

TLE tests are considered successful if pressure sealing requirements stated in 8.3.2 are met and no structural failure occurs.

If each of the tests conducted at the 90 % level pass, but the following tests conducted at the 95 % level fail, the connection has conformed to the stated assessment level at the 90 % level. If each of the tests conducted at the 90 % level and 95 % level pass, the connection has conformed to the stated assessment level at the 95 % level. See Figures 4 through 7 for the test requirements and test sequence.

The leak detection system by water level is sensitive and may be affected by environmental conditions such as temperature, barometric changes, and stabilization of systems. The leak detection system may also be influenced by volumetric changes due to changes in axial load and/or pressure. Time is required to allow the system to stabilize before the steady-state hold period is started. If the hold period is started too quickly, a false indication may result. Both judgment and environmental conditions should be considered to determine whether displacement represents a stabilization issue or a leak. Hold periods should be adjusted as necessary to determine whether displacement represents a stabilization issue or a leak. It is recognized that the test specimen internal volume may change with changes in axial load and/or pressure, and that this change may result in some displacement due to the leak-detection system response time. Therefore, a stabilization period is often required before starting the hold period. If displacements are greater than acceptable limits when using an external pressure chamber for leak detection, the external pressure chamber should be removed and a leak detection system installed as shown in 5.7.

8.3.2 Internal Pressure Sealing Tests for TS-A[a], TS-B, and TS-C

The test protocol as defined in this RP is achieved if the required test conditions and temperatures are completed and the connection displacement is not exceeded as defined below for each of the hold periods. A hold period shall begin after the target loads are applied and the leak-detection system is stabilized. A hold period is considered to be leak-free when the following are satisfied. There is no displacement criterion requirement for specified holds under 5 minutes.

a) For a 5-minute hold period, allowable displacement is ≤0.3 cm^3. If more than 0.3 cm^3 displacement is observed in a 5-minute hold period, then the hold shall be extended another 5 minutes for a total of 10 minutes and evaluated as a 10-minute hold period.

b) For a 10-minute hold period, two consecutive 5-minute intervals are to be completed, with data recorded for each 5-minute interval. The allowable displacement is ≤0.6 cm^3 for the 10-minute hold period. If more than 0.6 cm^3 displacement is observed in the 10-minute hold period, then the hold shall be extended another 5 minutes for a total of 15 minutes. For this 15-minute hold period, allowable displacement is ≤0.9 cm^3. If more than 0.9 cm^3 is observed, then the hold shall be extended 15 minutes and evaluated as a 15-minute hold period as required in c) 4) below.

c) For a 15-minute hold period:

    1) three consecutive 5-minute intervals are to be completed, with data recorded for each 5-minute interval;

    2) the connection total displacement measured in the 15-minute hold period shall not exceed 0.9 cm^3;

    3) the last 5-minute interval shall not exceed 0.3 cm^3;

    4) if the connection total displacement exceeds 0.9 cm^3/15 minutes or the last 5-minute interval exceeds 0.3 cm^3, extend the hold period in 5-minute intervals, recording data for each 5-minute interval. If the last three 5-minute intervals do not exceed a total of 0.9 cm^3 displacement, and the last 5-minute interval does not exceed 0.3 cm^3, the hold period is considered leak-free. The total hold time shall not exceed 60 minutes (15-minute hold plus up to a maximum of nine additional 5-

minute intervals). After the extended hold period, if the manufacturer believes that the displacement is not the result of a connection leak, the manufacturer may stop the test for further evaluation of the displacement. The manufacturer shall provide an assignable cause and a plan to evaluate the displacement, and this shall be clearly documented in the test report. If the results of the displacement evaluation plan are successful, restart the testing from the previous load point with the specified hold period. Failure to meet the above criteria results in non-compliance of the CEE validation. The CEE may be reduced and the TLE re-calculated to continue with the test.

d) For a 30-minute hold period:

1) six consecutive 5-minute intervals are to be completed, with data recorded for each 5-minute interval;

2) the connection total displacement measured in the 30-minute hold period shall not exceed 1.8 cm^3;

3) the last 5-minute interval shall not exceed 0.3 cm^3;

4) if the connection total displacement exceeds 1.8 cm^3/30 minute or the last 5-minute interval exceeds 0.3 cm^3, extend the hold period in 5-minute intervals, recording data for each 5-minute interval. If the last six 5-minute intervals do not exceed a total of 1.8 cm^3 displacement, and the last 5-minute interval does not exceed 0.3 cm^3, the hold period is considered leak-free. The total hold time shall not exceed 60 minutes (30-minute hold plus up to a maximum of six additional 5-minute intervals). After the extended hold period, if the manufacturer believes that the displacement is not the result of a connection leak, the manufacturer may stop the test for further evaluation of the displacement. The manufacturer shall provide an assignable cause and a plan to evaluate the displacement, and this shall be clearly documented in the test report. If the results of the displacement evaluation plan are successful, restart the testing from the previous load point with the specified hold period. Failure to meet the above criteria results in non-compliance of the CEE validation. The CEE may be reduced and the TLE re-calculated to continue with the test.

e) For a 60-minute hold period:

1) four consecutive 15-minute intervals are to be completed.

2) record data in 15-minute intervals—the total connection displacement for the 60-minute hold period shall not be greater than 3.6 cm^3;

3) the last 15-minute interval shall not show a connection displacement greater than 0.9 cm^3;

4) if the connection total displacement exceeds 3.6 cm^3/60 minutes or the last 15-minute interval exceeds 0.9 cm^3, extend the hold period with 15-minute intervals, recording data for each 15-minute interval. If the last four consecutive 15-minute intervals comprising a 60-minute interval do not exceed a total of 3.6 cm^3 displacement, and the last 15-minute interval does not exceed 0.9 cm^3, then the hold period is considered leak-free. The total hold time shall not exceed four hours (the initial 1-hour hold plus up to a maximum of 12 additional 15-minute intervals). After the extended hold period, if the manufacturer believes that the displacement is not the result of a connection leak, the manufacturer may stop the test for further evaluation of the displacement. The manufacturer shall provide an assignable cause and a plan to evaluate the displacement, and this shall be clearly documented in the test report. If the results of the displacement evaluation plan are successful, restart the testing from the previous load point with the specified hold period. Failure to meet the above criteria results in non-compliance of the CEE validation. The CEE may be reduced and the TLE re-calculated to continue with the test.

8.3.3 Sealing Tests for TS-A[e]

For TS-A internal and external pressure tests at elevated temperature, no leak criteria have been established; therefore, the following data shall be collected for informational purposes:

a) pressure loss rate during each hold,

b) trend in pressure loss during each hold,

c) number of times pressure shall be increased during each hold shall be recorded.

If the load point pressure cannot be maintained, see 5.8.2.4 to verify equipment integrity. If the equipment is not the source of the observed pressure drop, alternative testing may continue to identify the source of the pressure drop; see 5.8.2.4.

8.4 Limit Load Tests

A limit load test further validates the CEE provided that:

a) the end of the test, as defined in 7.4, is reached and

b) the limit load established is a load greater than the manufacturer's TLE, based on actual material strength and actual connection dimensions.

On failed 95 % level test specimens, limit loads tests are required for conformance. If a failed 95 % level test specimen does not allow continuing to the limit load test, a replacement test specimen shall be manufactured to complete the limit load test to satisfy the 90 % level test. For the replacement test specimen, use the specified FMU and bake-out for that specimen; however, sealability testing is not required prior to the limit load test.

9 Test Report

A full detailed test report shall be prepared documenting the connection tested and the test results following the format in Annex C. Results of tests performed shall be reported without exception. The first section of this test report is a summary of the test results with an emphasis on a compact presentation of data for broader distribution so that a connection purchaser can do the following:

a) fully specify the connection tested,

b) make up the connection properly,

c) have access to the loads to which the connection was successfully tested.

The test data shall provide objective evidence of validation of the connection TLE and failure limit loads.

Before starting a test program, participants shall decide who shall prepare and maintain the final test report. The test report shall be prepared in electronic format. Copies of the test report and results shall be maintained by the manufacturer for as long as the connection is offered to the industry. The test results shall be assembled into a test report in accordance with Annex C. Photographs specified by this RP shall include identification of appropriate items shown in the photographs and be included in the test report. Test reports may be filed for public access with a national standards body.

Annex A
(normative)

Connection Specification Sheet and Test Specimen Datasheet

A.1 Connection Specification Sheet

A.1.1 General

The connection manufacturer shall provide the connection specification information required in Table A.1 prior to the beginning of any testing.

A.1.2 Connection Identification

The connection manufacturer shall provide the size, weight, material grade (pipe and coupling stock if applicable), and connection name for the connection being tested, as well as the CAL to which the connection shall be tested.

A.1.3 Connection Geometry

The connection manufacturer should provide a detailed description listing the design features and benefits of the threads, seals, shoulders, and body configuration.

A.1.4 Connection Diagram

The connection manufacturer shall provide a representative cross-sectional diagram of the connection identifying the critical planes for tension, compression, internal pressure, external pressure, and bending.

A.1.5 Connection Datasheet

The connection manufacturer shall provide a connection datasheet listing the connection minimum performance properties, the uni-axial load limits in terms of tension, compression, internal pressure, external pressure, and bending, using specified OD, specified wall, minimum wall at 87.5 % of specified wall, and SMYS as input. The load limits for the connection shall also be expressed as percentages of the pipe body minimum performance properties.

A.1.6 Connection Manufacturing Specification

The connection manufacturer shall provide a process control plan that details applicable specifications, processes, and procedures, along with the associated control numbers and revision levels necessary for the complete manufacture and inspection of the connection.

A.1.7 Connection Assembly and Repair Procedures

The connection manufacturer shall provide the connection field running procedure number and revision level, the mill coupling/accessory makeup procedure number and revision level, and the field service repair procedure number and revision level.

A.1.8 Test Specimen Makeup/Breakout Procedure

The connection manufacturer shall document complete makeup parameters listing the thread compound type, amount, and application method, along with the makeup speed, required shoulder torque values, minimum and maximum final torque values, and makeup loss for the test specimens. This RP shall have a controlled procedure and revision level and be listed in the manufacturer's process control plan for the test specimens. Connection repair of the test specimens shall be in accordance with the manufacturer's field service repair procedure. The connection manufacturer shall provide a complete description of connection repair and methodology for repair of the test specimens.

Table A.1—Connection Specification Sheet

<table>
<tr><td colspan="5">A.1.1 Connection Identification</td></tr>
<tr><td>Product description</td><td>Size, mass (label: weight)</td><td>Wall thickness</td><td>Grade</td><td>Product name</td></tr>
<tr><td colspan="5">Coupling grade (if different from the pipe body)</td></tr>
<tr><td colspan="5">Connection assessment level (CAL) to which test is performed</td></tr>
<tr><td colspan="5">A.1.2 Connection Geometry</td></tr>
<tr><td colspan="5">A.1.3 Connection Diagram: (attach separate page(s) with schematic cross-sectional diagram)</td></tr>
<tr><td colspan="3">A.1.4 Connection Datasheet Document No. (attach copy)</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="5">A.1.5 Connection Manufacturing Specifications
Provide complete documentation detailing the applicable specifications, processes, and procedures, with the associated control numbers and revision levels necessary for the complete manufacture and inspection of the connection. At a minimum, the following information shall be provided:</td></tr>
<tr><td colspan="3">Process Control Plan No. (attach copy)</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Pin Drawing No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Box Drawing No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Pin Thread Drawing No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Box Thread Drawing No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Seal Ring Drawing No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Pin Surface Treatment/Type Specification No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Box Surface Treatment/Type Specification No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Gauge Calibration Procedure No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Gauging and Inspection Procedures No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Seal Ring Inspection Procedure No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Swage/Stress-relief Procedure No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">First Article/Last Article Procedure No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="5">A.1.6 Connection Field/Mill Assembly and Field Repair Procedures</td></tr>
<tr><td colspan="3">Mill Coupling/Accessory Makeup Procedure No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Connection Field Running Procedure No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Connection Field Repair Procedure No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">A.1.7 Test Specimen Makeup/Breakout Procedure No.</td><td colspan="2">Revision No./Date</td></tr>
<tr><td colspan="3">Thread Compound</td><td colspan="2">Type and Quantity</td></tr>
</table>

A.2 Test Specimen Datasheet

A.2.1 General

The connection manufacturer shall provide the test specimen information required in Table A.2 for each test specimen prior to the beginning of any testing.

A.2.2 Test Specimen Pipe Body Reference Evaluation Envelope

The connection manufacturer shall provide the pipe body reference envelope in terms of tension, compression, internal pressure, and external pressure for each test specimen based on measured properties (see 7.3.1.2).

A.2.3 Test Specimen CEE

The connection manufacturer shall provide the CEE in terms of tension, compression, internal pressure, external pressure, and bending for each test specimen defining each required CEE point based on measured properties (see 7.3.1.3 and Table 7).

A.2.4 Test Specimen Test Load Envelope

The connection manufacturer shall fully quantify the TLE for each test specimen defining the required load points so that test load schedules can be efficiently derived that account for the actual properties of the test specimens (refer to 7.3.1.4 and Table 7). Example TLEs in tabular and graphic form are provided in Annex E.

A.2.5 Test Specimen Load Schedules

The connection manufacturer shall provide the required load schedules for each test specimen (refer to Table 8 through Table 13).

A.2.6 Test Specimen Limit Loads

The connection manufacturer should identify the expected failure loads for the limit load test of each specimen to be tested. These limit load calculations should be based on the specified design and actual material properties. The actual expected limit loads could be derived once the actual design performance and material properties are determined. The connection manufacturer shall provide a test procedure for the required limit load test for each test specimen.

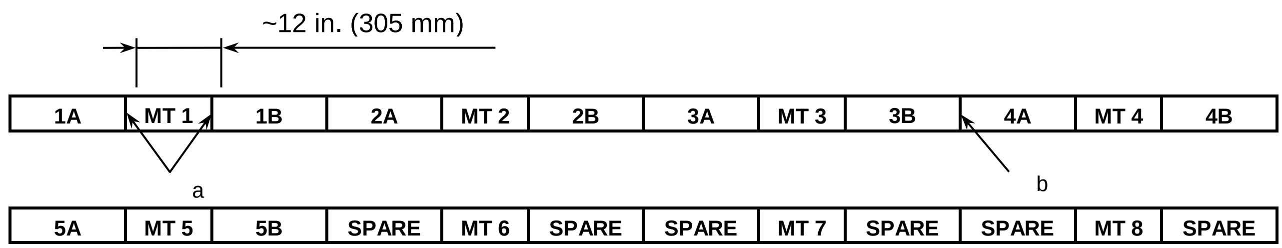
Table A.2—Test Specimen Datasheet

Identifying Section	Dated Revision
A.2.1 Test Specimen Pipe Body Reference Envelope Document No. (attach copy)	Revision No./Date
A.2.2 Test Specimen Connection Evaluation Envelope Document No. (attach copy)	Revision No./Date
A.2.3 Test Specimen Test Load Envelope Document No. (attach copy)	Revision No./Date
A.2.4 Test Specimen Load Schedule Document No. (attach copy)	Revision No./Date
A.2.5 Test Specimen Limit Load Document No. (attach copy)	Revision No./Date

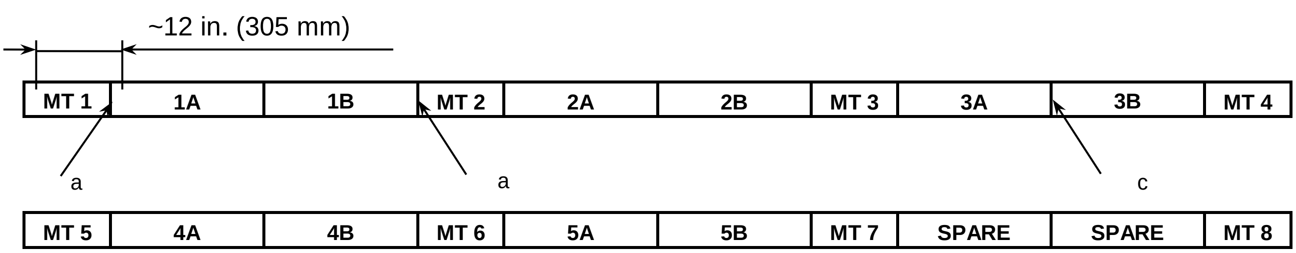
Annex B
(normative)

Data Forms

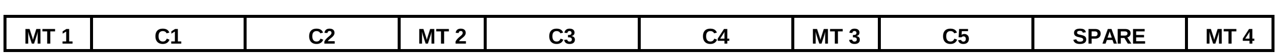
Data forms provided in this annex or equivalent in electronic format shall be used with this RP—substituted representations of these forms shall reflect data pertinent to the intent of the data form in accordance with C.1 as referenced. Material datasheets can duplicate the report from the mechanical test laboratory. As there is tremendous effort in copying over the results with the potential for error, it is suggested that the mechanical test laboratory format be used and accepted. If, however, the data are inserted by hand, then use A3 datasheets (or equivalent size) to report actual test data. If the datasheets are filled out electronically, by typed print or spreadsheet, then A4 datasheets (or equivalent size) may be used to report the data, provided the same format is used and data are clear and easily read. It is permissible to use enlarged reproduced copies of the data forms in this annex. Material test laboratory standard reporting form shall be included along with Figure B.3. Refer to Figure B.1 for recommended mapping of MTs.



a) Mother Joint Mapping—Option 1



b) Mother Joint Mapping—Option 2



c) Coupling Stock Mother Tube Mapping

MT = material test coupon

[a] Connections to be adjacent to material coupon.

[b] Plain end (torch or saw cut anytime).

[c] Plain end (torch or saw cut after threading).

Figure B.1—Recommended Layout of Mother Joints and Coupling Stock Mother Tubes for Material Coupons and Full-scale Test Specimens

Refer to Figure B.2 for recommended layout for dimensional measurements of each test specimen. Use Figure B.2 in conjunction with Figure B.5. In each section, the 0° plane is located at the measured minimum wall for that section. The 0° plane most likely will be oriented differently in each section. The manufacturer shall provide a value for L_D for each integral box connection.

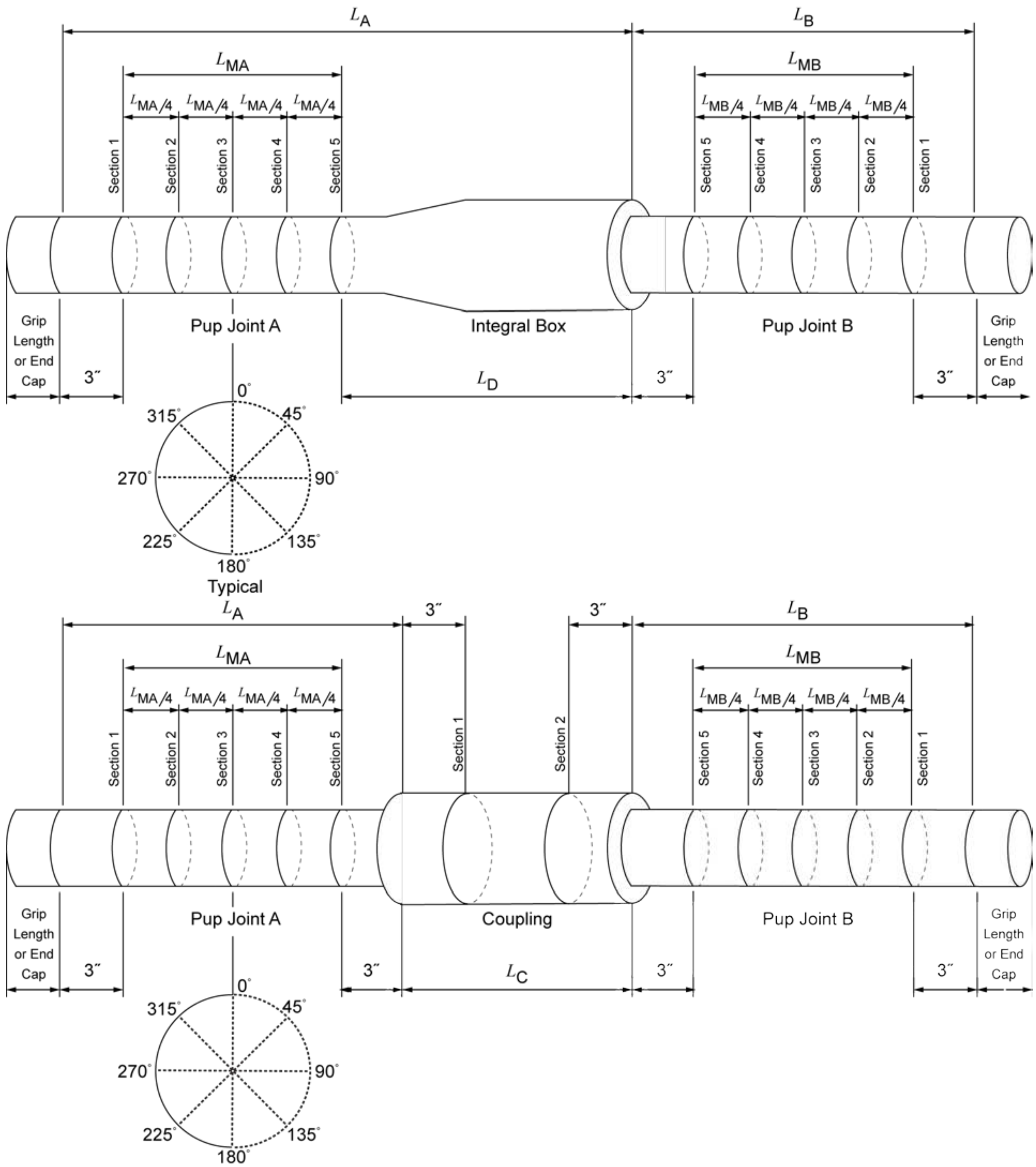


Figure B.2—Layout for Dimensional Measurements of Test Specimens

Size		Grade		Project No.		Date	
Weight		Connection		Location		Technician	
Specified Wall		Specimen No.		UT Meter		Witness	

Pup Joint A | Coupling | Pup Joint B

1			Pup Joint A						Coupling						Pup Joint B					
2		Mother Tube No.																		
3		Coupon No.																		
4			Spec. No.	Temp.	API AMYS	0.2 % Off-set Yld.	Ultimate Strength	Young's Modulus	Spec. No.	Temp.	API AMYS	0.2 % Off-set Yield.	Ultimate Strength	Young's Modulus	Spec. No.	Temp.	API AMYS	0.2 % Off-set Yield.	Ultimate Strength	Young's Modulus
	Test Results																			
5	Quadrant 1	Strip 1																		
6		Strip 2																		
7		Round 1																		
8		Round 2																		
9	Quadrant 2	Strip 1																		
10		Strip 2																		
11		Round 1																		
12		Round 2																		
13	Quadrant 3	Strip 1																		
14		Strip 2																		
15		Round 1																		
16		Round 2																		
17	Quadrant 4	Strip 1																		
18		Strip 2																		
19		Round 1																		
20		Round 2																		

Page ______ of ______

Figure B.3—Material Property Datasheet

Size		Specimen(s) No.					Date	
Weight		Thd. Comp: Type | Mfg. | Batch No.					Project No.	
Grade			*Minimum*		*Maximum*		Technician	
Connection Mfg.		Torque Range					Witness	
Connection Name		Thread Compound Range: Pin					Location	
Pin End Finish		Thread Compound Range: Box					Tongs | Vert. or Horiz.	
Box End Finish								

	Specimen		Pin No.	Box No.	Makeup No.	Lubrication (grams)		Target Torque	Shoulder		Full Makeup		Speed (RPM)	Breakout Torque	Refurbishing & Galling Observations
	Number	End: A/B				Pin	Box		Torque	Turns	Torque	Turns			
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20															

Figure B.4—Makeup/Breakout Log

Size		**Grade**		**Project No.**		**Date**	
Weight		**Connection**		**Location/Frame**		**Technician**	
Specified Wall		**Specimen No.**		**UT Meter**		**Witness**	

	Location	**Pup Joint A**					**Pup Joint B**					**Coupling**		**Comments**
		Section 1	**Section 2**	**Section 3**	**Section 4**	**Section 5**	**Section 5**	**Section 4**	**Section 3**	**Section 2**	**Section 1**	**Section A**	**Section B**	
1	**Length from Face of End**													
	OD Measurements													
2	**0° ~ 180°**													
3	**45° ~ 225°**													
4	**90° ~ 270°**													
5	**135° ~ 315°**													
6	***Min***													
7	***Max***													
8	***Average***													
	Wall Measurements													
9	**0°**													
10	**45°**													
11	**90°**													
12	**135°**													
13	**180°**													
14	**225°**													
15	**270°**													
16	**315°**													
17	***Min***													
18	***Max***													
19	***Average***													
	Average ID													
20	***Average ID***													

Refer to Figure B.2

	Pup Joint A—L_A	**Pup Joint B—L_B**	**Coupling—L_C**	**Integral Box—L_D**	**Measurement—L_{ma}**	**Measurement—L_{mb}**	D_{avg}	t_{min}	t_{avg}
21									

Figure B.5—Form for Test Specimen Pipe Geometry

Connection Manufacturer	
Connection	
Size	
Weight	
Specified Wall	
Grade	

Specimen No.	
Coupling (Box) Number	
Pin A Number	
Pin B Number	

Drawing No.	
Drawing Revision Level	
Revision Date	

	A End (As Machined [a])		B End (As Machined [a])	
	In	Out	In	Out
Pin Metal Seal Diameter				
Box Metal Seal Diameter				
Metal Seal Interference				
Ring Groove Diameter				
Ring Groove Width				
Ring Groove Location				
Plug Gauge Stand-off/Thd. Dia.				
Ring Gauge Stand-off/Thd. Dia.				
Thread Interference (Clearance)				
Pin Taper				
Box Taper				
Pin Lead Error				
Box Lead Error				
Pin Metal Seal Ovality				
Box Metal Seal Ovality				

Technician		Date	
Witness		Date	

[a] Before plating, coating, or any other surface treatment

Figure B.6—Connection Geometry Datasheet

Size		**Specimen No**		**Date**	
Weight		**Test Protocol**		**Project No.**	
Grade		**Location/Frame**		**Technician**	
Connection		**Transducer(s)**		**Witness**	

Pressure Medium | Pressurizing Rate | Axis Loading Rate

	Time	**Machine Load**	**Pressure**	**Leak Detection**		**Comments**
				A	**B**	
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						

Applied Loads Failure:				Failure Loads:	
	Pressure		Frame Load		Frame Load + CEPL
At Leaked Pressure		Machine Load		Total Load	
At Failure Pressure		Machine Load		Total Load	
Maximum Test Parameters		Machine Load		Total Load	

Final Length: L_A | Final Length: L_B | Final Length: L_C

Description and Location of Failure

Comments

Figure B.7—Test Log–Failure/Limit Load

Page ______ of ______

Size		Specimen No.		Date	
Weight		Test Protocol		Project No.	
Grade		Location/Frame		Technician	
Connection		Transducer(s)		Witness	

	Time	Load Step	Load Point	Frame Load	Bend	Pressure	Temperature	Leak Detection				Notes
								cc A	Δ cc A	cc B	Δ cc B	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

Figure B.8—Connection Sealability Test Log (with Internal Pressure Leak Detection)

Size		Specimen No.		Date	
Weight		Test Protocol		Project No.	
Grade		Location/Frame		Technician	
Connection		Transducer(s)		Witness	

	Time	Load Step	Load Point	Frame Load	Bend	Pressure		Temperature	Leak Detection		Notes
						Internal	External		cc	Δ cc	
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											

Figure B.9—Connection Sealability Test Log (with External Pressure Vessel As Leak Detection)

Annex C
(normative)

Connection Full Test Report

C.1 General

The following guidelines are provided for generating the report on the connection tests performed in accordance with this RP. The purpose is to provide the information required to fully document the connection tested, the manufacturing and assembly procedures, and the test results for connection assembly, TLEs executed, and limit load tests. Sufficient information shall be provided such that the reader of the report understands how the connection was successfully tested and is made aware of any limitations.

The report shall identify deviations to the specified procedures (if any), but should not duplicate information on the test procedures, which is already found in this RP. The report should also include noteworthy events that are not deviations, but are beneficial to include with the report such as equipment leaks, extended holds, switching from external pressure chamber to leak boot for TS-A ambient, etc. Also, additional tests that were performed but are not required for an application level should be included and should be clearly identified as additional to this RP.

A summary test report shall contain, at a minimum, the information specified in Section 1, Executive Summary.

The structure of the report format contains 10 numbered sections (folders in digital format) with an Executive Summary folder “1.” Each folder or sub-folder contains the digital data taken during the test and scanned hand-written logs (where applicable). Upon completion of the test, delivery of the report may be provided in either electronic format with folders used to delineate the sections of the test report or in paper format in accordance with the specified structure. Sub-folders under each section may be used to separate each specimen’s data. File names shall be unique to each data set and reflect the specimen number and test protocol. The number identifier of each section is given below in C.2.

Each data set, whether digital, forms, or hand logs, shall identify as first line title the size, weight, grade, connection, specimen number, and a unique identification number (i.e. project number or purchase order number). Each data entry or log entry shall include a date and time notation relevant to the data. Digital files, forms, and logs shall note the person or persons recording or controlling the recording of the data.

The data forms provided in Annex B are required, but since they are not necessarily conducive to digital implementation, an equivalent in electronic format is allowed as stated in the annex’s introductory paragraph. Substituted representations of these forms shall reflect data pertinent to the intent of the data form and as noted above.

The reporting format is grouped into 10 sections as shown in Table C.1.

Table C.1—Reporting Format

Topic	Section
Executive Summary	1
Connection Specifications	2
Material Specification and Mechanical Properties	3
Material Geometry	4
Test Specimen Geometry	5
Test Specimen Makeup and Breakout Data	6
Test Specimen Envelopes and Load Schedules	7
Test Specimen Sealability and Limit Load Test Data	8
Test Facility Documentation	9
Appendices	10

C.2 Report Section Index

1 Executive Summary

At a minimum, include the following information in the Executive Summary:

a) identification reference for the connection (connection name);

b) identification reference for the pipe (size, weight, grade);

c) reference to this RP and the edition used (i.e. API 5C5, Fourth Edition);

d) CAL test classification;

e) number of specimens tested;

f) temperature used in the tests;

g) dates of testing and the test facility;

h) identification of the personnel who performed the tests;

i) declaration of any third party monitoring the tests;

j) testing summary table showing specimens tested, tests performed, and base test results;

k) results of the tests performed;

l) supplemental tests performed as a part of the test program;

m) planned deviations/variations to this RP;

n) unplanned deviations to this RP.

2 Connection Specifications

Include the following information for the connection specifications.

a) Connection identification (Table A.1, A.1.1).

b) Connection geometry (Table A.1, A.1.2).

c) Connection diagram (Table A.1, A.1.3).

d) Connection datasheet (Table A.1, A.1.4).

The manufacturer's catalog data or specification sheet for the connection description shall include the connection minimum performance properties, connection geometry (OD, ID, drift, makeup loss, coupling OD, and coupling length), recommended torques values, and other data applicable for general use of the connection.

e) Connection manufacturing specification (Table A.1, A.1.5).

The manufacturer's manufacturing specifications, processes, procedures, etc., by document number, release date, and revision level. These should include, but are not limited to, the manufacturer's, process control plan, product drawing no., tooling requirements, inspection procedures, gauge calibration procedures, other manufacturing processes, surface treatment requirements, coatings and plating, packaging, thread protectors, and corrosion protection.

f) Connection field/mill assembly and field repair procedures (Table A.1, A.1.6).

Include procedures used in the protection, handling, mill coupling/accessory assembly, field running, and repair of the connection tested.

g) Test specimen makeup/breakout procedure (Table A.1, A.1.7).

Include thread compound requirements, torque requirements, and rotational speed for each test specimen.

h) Test specimen pipe body reference envelope document number (Table A.2, A.2.1).

i) Test specimen CEE document number (Table A.2, A.2.2).

j) Test specimen TLE document number (Table A.2, A.2.3).

k) Test specimen load schedule document number (Table A.2, A.2.4).

l) Test specimen limit load document number (Table A.2, A.2.5).

3 Material Specification and Mechanical Properties

Include the following for the material specification and mechanical properties.

a) Pipe and coupling stock specifications required for the connection.

b) Test specimen and test coupon mapping (mother joint and coupling stock).

Include material mapping for the test specimens and MTs (coupling stock mother tube, pipe mother joint)—see Figure B.1. Maintain traceability of each test specimen pup and MT to the mother tube, including location within the mother tube.

c) Mechanical property test results.

This section requires copies of the material test report(s) (MTRs) and the mechanical property test reports from the MTs for material used for the test specimens. Include the material property datasheets for each test specimen (see Figure B.3).

4 Material Geometry for the Pipe and Coupling Stock (OD and Wall Thickness Measurements)

This section requires minimum wall, minimum average wall, and OD measurements of each test specimen pup, as well as the OD measurement of each test specimen coupling. Include the pipe geometry datasheets for each test specimen (see Figure B.5).

5 Test Specimen Geometry (As Machined In/Out, After Initial Breakout, After Last Breakout)

Include the connection geometry datasheet including interference calculations for each test specimen (see Figure B.6). This is supplied by the manufacturer.

6 Test Specimen Makeup and Breakout Test Data

Include the following for the test specimen makeup and breakout data.

a) Makeup and breakout—datasheets (see Figure B.4).

At a minimum, the following data should be included in the log sheet: makeup speed, reference torque, shoulder torque, total torque, turns past shoulder and turns to full makeup, breakout torque ranges, thread compound weight (pin and/or box), date, personnel, and equipment used. Include required photographs.

b) Makeup and breakout—torque vs rotation plots.

Torque vs rotation plots of connection makeup and breakout shall be provided in digital format. Scanned images of the makeup plots are acceptable.

c) Makeup and breakout—strain gauge data.

Raw strain gauge data shall be provided digitally. Plotted data may be provided at the request of the customer.

d) Makeup and breakout—anomalies or field repairs.

Note tests when galling occurred, if repaired how it was repaired, assignable cause, and preventive measures taken (if any) to reduce potential of future galling. Include torque vs rotation plots and required photographs. Also state whether any connections were overtorqued and whether any problems resulted.

e) Makeup/breakout photos.

7 Test Specimen Envelopes and Load Schedules

Include the following for the test specimen envelopes and load schedules.

a) Pipe body reference envelope.

Include the plot of the pipe body reference envelope for each test specimen.

b) CEE.

Include the plot of the CEE for each test specimen and the CEE points defined in Table 7 on the CEE plot.

c) TLE.

Include the plot of the TLE for each test specimen and the TLE load points defined in Table 7 on the TLE plot.

d) Load schedules.

Include the TS-A load schedules for each test specimen, the TS-B load schedules for each test specimen, and the TS-C load schedules for each test specimen.

e) Limit load tests.

Include the limit load test procedures for each test specimen.

8 Test Specimen Sealability and Limit Load Test Data

Include the following sealability and limit load test data grouped for each test specimen.

a) Bake-out data.

Include time and temperature plots for each test specimen.

b) Photos of the setup for each test for each test specimen.

c) Test logs for TS-A.

Include test leak logs for each test specimen using Figure B.8 or Figure B.9, and leak system verification log.

d) Test logs for TS-B and TS-C.

Include test leak logs for each test specimen using Figure B.8 and leak system verification log.

e) Test data plots.

Include time history plots to document applied loads (pressure, axial load, bending, and temperature), with non-procedural events noted. These may be represented in one or multiple charts for each test series. Include x-y plots to document applied loads (pressure, axial load, bending, and temperature), with non-procedural events noted. Tested load points should be plotted on the plot of the nominal pipe body reference envelope for each specimen.

f) Limit load test data plots.

Failure (or test termination) load points shall be plotted on the plot of the pipe body reference envelope for each test specimen. Report observations regarding the limit load test for each specimen. Include photographs of the limit load specimens prior to and after testing. Include Figure B.7 and a summary of the axial pressure load diagram showing the final limit load points, limit load displacements, structural failure, and/or test termination load points, with annotations for unusual events.

g) Helium leak detection.

Report results of any tests where helium leak detection methods were used for each specimen.

9 Test Facility Documentation

Include the following information for the test facility documentation.

a) Specimen preparation—test specimen preparation for testing shall document setup or configuration for the following:

1) end cap method (welded, threaded);

2) load frame description;

3) bend method;

4) heating and cooling system description;

5) internal pressure application method (ambient and elevated temperature);

6) external pressure application method (ambient and elevated temperature);

7) leak detection method;

8) instrumentation (axial loads, pressure, temperature, strain gauge).

b) Test equipment—for testing the specimen shall document the following:

1) description or photographs of equipment (brochures);

2) instrumentation calibration certificates—to also include test equipment calibration (load measuring devices, pressure transducers).

10 Appendices

Use appendices for any additional testing or information not identified above regarding the testing performed, special requirements outside the scope of this RP, or other information not categorized in the reporting above.

Annex D
(informative)

Calculations for Pipe Body Reference Envelope and Examples of Load Schedules for Each Test Series

D.1 General

The following examples are merely examples for illustration purposes only. [Each company should develop its own approach.] They are not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this annex.

In order to conduct a test to this RP, pipe body reference envelopes along with the CEE, test loads, and load schedules shall be generated for each test specimen. As an example, a 9.625 in. OD 53.50 lb/ft, P-110 HC test specimen is detailed for a CAL IV test in D.2 through D.6. This example assumes that test loads are based strictly on the controlling pipe body reference envelope, for example, the connection CEE is the same as the limiting pipe body reference envelope.

Specific inputs required for calculations are indicated by **BOLD** type. These inputs show all digits (no rounding has been applied). Some intermediate calculations are also shown; however, these results may be rounded to the displayed number of digits and are in normal font. To exactly duplicate the calculated results, use the **BOLD** inputs and non-rounded intermediate calculations to develop the appropriate CEE points and TLE load points.

Below, D.7 highlights non-normative examples of potential connection limitations relative to the specimen pipe body reference curves. These examples are typical of connections with connection efficiencies of less than 100 % of the pipe body.

NOTE Unless stated otherwise, references to API 5C3 in this annex concern API 5C3, First Edition, December 2008.

D.2 Specimen Characterization

D.2.1 General

As shown in Figure D.1, specific specimen pipe body measurements and material tests results are required to define the inputs for the pipe body reference envelopes.

D.2.2 Mother Joint Mapping

MTs are required adjacent to the A and B pup joints from each specimen. As described in Annex C, two potential layouts are possible. For this example, Figure B.1, Option 2 has been chosen. As a result, MT1 represents the coupon adjacent to Pup 1A and MT2 represents the coupon adjacent to Pup 1B, as shown in Figure D.1.

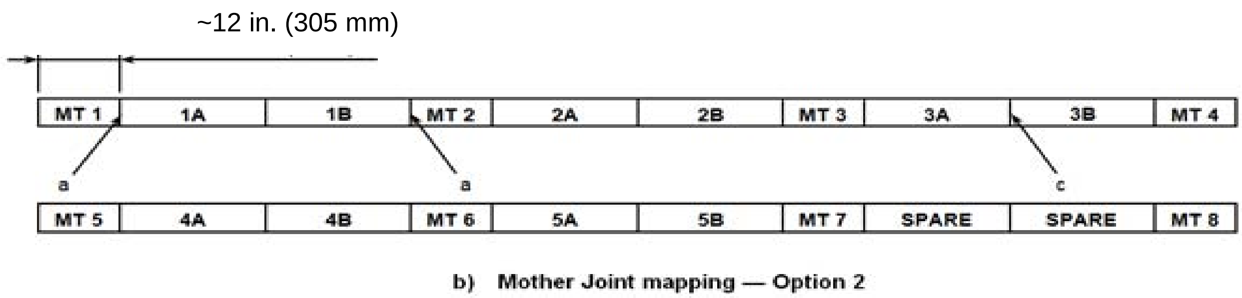


Figure D.1—Mother Joint Mapping (from Annex B)

D.2.3 Material Testing

To determine the ambient temperature material yield strength (AMYS) and elevated temperature scaling factor (K_{temp}) at 383 °F (195 °C) used in the test specimen pipe body reference envelope calculations, the following material tests are required in accordance with 5.5, as shown in Figure D.2.

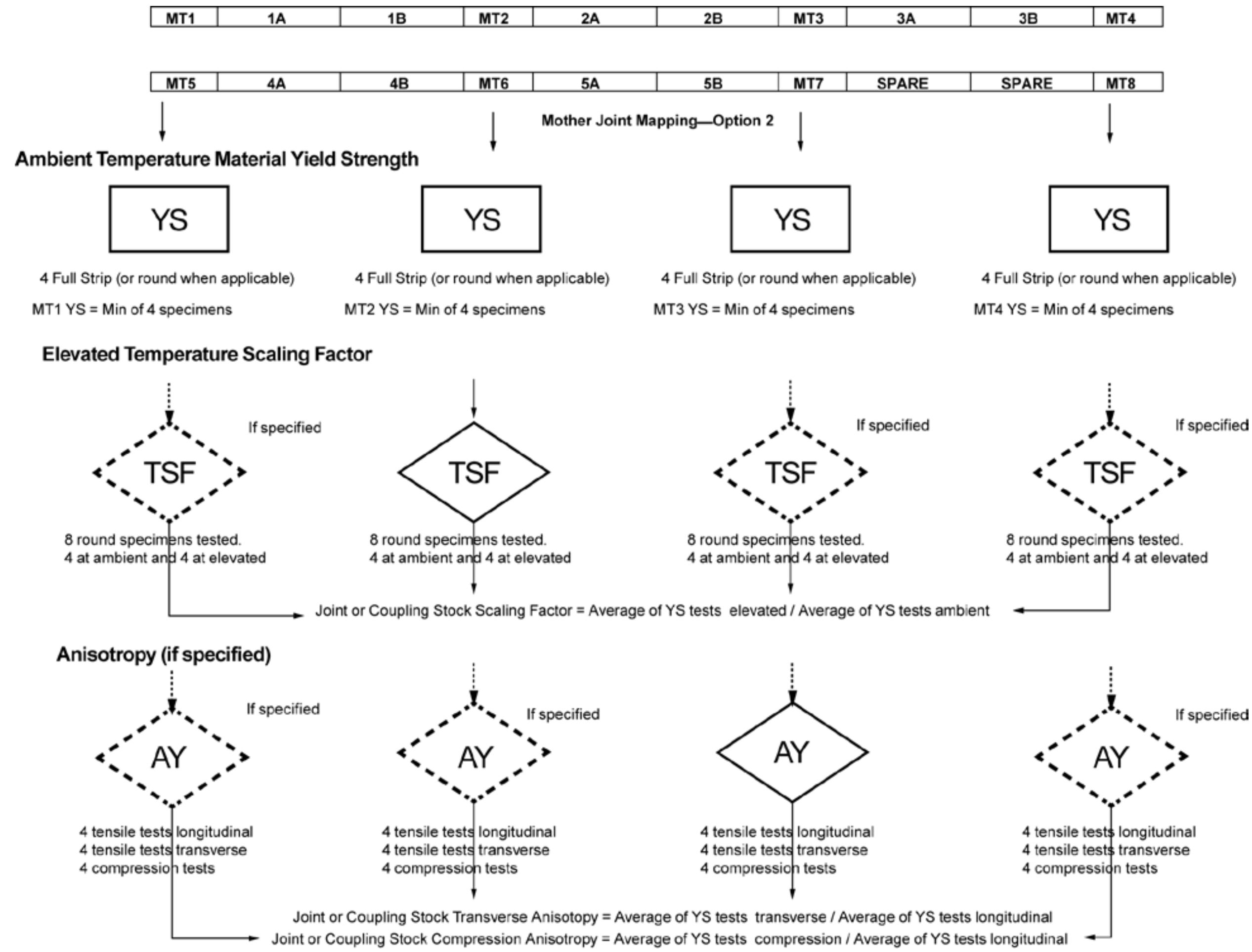


Figure D.2—Mechanical Test Requirements Flow Chart

Joint 1

MT1

— Four longitudinal ambient temperature tensile tests on full body wall strips (preferred).

MT2

— Four longitudinal ambient temperature tensile tests on full body wall strips (preferred).

— Four longitudinal ambient temperature tensile tests on ASTM round bar specimens (required for K_{temp}).

— Four longitudinal elevated temperature tensile tests on ASTM round bar specimens at 383 °F +0/−9 °F (195 °C +0/−41 °C) (required for $K_{383°}$).

MT3

— Four longitudinal ambient temperature tensile tests on full body wall strips (preferred).

MT4

— Four longitudinal ambient temperature tensile tests on full body wall strips (preferred).

Joint 2

MT5

— Four longitudinal ambient temperature tensile tests on full body wall strips (preferred).

MT6

— Four longitudinal ambient temperature tensile tests on full body wall strips (preferred).

— Four longitudinal ambient temperature tensile tests on ASTM round bar specimens (required for K_{temp}).

— Four longitudinal elevated temperature tensile tests on ASTM round bar specimens at 383 °F +0/−9 °F (195 °C +0/−41 °C) (required for $K_{383°}$).

MT7

— Four longitudinal ambient temperature tensile tests on full body wall strips (preferred).

MT8

— Four longitudinal ambient temperature tensile tests on full body wall strips (preferred).

If the material grade were expected to be anisotropic, the following material tests would also be required on MT3 and MT7:

— four longitudinal ambient temperature tensile tests on ASTM round bar specimens,

— four transverse ambient temperature tensile tests on ASTM round bar specimens,

— four longitudinal ambient temperature compression tests on ASTM E9 specimens.

D.2.4 Selection of MT Results

The minimum measured yield strength from the full wall strip tensile tests at ambient temperature from the MTs directly adjacent to each pup joint is required to determine the specimen pipe body reference curves for each specimen. In addition, the average measured yield strength from the four round bar tensile tests at elevated temperature and the average measured yield strength from the four round bar tensile tests at ambient temperature from the selected MT for each joint are required. Table D.1 summarizes the MT results required to determine the specimen pipe body reference curves for Specimen 1.

Table D.1—Example MT Test Results from Joint 1

Coupon	MT1	MT2			MT3	MT4
Temperature	70 °F (21.1 °C)	70 °F (21.1 °C)	70 °F (21.1 °C)	383 °F (195 °C)	70 °F (21.1 °C)	70 °F (21.1 °C)
Geometry	Strip	Strip	0.500 RB	0.500 RB	Strip	Strip
0°	128.0	132.3	125.0	110.8	130.2	131.5
90°	**125.0**	128.6	122.8	108.9	128.6	128.7
180°	126.3	130.5	123.8	109.7	**127.4**	129.3
270°	131.5	127.8	128.4	113.8	129.8	130.9
Average	127.7	129.8	**125.0**	**110.8**	129.0	130.1

Since full wall strip material tests are preferred, the yield strength from MT1 at 90° (**125.0 ksi**) will be used as AMYS for Specimen 1 (the lowest full wall strip adjacent to one of the pups from Specimen 1). The yield strength from MT3 at 180° (**127.4 ksi**) will be used as AMYS for both Specimen 2 and Specimen 3.

The 90° RB material test from MT2 has the lowest measured yield strength (122.8 ksi); however, this result has been intentionally disregarded for determining the AMYS of Specimen 1 and Specimen 2 at ambient temperature since full wall strip material tests are preferred.

Based on the average RB yield strength at ambient and elevated temperature from MT2, K_{temp} = $\boxed{\textbf{110.8 ksi}}$ / $\boxed{\textbf{125.0 ksi}}$ = **88.64 %**.

This elevated temperature scaling factor will be used for Specimens 1, 2, and 3 (all specimens from the mother joint).

D.2.5 Dimensional Measurements

Measurements of the actual outer diameters and wall thicknesses of the pup joints are required to determine the specimen pipe body reference curves. Measurement locations are specified in Annex C (as shown in Figure D.3). The maximum average OD, minimum average wall thickness, and minimum wall thickness are used in the calculations. Table D.2 and Table D.3 summarize the dimensional measurements from Pup A and Pup B used in the example.

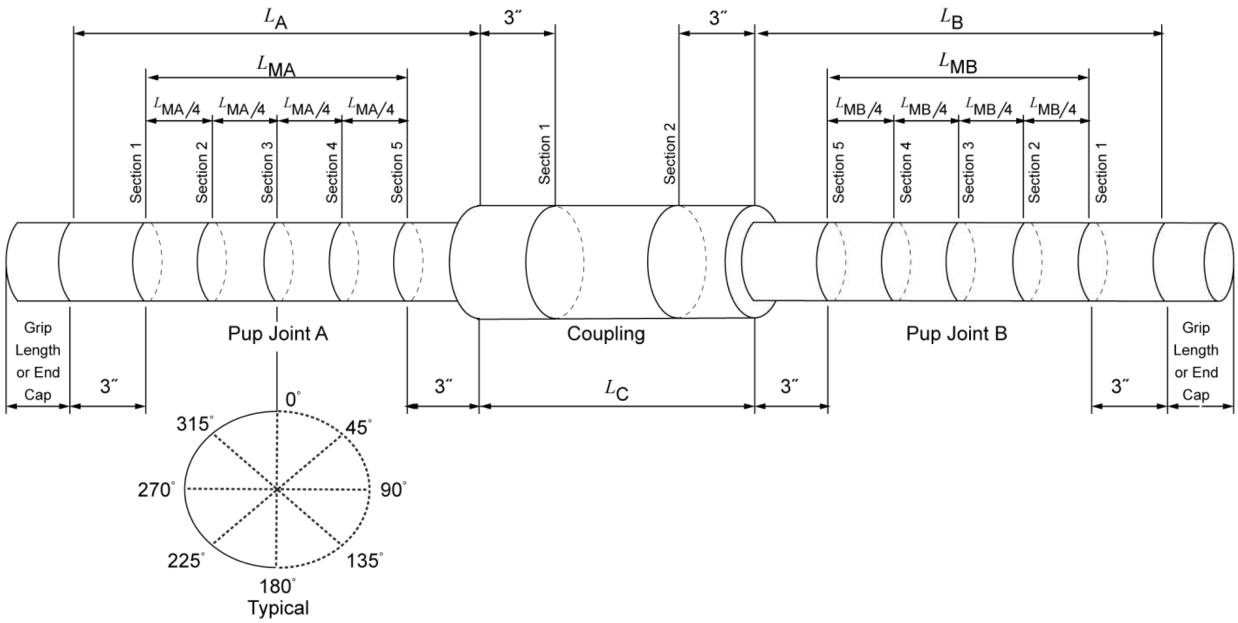


Figure D.3—Measurement Locations

Table D.2—Measurements from Pup A (inches)

Measurement	Plane 1	Plane 2	Plane 3	Plane 4	Plane 5
$OD_{0°–180°}$	9.687	9.690	9.677	9.683	9.667
$OD_{45°–225°}$	9.705	9.681	9.692	9.700	9.689
$OD_{90°–270°}$	9.707	9.655	9.690	9.700	9.695
$OD_{135°–315°}$	9.689	9.665	9.676	9.684	9.673
D_{avg}	**9.697**	9.673	9.684	9.692	9.681
$t_{0°} = t_{min}$	0.532	0.520	0.525	0.530	0.527
$t_{45°}$	0.550	0.522	0.528	0.533	0.531
$t_{90°}$	0.567	0.523	0.531	0.536	0.535
$t_{135°}$	0.556	0.543	0.546	0.548	0.545
$t_{180°}$	0.545	0.563	0.561	0.559	0.555
$t_{225°}$	0.540	0.559	0.560	0.561	0.562
$t_{270°}$	0.535	0.554	0.559	0.562	0.568
$t_{315°}$	0.534	0.537	0.542	0.546	0.548
t_{avg}	0.545	**0.540**	0.544	0.547	0.546

Table D.3—Measurements from Pup B (inches)

Measurement	Plane 1	Plane 2	Plane 3	Plane 4	Plane 5
$OD_{0°–180°}$	9.672	9.663	9.700	9.628	9.637
$OD_{45°–225°}$	9.687	9.662	9.683	9.678	9.672
$OD_{90°–270°}$	9.685	9.645	9.650	9.712	9.690
$OD_{135°–315°}$	9.671	9.646	9.667	9.662	9.656
D_{avg}	9.679	9.654	9.675	9.670	9.664
$t_{0°} = t_{min}$	0.543	0.540	**0.507**	**0.507**	0.540
$t_{45°}$	0.547	0.541	0.534	0.536	0.551
$t_{90°}$	0.550	0.542	0.560	0.565	0.562
$t_{135°}$	0.548	0.552	0.555	0.564	0.567
$t_{180°}$	0.546	0.561	0.550	0.562	0.571
$t_{225°}$	0.555	0.565	0.558	0.554	0.556
$t_{270°}$	0.563	0.569	0.565	0.545	0.541
$t_{315°}$	0.553	0.555	0.536	0.526	0.541
t_{avg}	0.551	0.553	0.546	0.545	0.554

The $t_{0°}$ plane is defined separately for each measurement plane. Consequently, the 0° reference orientation may not align circumferentially within a pup or across a specimen. As a result, additional OD and wall measurements may be required when monitoring pipe body bending with strain gauges as the gauges may not be aligned with existing OD and wall measurements.

Based on the measurements from Table D.2 and Table D.3, the dimensional inputs for the specimen pipe body reference curves based on actual dimensions are as follows.

— Maximum Average OD = **9.697** (from Pup A Plane 1).

— Minimum Average Wall = **0.540** (from Pup A Plane 2).

— Minimum Wall = **0.507** (from Pup B Plane 3 and Plane 4).

D.3 Test Specimen Pipe Body Reference Envelope at Ambient Temperature

D.3.1 General

As shown in Figure 2, pipe body reference curves shall be calculated based on specified and measured pipe body dimensions and material yield strengths at ambient temperature. Table D.4 summarizes the specified and measured pipe dimensions, specified and actual material yield strengths, and proprietary high collapse rating for this specimen.

Table D.4—Example Pipe Parameters Used to Calculate Reference Curves at Ambient Temperature

Specified OD	Specified Wall	SMYS	D_{avg}	t_{min}	t_{avg}	AMYS[a]	HC Rating
9.625 in.	**0.545** in.	**110,000** psi	**9.697** in.	**0.507** in.	**0.540** in.	**125,000** psi	**9140** psi

D.3.2 Curve 1[a]: Pipe Body Nominal VME Curve at Ambient Temperature

The pipe body nominal VME curve at ambient temperature (Curve 1[a]) shall be a plot of the API 5C3, Section 6 variables p_i and p_o vs F_a. For any given load F_a, Equation (12) of API 5C3 shall be used to calculate the internal pressure p_i such that the equivalent stress σ_e equals SMYS with no external pressure applied. For any given load F_a, Equation (12) of API 5C3 shall be used to calculate the external pressure p_o such that the equivalent stress σ_e equals SMYS with no internal pressure applied. Table D.5 describes the input parameters that shall be used in the calculation of the pipe body nominal VME curve (Curve 1[a]). Figure D.4 depicts the resulting plot of the pipe body nominal VME curve.

Table D.5—Pipe Input Parameters and Pipe Parameter Descriptions for Nominal VME Curve

API 5C3, Section 6 (Curve 1[a])	
Pipe Input Parameter	**Pipe Parameter Description**
$\sigma_e = f_{ymn}$ = 110,000 psi	SMYS
D = 9.625 in.	Specified OD
t = 0.545	Specified wall thickness
t_{min} = 0.875 * t = 0.477 in.	Minimum wall thickness
$d_{wall} = D - 2t_{min}$ = 8.671 in.	Maximum ID
$d = D - 2t$ = 8.535 in.	Nominal ID
$A_p = \pi/4\ (D^2 - d^2)$ = 15.5465 in.^{2}	Nominal cross-sectional area

Equations (3) through (5) and Equation (12) are taken directly from API 5C3 and are subject to change. The equations shall be verified with the latest edition of API 5C3 prior to their usage.

If bending and torsion are zero, the equivalent stress is defined as:

$$\sigma_e = [\sigma_r{}^2 + \sigma_h{}^2 + \sigma_a{}^2 - \sigma_r\sigma_h - \sigma_r\sigma_a - \sigma_h\sigma_a]^{1/2} \tag{12}$$

with

$$\sigma_r = [(p_i d_{wall}{}^2 - p_O D^2) - (p_i - p_O) d_{wall}{}^2 D^2/(4r^2)]/(D^2 - d_{wall}{}^2) \tag{3}$$

$$\sigma_h = [(p_i d_{wall}{}^2 - p_O D^2) + (p_i - p_O) d_{wall}{}^2 D^2/(4r^2)]/(D^2 - d_{wall}{}^2) \tag{4}$$

$$\sigma_a = F_a/A_p \tag{5}$$

NOTE The maximum stress is achieved when $r = d_{wall}/2$.

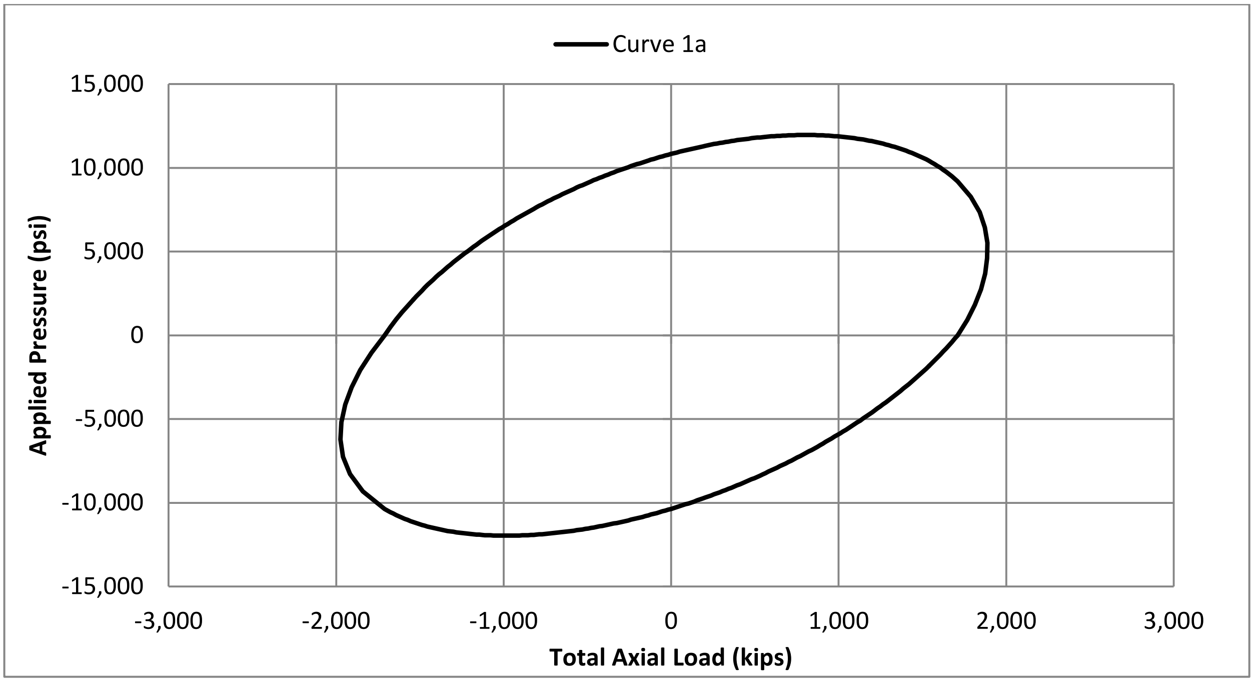


Figure D.4—Pipe Body Nominal VME Curve at Ambient Temperature

D.3.3 Curve 2[a]: Pipe Body Nominal API Collapse Curve at Ambient Temperature

The pipe body nominal API collapse curve at ambient temperature (Curve 2[a]) shall be a plot of the API 5C3, Section 8 parameters p_o vs F_a. For any given axial load F_a, the nominal API collapse pressure shall be calculated using API 5C3, Section 8 equations for pipe body collapse. Table D.6 describes the parameters that shall be used to calculate the nominal API collapse curve. Figure D.5 depicts the resulting plot of the pipe body nominal API collapse curve.

Table D.6—Pipe Input Parameter and Pipe Parameter Descriptions for Nominal API Collapse Curve

API 5C3, Section 8 (Curve 2[a])	
Pipe Input Parameter	**Pipe Parameter Description**
f_{ymn} = 110,000 psi	SMYS
D = 9.625 in.	Specified OD
t = 0.545 in.	Specified wall
$d = D - 2t$ = 8.535 in.	Nominal ID
$A_p = \pi/4\ (D^2 - d^2)$ = 15.5465 in.^{2}	Nominal cross-sectional area
$\sigma_a = F_a/A_p$	Axial stress

Below, 8.4.2 through 8.4.6 and 8.5.3 are taken directly from API 5C3 and are subject to change. The equations shall be verified with the latest edition of API 5C3 prior to their usage.

8.4.2 Yield strength collapse pressure equation

The yield strength collapse pressure is not a true collapse pressure, but rather the external pressure, p_{Yp}, that generates the minimum yield stress, f_{ymn}, on the inside wall of a tube as calculated by Equation (35).

$$p_{Yp} = 2\, f_{ymn} \frac{\left[\left(\frac{D}{t}\right) - 1\right]}{\left(\frac{D}{t}\right)^2} \tag{35}$$

Equation (35) for yield strength collapse pressure is applicable for D/t values up to the value of D/t corresponding to the intersection with the plastic collapse Equation (37). This intersection is calculated by Equation (36) as follows:

$$\left(\frac{D}{t}\right)_{yp} = \frac{\left\{\left[(A_C - 2)^2 + 8\left(B_C + \frac{C_C}{f_{ymn}}\right)\right]^{1/2} + (A_C - 2)\right\}}{\left[2\left(B_C + \frac{C_C}{f_{ymn}}\right)\right]} \tag{36}$$

8.4.3 Plastic collapse pressure equation

The minimum collapse pressure for the plastic range of collapse is calculated by Equation (37):

$$p_P = f_{ymn}\left[\frac{A_c}{\frac{D}{t}} - B_C\right] - C_C \tag{37}$$

The equation for minimum plastic collapse pressure is applicable for D/t values ranging from $(D/t)_{yp}$, Equation (36) for yield strength collapse pressure, to the intersection with Equation (39) for transition collapse pressure $(D/t)_{pt}$. Values for $(D/t)_{pt}$ are calculated by means of Equation (38):

$$\left(\frac{D}{t}\right)_{pt} = \frac{\left[f_{ymn}(A_C - F_C)\right]}{\left[C_C + f_{ymn}(B_C - G_C)\right]} \tag{38}$$

8.4.4 Transition collapse pressure equation

The minimum collapse pressure for the plastic to elasitic transition zone, p_T, is calculated by Equation (39):

$$p_T = f_{ymn}\left[\frac{F_C}{\frac{D}{t}} - G_C\right] \tag{39}$$

The equation for p_T is applicable for D/t values from $(D/t)_{pt}$, Equation (38) for plastic collapse pressure, to the intersection $(D/t)_{te}$ with Equation (41) for elastic collapse. Values for $(D/t)_{te}$ are calculated by Equation (40):

$$\left(\frac{D}{t}\right)_{te} = \frac{\left[2 + \frac{B_C}{A_C}\right]}{\left[3\left(\frac{B_C}{A_C}\right)\right]} \tag{40}$$

8.4.5 Elastic collapse pressure equation

The minimum collapse pressure for the elastic range of collapse is calculated by Equation (41):

$$p_E = \frac{46.95 \times 10^6}{\left[\left(\frac{D}{t}\right)\left(\frac{D}{t} - 1\right)^2\right]} \tag{41}$$

8.4.6 Collapse pressure under axial tension stress

The collapse resistance of casing in the presence of an axial stress is calculated by modifying the yield stress to an axial stress equivalent grade according to Equation (42):

$$f_{yax} = \left(\left[1 - 0.75\left(\frac{\sigma_a}{f_{ymn}}\right)^2\right]^{\frac{1}{2}} - \frac{0.5\,\sigma_a}{f_{ymn}}\right) f_{ymn} \tag{42}$$

8.5.3 USC units

$$A_C = 2.8762 + 0.10679 \times 10^{-5} f_{ymn} + 0.21301 \times 10^{-10} f_{ymn}^2 - 0.53132 \times 10^{-16} f_{ymn}^3 \tag{49}$$

$$B_C = 0.026233 + 0.50609 \times 10^{-6} f_{ymn} \tag{50}$$

$$C_C = -465.93 + 0.030867 f_{ymn} - 0.10483 \times 10^{-7} f_{ymn}^2 + 0.36989 \times 10^{-13} f_{ymn}^3 \tag{51}$$

$$F_C = \frac{46.95 \times 10^6 \left[\frac{\left(\frac{3\,B_C}{A_C}\right)}{\left(2 + \frac{B_C}{A_C}\right)}\right]^3}{\left\{ f_{ymn}\left[\frac{\frac{3B_C}{A_C}}{2 + \frac{B_C}{A_C}} - \frac{B_C}{A_C}\right]\left[1 - \frac{3\,\frac{B_C}{A_C}}{2 + \frac{B_C}{A_C}}\right]^2 \right\}} \tag{52}$$

$$G_C = F_C B_C / A_C \tag{53}$$

There is no guidance given in API 5C3 for pipe body performance under combined external pressure (p_o) and compression (F_c). The industry convention is to maintain the uni-axial collapse pressure rating constant throughout QIII; therefore, for combinations of F_a, p_o is equal to p_c. With this assumption, the pipe body API collapse curve in QIII can be defined for combinations of F_a and p_o, such that for p_o equal to p_c, F_a ranges from zero to F_c, and for F_a equal to F_c, p_o ranges from zero to p_c. Graphically, this is the intersection of the horizontal line between points (0, p_c) and (F_c, p_c) and the vertical line between points (F_c, 0) and (F_c, p_c).

API 5C3, Equation (42) is only valid for tension values between zero and an axial stress equivalent grade of 24 ksi. As a result, the collapse pressure is assumed constant under compressive axial loads and becomes undefined under higher tension loads, as shown in Figure D.5.

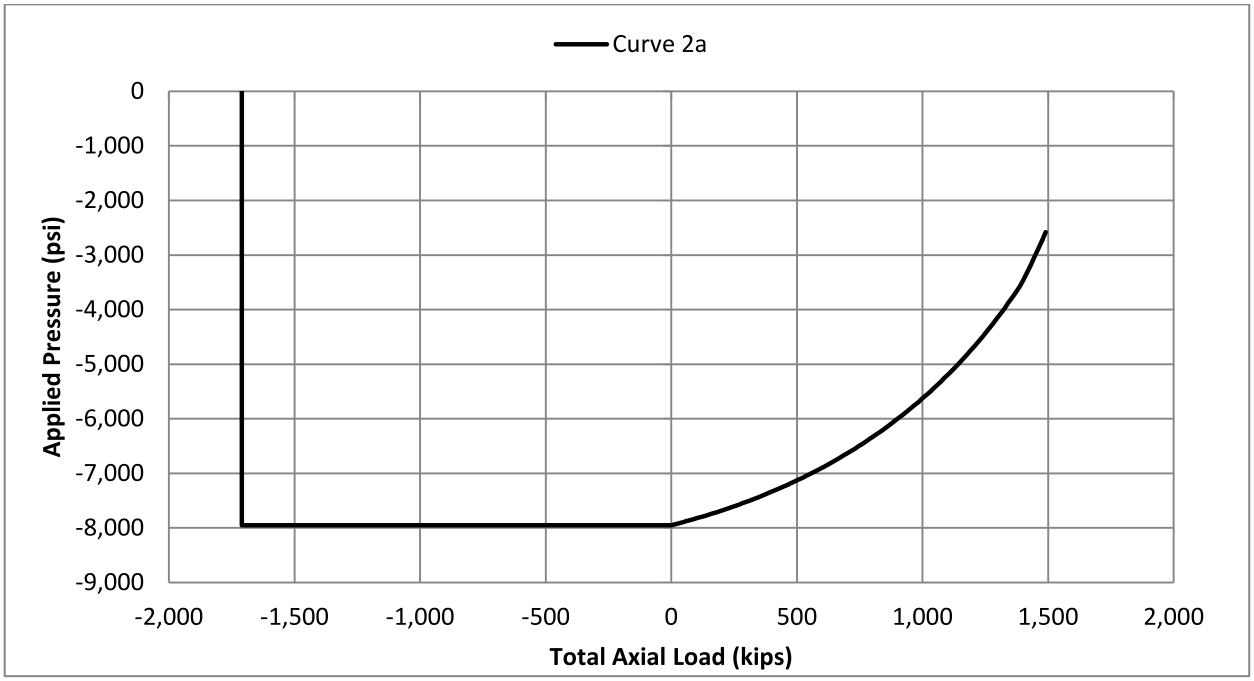


Figure D.5—Pipe Body Nominal API Collapse Curve at Ambient Temperature

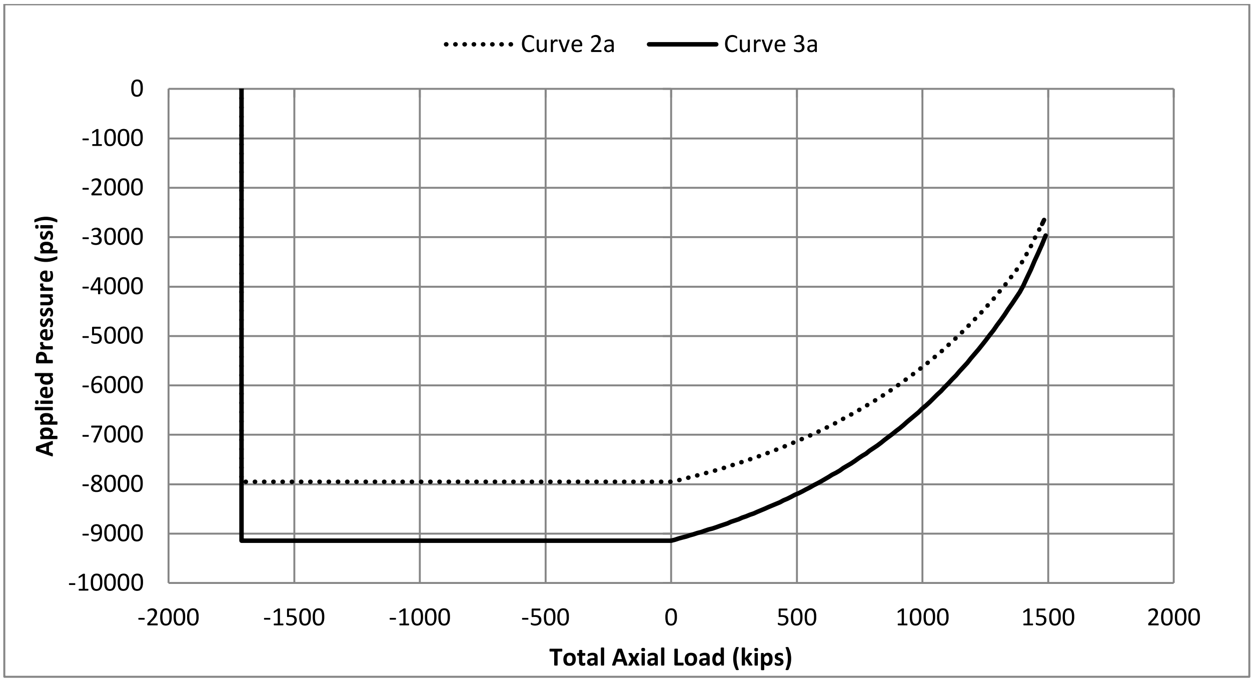
D.3.4 Curve 3[a]: Proprietary High Collapse Curve at Ambient Temperature

For proprietary high collapse rated pipe grades, manufacturers may only specify the high collapse rating at zero axial load. However, for the purposes of API 5C5 testing, this rating shall be extrapolated to provide testing guidance for axial loads. As a result, the pipe body proprietary high collapse reference curve (Curve 3[a]) at ambient temperature shall be uni-axially scaled outward from the nominal API collapse curve (Curve 2[a]) using the ratio between the uni-axial proprietary high collapse value and the uni-axial nominal API collapse value as the scaling factor. See D.3.3 to calculate the nominal API collapse curve.

From the nominal API collapse curve, for each axial load F_a multiply p_o by the scaling factor to generate p_o for the proprietary high collapse curve. The proprietary high collapse curve shall be plotted. Table D.7 defines the parameters that shall be used in the calculation of the proprietary high collapse curve and Figure D.6 depicts the resulting plots of the specimen nominal API and proprietary high collapse curves.

Table D.7—Pipe Input Parameters and Pipe Parameter Descriptions for Proprietary High Collapse Curve

API 5C3, Section 8 (Curve 2[a])		API 5C5 (Curve 3[a])	
Pipe Input Parameter	**Pipe Parameter Description**	**Pipe Input Parameter for Specimen**	**Pipe Parameter Description for Specimen**
p_o = −7950 psi	Nominal API collapse rating	p_o = −9140 psi	Proprietary high collapse rating
—	—	K_{hc} = 9140/7950 = 1.1497	Uni-axial scaling factor



NOTE The pipe body nominal API collapse curve is shown for comparison.

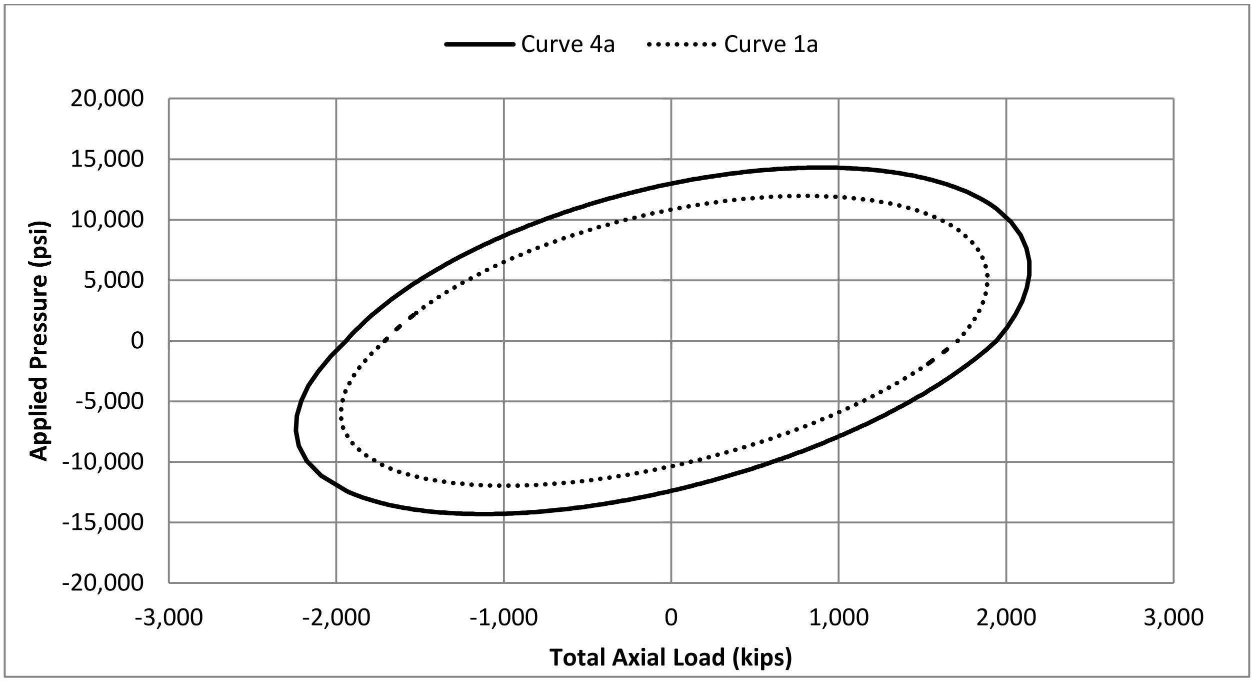
Figure D.6—Pipe Body Nominal API Collapse and Proprietary High Collapse Curves at Ambient Temperature

D.3.5 Curve 4[a]: Test Specimen Pipe Body Actual VME Curve at Ambient Temperature

Due to differences in actual material dimensions and yield strength, the test specimen will have pipe body performance properties that are different from the nominal VME ratings calculated in D.2.2 for Curve 1[a]. As a result, the test specimen pipe body actual VME curve at ambient temperature (Curve 4[a]) shall be a plot of the API 5C3, Section 6 variables p_i and p_o vs F_a based on actual test specimen pipe body dimensions and material yield strength. For any given load F_a, Equation (12) of API 5C3 shall be used to calculate the internal pressure p_i such that the equivalent stress σ_e equals AMYS[a] with no external pressure applied. For any given load F_a, Equation (12) of API 5C3 shall be used to calculate the external pressure p_o such that the equivalent stress σ_e equals AMYS[a] with no internal pressure applied. Descriptions for the pipe input parameters used in the API 5C3, Section 6 equations are unique to this RP. Table D.8 describes the input parameters that shall be used in the calculation of the test specimen pipe body actual VME curve (Curve 4[a]). Figure D.7 depicts the resulting plot of the test specimen pipe body actual VME curve.

Table D.8—Pipe Input Parameters and Pipe Parameter Descriptions for Actual VME Curve

API 5C3, Section 6 (Curve 1[a])		API 5C5 (Curve 4[a])	
Pipe Input Parameter	**Pipe Parameter Description**	**Pipe Input Parameter for Specimen**	**Pipe Parameter Description for Specimen**
$\sigma_e = f_{ymn}$ = 110,000 psi	SMYS	σ_e = AMYS[a] = 125,000 psi	AMYS[a] at ambient temperature
D = 9.625 in.	Specified OD	$D = D_{avg}$ = 9.697 in.	Measured maximum average OD
t = 0.545	Specified wall thickness	$t = t_{avg}$ = 0.540 in.	Measured minimum average wall thickness
t_{min} = 0.875 * t = 0.477 in.	Minimum wall thickness	t_{min} = 0.507 in.	Measured minimum wall thickness
$d_{wall} = D - 2t_{min}$ = 8.671 in.	Maximum ID	$d_{wall} = D_{avg} - 2t_{min}$ = 8.683 in.	Maximum ID
$d = D - 2t$ = 8.535 in.	Nominal ID	$d = d_{avg} = D_{avg} - 2t_{avg}$ = 8.617 in.	Maximum average ID
$A_p = \pi/4\ (D^2 - d^2)$ = 15.5465 in.^{2}	Nominal cross-sectional area	$A_p = \pi/4\ (D_{avg}^2 - d_{avg}^2)$ = 15.5345 in.^{2}	Actual cross-sectional area



NOTE The pipe body nominal VME curve is shown for comparison.

Figure D.7—Test Specimen Pipe Body Actual and Nominal VME Curves at Ambient Temperature

D.3.6 Curve 5[a]: Test Specimen Pipe Body Actual API Collapse Curve at Ambient Temperature

Although the API 5C3, Section 8 collapse equations were not developed based on actual pipe dimensions or material yield strength, an actual API collapse curve is desirable for test evaluation purposes. The test specimen pipe body actual API collapse curve at ambient temperature (Curve 5[a]) shall be a plot of the API 5C3, Section 8 variables p_o vs F_a based on the test specimen actual pipe body dimensions and material yield strength. For any given axial load F_a, the test specimen pipe body collapse pressure p_o is calculated using modifications to the API 5C3, Section 8 equations for pipe body collapse. The descriptions for the input parameters used in Section 8 of API 5C3 are unique to this RP. Table D.9 describes the input parameters that shall be used in the calculation of the test specimen pipe body actual API collapse curve (Curve 5[a]). Figure D.8 is the resulting plot of the test specimen pipe body actual API collapse curve.

Table D.9—Pipe Input Parameters and Pipe Parameter Descriptions for Actual API Collapse Curve

API 5C3, Section 8 (Curve 2[a])		API 5C5 (Curve 5[a])	
Pipe Input Parameter	**Pipe Parameter Description**	**Pipe Input Parameter for Specimen**	**Pipe Parameter Description for Specimen**
f_{ymn} = 110,000 psi	SMYS	f_{ymn} = AMYS[a] = 125,000 psi	AMYS[a] at ambient temperature
D = 9.625 in.	Specified OD	$D = D_{avg}$ = 9.697 in.	Measured maximum average OD
t = 0.545 in.	Specified wall	$t = t_{avg}$ = 0.540 in.	Measured minimum average wall thickness
$d = D - 2t$ = 8.535 in.	Nominal ID	$d = d_{avg} = D_{avg} - 2t_{avg}$ = 8.617 in.	Maximum average ID
$A_p = \pi/4(D^2 - d^2)$ = 15.5465 in.^{2}	Nominal cross-sectional area	$A_p = \pi/4\ (D_{avg}^2 - d_{avg}^2)$ = 15.5345 in.^{2}	Actual cross-sectional area
$\sigma_a = F_a/A_p$	Axial stress	$\sigma_a = F_a/A_p$	Axial stress

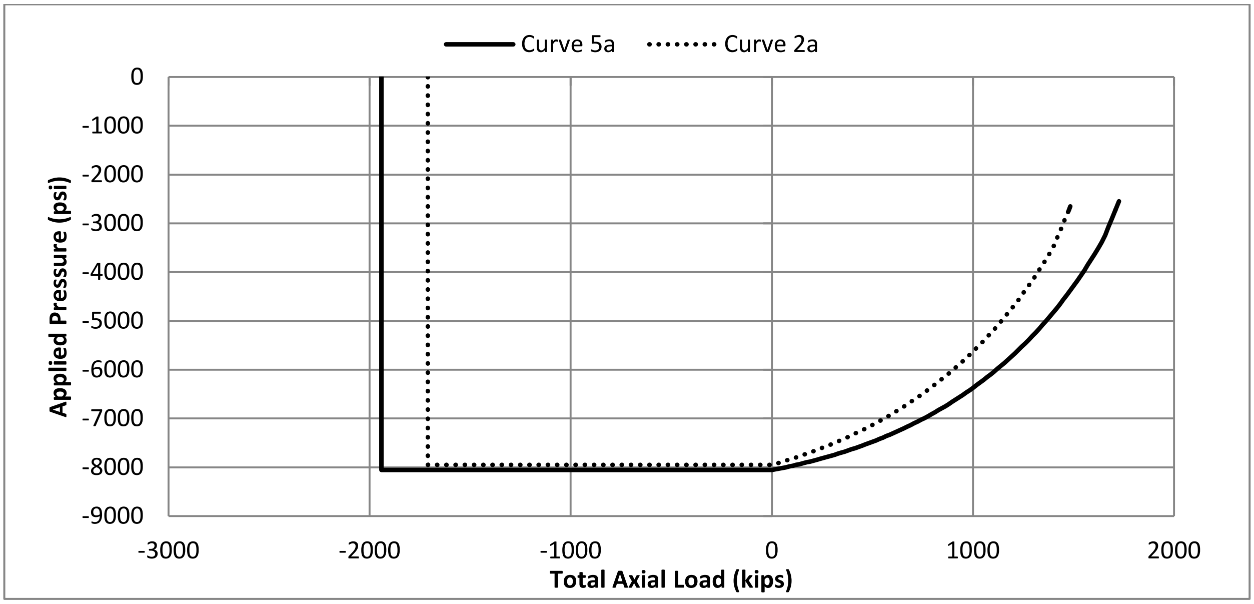


Figure D.8—Test Specimen Pipe Body Actual and Nominal API Collapse Curves at Ambient Temperature

The pipe body nominal API collapse curve is shown for comparison purposes. API 5C3, Section 8 does not provide guidance for calculating the collapse value of pipe based on actual test specimen dimensions and material yield strength. Depending on the actual test specimen pipe body dimensions and material yield strength, the actual API collapse pressure, p_o, could be less than the nominal API pipe body collapse rating, p_c.

D.4 Test Specimen Pipe Body Reference Envelope at Elevated Temperature

D.4.1 General

As shown in Figure 2, pipe body reference curves at elevated temperature shall be calculated by bi-axially scaling the ambient temperature pipe body reference curves calculated in D.3 inward using K_{temp} as the scaling factor. Table D.10 summarizes the specified and measured pipe dimensions, SMYS, actual yield strength test results, and proprietary high collapse rating.

Table D.10—Parameters Used to Calculate Reference Curves at Elevated Temperature

Specified OD	Specified Wall	SMYS	D_{avg}	t_{min}	t_{avg}	AMYS[a]	AAYS[a]	AAYS[e]	HC Rating	Max Temp
9.625 in.	**0.545** in.	110,000 psi	**9.697** in.	**0.507** in.	**0.540** in.	**125,000** psi	**125,000** psi	**110,800** psi	**9140** psi	**383 °F**

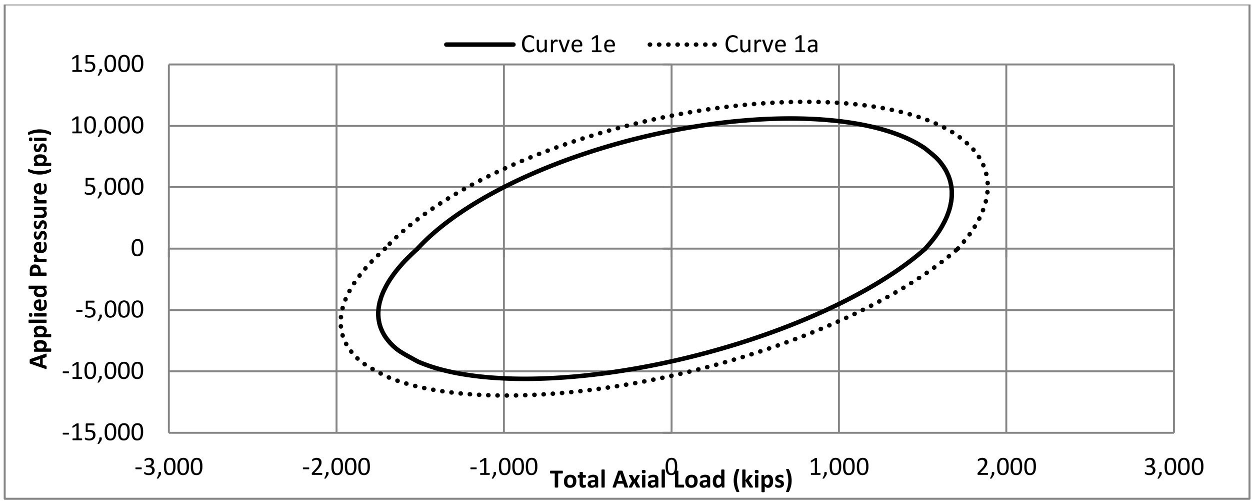
Refer to Table D.11 for the calculation of the elevated temperature scaling factor (K_{temp}). Since there is no guidance on determining SMYS at elevated temperature, the elevated temperature scaling factor as a function of AAYS[e] and AAYS[a] shall be used to scale the nominal as well as the actual elevated temperature reference curves. Since AAYS is used, the nominal reference curves need to be calculated for each test specimen if the specimens are from different mother joints.

Table D.11—Calculation of Scaling Factor for Reference Curves at Elevated Temperature

API 5C5, Section D.2.3	
Pipe Input Parameter for Specimen	**Pipe Parameter Description for Specimen**
AAYS[a] = 125,000 psi	AAYS[a] of the specimen mother joint at ambient temperature
AAYS[e] = 110,800 psi	AAYS[e] of the specimen mother joint at elevated temperature
$K_{383°}$ = AAYS[e]/AAYS[a] = **0.8864**	Elevated temperature scaling factor

D.4.2 Curve 1^e: Test Specimen Pipe Body Nominal VME Curve at Elevated Temperature

The test specimen pipe body nominal VME curve at elevated temperature (Curve 1^e) shall be bi-axially scaled inward from the pipe body nominal VME curve at ambient temperature (Curve 1^a) using $K_{383°}$ as the scaling factor. For any given load F_a, multiply both F_a and p_i or p_o by the scaling factor. Table D.11 describes the parameters that shall be used to calculate the scaling factor. Curve 1^e and Curve 1^a are shown in Figure D.9.

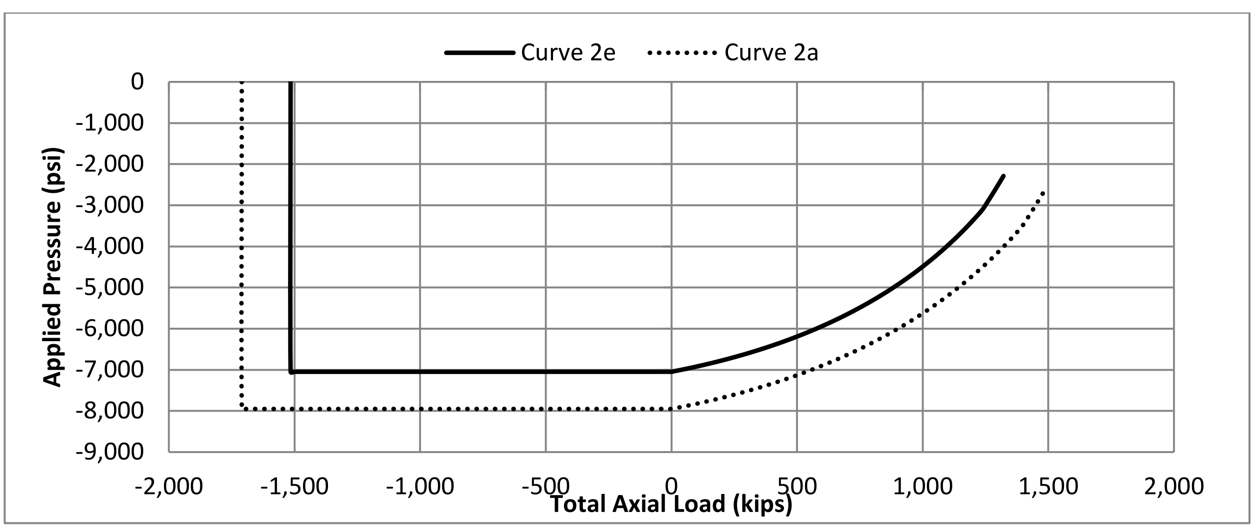


NOTE Curve 1^a is shown for reference.

Figure D.9—Test Specimen Pipe Body Nominal VME Curves at Ambient and Elevated Temperature

D.4.3 Curve 2^e: Test Specimen Pipe Body Nominal API Collapse Curve at Elevated Temperature

Since API 5C3 does not provide guidance for determining collapse properties at elevated temperature, the test specimen pipe body nominal API collapse curve at elevated temperature (Curve 2^e) shall be bi-axially scaled inward from the pipe body nominal API collapse curve at ambient temperature (Curve 2^a) using $K_{383°}$ as the scaling factor. For any given load F_a, multiply both F_a and p_o by the scaling factor. Table D.11 describes the parameters that shall be used to calculate the scaling factor. Curve 2^e and Curve 2^a are depicted in Figure D.10.

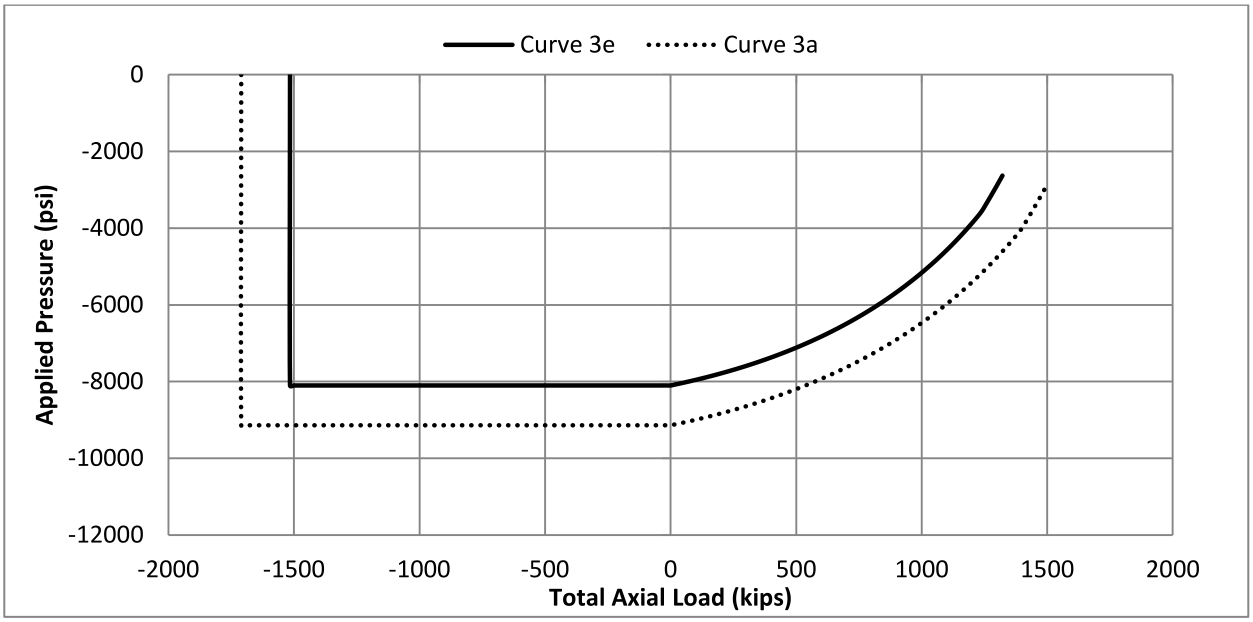


NOTE Curve 2^a is shown for reference.

Figure D.10—Test Specimen Pipe Body Nominal API Collapse Curve at Ambient and Elevated Temperature

D.4.4 Curve 3^e: Test Specimen Proprietary High Collapse Curve at Elevated Temperature

For proprietary high collapse pipe, manufacturers typically only specify the high collapse rating at zero axial load and ambient temperature. However, for the purposes of API 5C5 testing, the ambient proprietary high collapse rating at zero axial load shall be extrapolated to provide testing guidance for axial loads at elevated temperature. As a result, the test specimen pipe body proprietary high collapse curve at elevated temperature (Curve 3^e) shall be bi-axially scaled inward from the proprietary high collapse curve at ambient temperature (Curve 3^a) using $K_{383°}$ as the scaling factor. For any given load F_a, multiply both F_a and p_o by the scaling factor. Table D.11 describes the parameters that shall be used to calculate the scaling factor. Curve 3^e and Curve 3^a are shown in Figure D.11. Alternative scaling methods may be used in the calculation of the pipe body reference envelopes at elevated temperature provided they are reported in API 5C3 or experimental evidence of these can be demonstrated and is included in detail in the test plan.

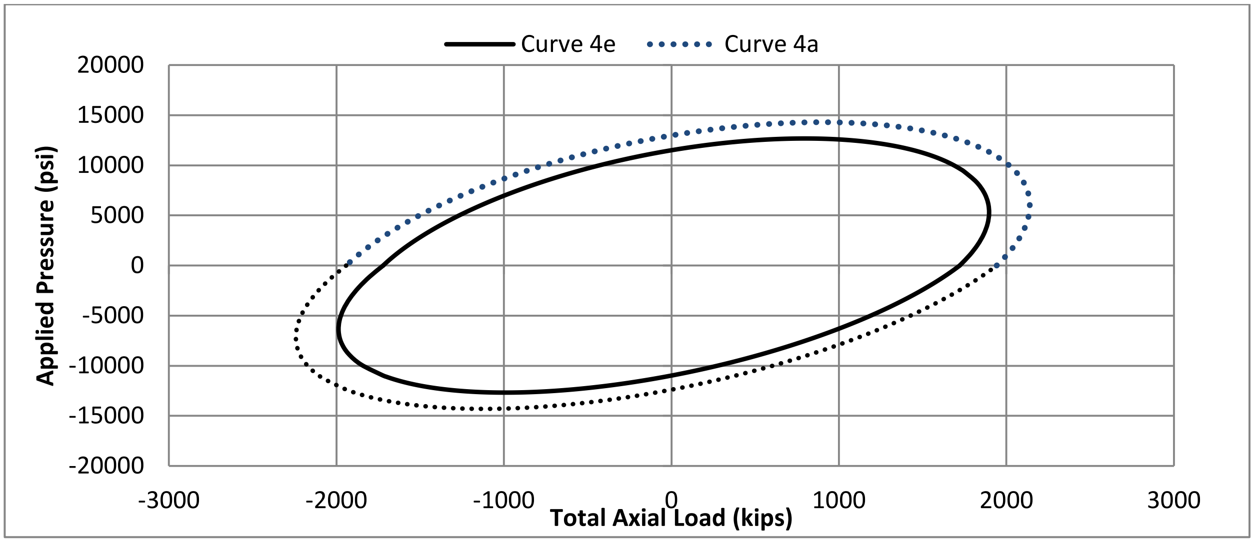


NOTE Curve 3^a is shown for reference.

Figure D.11—Test Specimen Pipe Body Proprietary High Collapse Curve at Ambient and Elevated Temperature

D.4.5 Curve 4^e: Test Specimen Pipe Body Actual VME Curve at Elevated Temperature

The test specimen pipe body actual VME curve at elevated temperature (Curve 4^e) shall be bi-axially scaled inward from the test specimen pipe body actual VME curve at ambient temperature (Curve 4^a) using $K_{383°}$ as the scaling factor. For any given load F_a, multiply both F_a and p_i or p_o by the scaling factor. Table D.11 describes the parameters that shall be used to calculate the scaling factor. Curve 4^e and Curve 4^a are shown in Figure D.12.

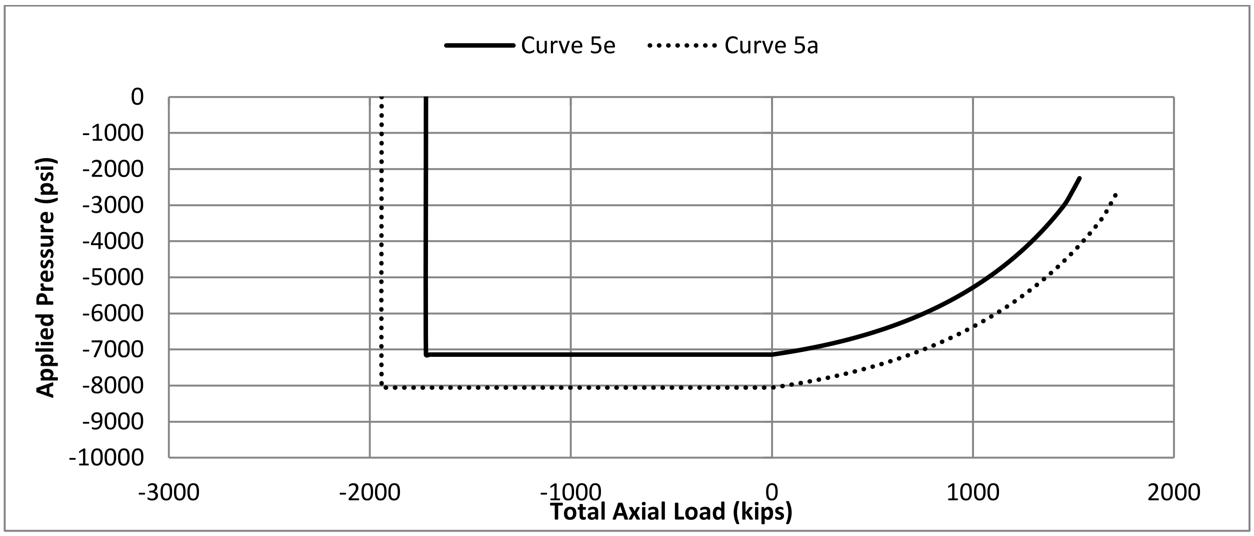


NOTE Curve 4[a] is shown for reference.

Figure D.12—Test Specimen Pipe Body Actual VME Curves at Ambient and Elevated Temperature

D.4.6 Curve 5[e]: Test Specimen Pipe Body Actual API Collapse Curve at Elevated Temperature

Since API 5C3 does not provide guidance for determining collapse properties at elevated temperature, the test specimen pipe body actual API collapse curve at elevated temperature (Curve 5[e]) shall be bi-axially scaled inward from the test specimen pipe body actual API collapse curve at ambient temperature (Curve 5[a]) using $K_{383°}$ as the scaling factor. For any given load F_a, multiply both F_a and p_o by the scaling factor. Table D.11 describes the parameters that shall be used to calculate the scaling factor. Curve 5[e] and Curve 5[a] are shown in Figure D.13.



NOTE Curve 5[a] is shown for reference.

Figure D.13—Test Specimen Pipe Body API Actual Collapse Curve at Ambient and Elevated Temperature

D.5 Definition for CEE Points and TLE Load Points Without Bending

D.5.1 General

As stated in 4.2, it is the intent of this RP to test each specimen to as high a load or combination of loads as safely practical. Some connection performance properties may not be impacted by actual pipe body dimensions or material yield strength. The methodology used to define the connection performance for a specific test specimen is assumed to be proprietary in nature. The manufacturer is responsible for defining the CEE based on the connection design, test specimen pipe body and connection actual dimensions, and test specimen pipe body and connection actual material yield strengths at both ambient and elevated temperature. Once the CEE has been established by the manufacturer, the CEE points can be determined using Table 8. From the CEE points, TLE load points are determined for each test specimen based on bi-axial scaling at 80 %, 90 %, 95 %, or 100 % (whichever applies) of the CEE as defined in Table 8. There are 32 CEE points that define the TLE load points at ambient temperature, whereas only 15 CEE points define the TLE load points at elevated temperature. The individual TLE load points establish the TLE.

As required by 7.3.5.3 and Table 14, TLE load points 28_a90, 29_a90, 30_a90, and 31_a90 have been established to specify the load path for the ambient temperature mechanical cycles in TS-C (see Figure 34). There is no CEE point used as the basis for these TLE load points; they depend on TLE load point 14_a90.

The CEE may be limited by the pipe body or connection performance properties. If the CEE is less than the pipe body reference envelope, the bi-axial scaling factors depend on whether the CEE limitation is based on material yield strength or some other factor. If the CEE limitation is based on material yield strength, the TLE shall be scaled to 80 %, 90 %, or 95 % (whichever applies) of the CEE. If the CEE limitation is due to a factor other than material yield strength, then the TLE shall be 100 % of the CEE. Some examples of connection CEE limitations that would require 100 % scaling factors include connections limited to API MYIP (minimum internal yield pressure as defined by API 5C3) and connections limited to the nominal API collapse pressure. The 80 % scaling factor applies both to CEE's limited by material yield strength and to CEE's limited by some other factor.

The ambient and elevated temperature pipe body reference curves developed in D.3 and D.4, respectively, are used to evaluate and interpret the test results.

As shown in Figure 2, the manufacturer shall determine the CEE at ambient and elevated temperature for each test specimen. The TLEs at ambient and elevated temperature are developed based on the corresponding CEE as shown in Figure 3. Table D.12 summarizes the specified and measured dimensions, specified and actual material yield strengths, proprietary high collapse rating, and $K_{383°}$ used to calculate the CEE and TLE for this example.

Table D.12—Parameters Used to Calculate Reference Curves

Specified OD	Specified Wall	SMYS	D_{avg}	t_{min}	t_{avg}	AMYS[a]	HC Rating	$K_{383°}$	Max Temp
9.625 in.	**0.545** in.	**110,000** psi	**9.697** in.	**0.507** in.	**0.540** in.	**125,000** psi	**9140** psi	**0.8864**	**383** °F

D.5.2 CEE at Ambient and Elevated Temperature

In this example, the CEE is the same as the specimen pipe body actual VME curve for internal pressure loads at both ambient and elevated temperature. For external pressure loads, the CEE is equal to the lesser of the test specimen pipe body actual VME curve and maximum of the proprietary high collapse curve and the test specimen actual API collapse curve at both ambient and elevated temperature.

Therefore, for this example CEE[a] $t = F_t$

From Table D.8:

CEE[a] $t = A_p$ * AMYS[a] = 15.5345 * 125,000/1000 = 1942 kips

CEE[a] c = −CEE[a] t = −1942 kips

For F_a, CEE[a] p_i = Curve 4[a] p_i

For F_a, CEE[a] p_o = Min [90 % or 95 % of Curve 4[a], Max (100 % of Curve 3[a], 90 % or 95 % of Curve 5[a])] p_o

The CEE[a] depends on three test specimen pipe body reference curves. For external pressure, the controlling reference curve is a function of the axial load. The resulting CEE for ambient temperature is shown in Figure D.14 along with the three relevant specimen pipe body reference curves (Curve 3[a], Curve 4[a], and Curve 5[a]).

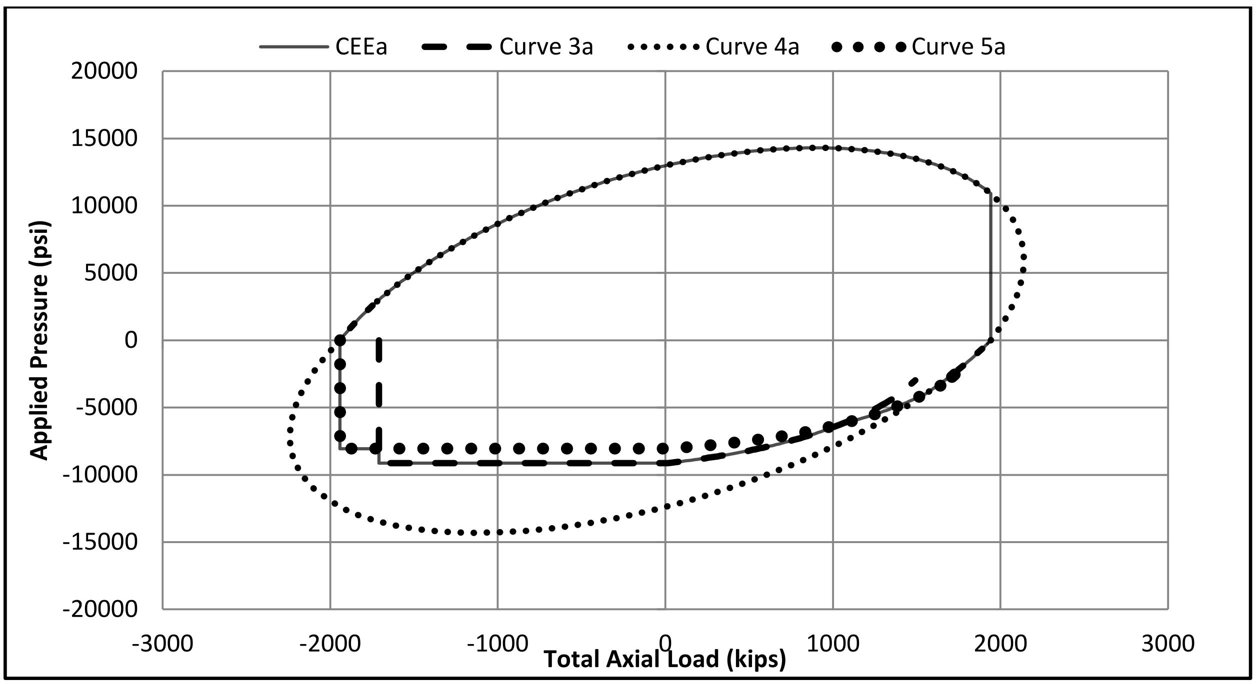


Figure D.14—Test Specimen CEE[a] at Ambient Temperature

From Table D.11:

CEE[e] t = CEE[a] $t * K_{temp}$ = 1942 * 0.8864 = 1721 kips

CEE[e] c = −CEE[e] t = −1721 kips

For F_a, CEE[e] p_i = Curve 4[e] p_i

For F_a, CEE[e] p_o = Min [90 % of Curve 4[e], Max (100 % of Curve 3[e], 90 % of Curve 5[e])] p_o

The CEE[e] depends on three test specimen pipe body reference curves. For external pressure, the controlling reference curve is a function of the axial load. The resulting CEE for elevated temperature is shown in Figure D.15 along with the three relevant specimen pipe body reference curves (Curve 3[e], Curve 4[e], and Curve 5[e]).

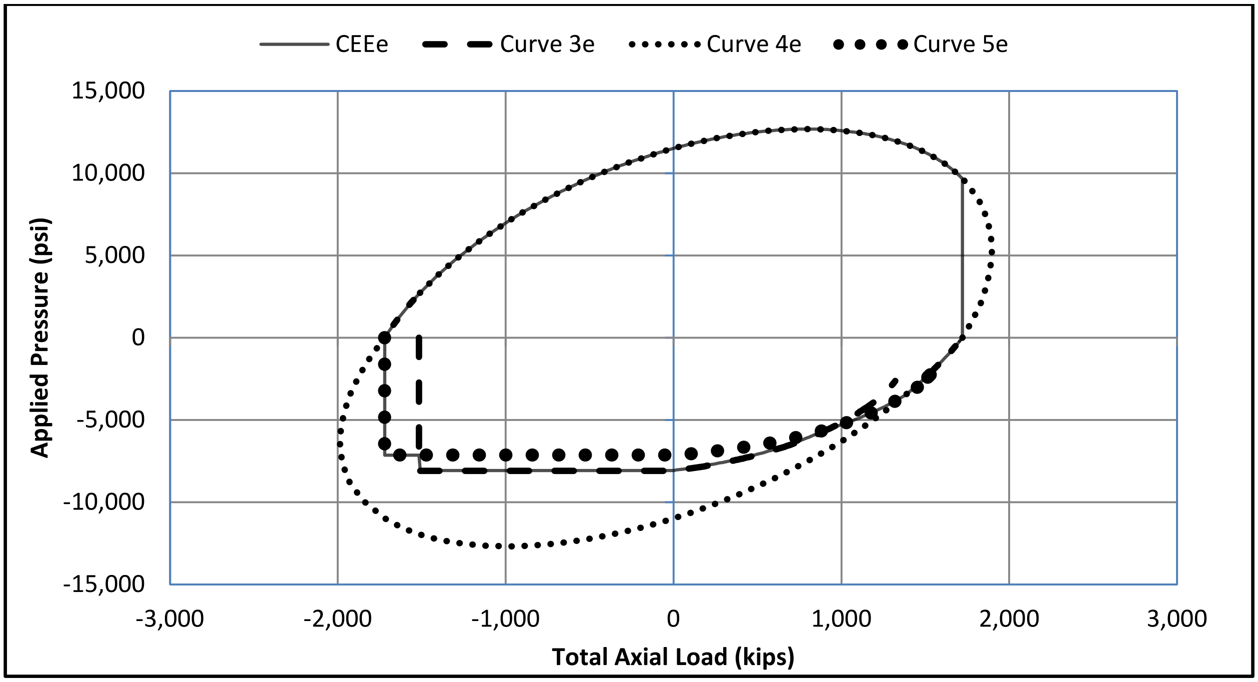


Figure D.15—Test Specimen CEE[e] at Elevated Temperature

D.5.3 CEE[a] Points and 80 % TLE[a] Load Points at Ambient Temperature

Refer to the equations for load points 1_a80 through 9_a80 in Table 8 to calculate CEE[a] F_a and p_i, and TLE[a] F_a and p_i.

For CEE[a] LP 1_a80 through LP 9_a80, LP 1_a80, LP 4_a80, LP 5_a80, LP 6_a80, LP 7_a80, and LP 9_a80 lie on the CEE[a]. LP 2_a80 and LP 3_a80 are a function of LP 4_a80, and LP 8_a80 is a function of LP 7_a80.

For TLE[a] LP 1_a80 through LP 9_a80, LP 4_a80 through LP 7_a80 are bi-axially scaled to the CEE[a] point indicated in Table 8 based on the specified 80 % bi-axial scaling factor. LP 2_a80, LP 3_a80, and LP 8_a80 are based on other TLE[a] load points and do not require bi-axial scaling. LP 1_a80 requires a specific 0.67 scaling factor so that the TLE F_a is constant for LP 1_a80 through LP 4_a80. Similarly, LP 9_a80 requires a specific 0.50 scaling factor so that the TLE F_a is constant for LP 7_a80 through LP 9_a80.

Example calculations for LP 4_a80:

LP 4_a80 CEE[a] F_a = 0.67/0.80 * CEE[a] t = 0.67/0.80 * 1942 = 1626 kips

LP 4_a80 CEE[a] p_i = 100 % CEE p_i @ CEE[a] F_a = 13,003 psi

LP 4_a80 TLE[a] F_a = 0.80 * LP 4_a80 CEE[a] F_a = 0.80 * 1626 = 1301 kips

LP 4_a80 TLE[a] p_i = 0.80 * LP 4_a80 CEE[a] p_i = 0.80 * 13,003 = 10,402 psi

Example calculations for LP 3_a80:

LP 3_a80 CEE[a] F_a = not applicable

LP 3_a80 CEE[a] p_i = not applicable

LP 3_a80 TLE[a] F_a = 0.80 * LP 4_a80 CEE[a] F_a = 0.80 * 1626 = 1301 kips

LP 3_a80 TLE[a] p_i = 0.50 * 0.80 * LP 4_a80 CEE[a] p_i = 0.50 * 0.80 * 13,003 = 5201 psi

Example calculations for LP 7_a80:

LP 7_a80 CEE[a] F_a = 0.50/0.80 * CEE[a] c = 0.50/0.80 * −1942 = −1214 kips

LP 7_a80 CEE[a] p_i = 100 % CEE p_i @ LP 7_a80 CEE[a] F_a = 7283 psi

LP 7_a80 TLE[a] F_a = 0.80 * LP 7_a80 CEE[a] F_a = 0.80 * −1214 = −971 kips

LP 7_a80 TLE[a] p_i = 0.80 * LP 7_a80 CEE[a] p_i = 0.80 * 7283 = 5826 psi

Example calculations for LP 8_a80:

LP 8_a80 CEE[a] F_a = not applicable

LP 8_a80 CEE[a] p_i = not applicable

LP 8_a80 TLE[a] F_a = 0.80 * LP 7_a80 CEE[a] F_a = 0.80 * −1215 = −971 kips

LP 8_a80 TLE[a] p_i = 0.50 * 0.80 * LP 7_a80 CEE[a] p_i = 0.50 * 0.80 * 7283 = 2913 psi

Based on the CEE[a] defined by the manufacturer, Table D.13 summarizes the resulting CEE[a] points and 80 % TLE[a] load points at ambient temperature. Figure D.16 depicts plots of the CEE[a] and CEE[a] points and the TLE[a] and TLE[a] load points. Notice the vectors passing through the CEE[a] points and TLE[a] load points due to the bi-axial scaling.

Table D.13—80 % CEE[a] Points and TLE[a] Load Points at Ambient Temperature

Load Point	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)	
	Axial Point F_a (kips)	Pressure Point p_i or p_o (psi)	Axial Load F_a (kips)	Pressure Load p_i or p_o (psi)
1_a80	1942	0	1301	0
2_a80	N/A	N/A	1301	2601
3_a80	N/A	N/A	1301	5201
4_a80	1626	13,003	1301	10,402
5_a80	834	14,296	667	11,437
6_a80	0	12,981	0	10,385
7_a80	−1214	7283	971	5826
8_a80	N/A	N/A	−971	2913
9_a80	−1942	0	−971	0

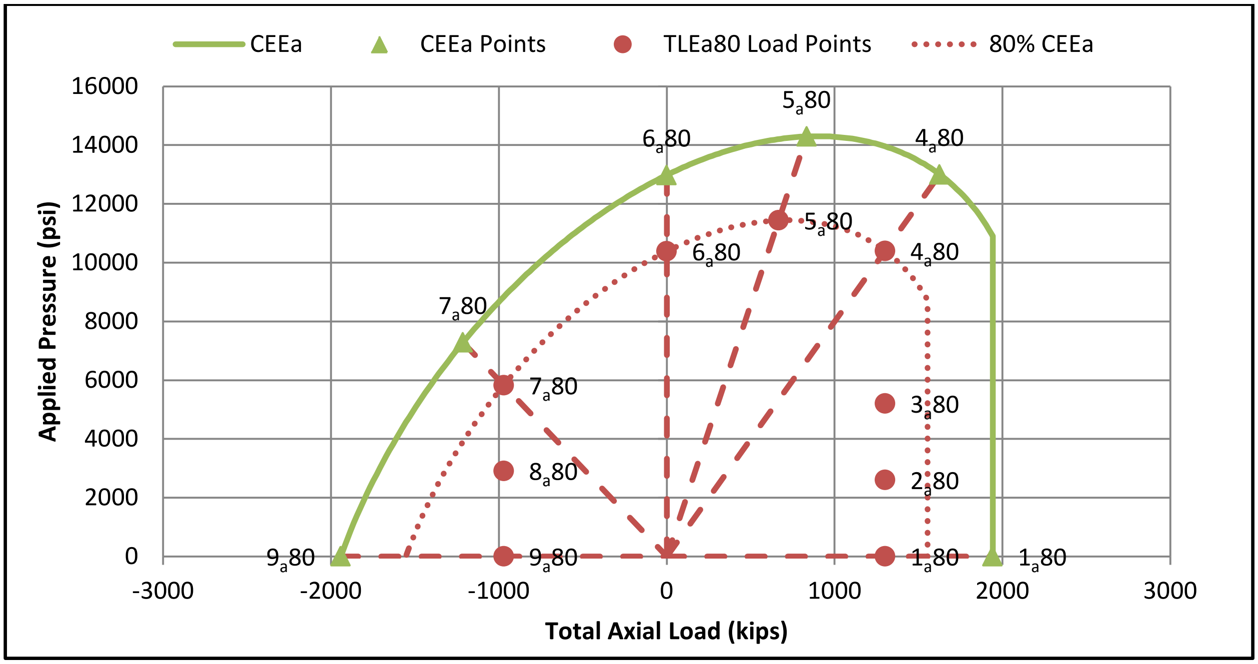


Figure D.16—CEE[a] Points and 80 % TLE[a] Load Points at Ambient Temperature

D.5.4 CEE[a] Points and 95 % TLE[a] Load Points at Ambient Temperature

Refer to the equations for load points 10_a95 through 27_a95 in Table 8 to calculate CEE[a] F_a and p_i or p_o and TLE[a] F_a and p_i or p_o.

For CEE[a] LP 10_a95 through LP 27_a95, LP 10_a95 and LP 13_a95 through LP 27_a95 lie on the CEE[a]. LP 11_a95 and LP 12_a95 are a function of LP 13_a95.

For TLE[a] LP 10_a95 through LP 21_a95, LP 13_a95 through LP 20_a95 are bi-axially scaled to the CEE[a] point indicated in Table 8 based on the specified 95 % bi-axial scaling factor. LP 11_a95 and LP 12_a95 are a function of LP 13_a95 and do not require bi-axial scaling. LP 10_a95 requires a specific 0.90 scaling factor so that the TLE F_a is constant for LP 10_a95 through LP 13_a95. Similarly, LP 21_a95 requires a specific 0.90 scaling factor so that the TLE F_a is constant for LP 20_a95 and LP 21_a95.

TLE[a] LP 22_a95 through LP 27_a95 are bi-axially scaled to the CEE[a] point indicated in Table 8; however, the scaling factor depends on the controlling reference curve. Curve 3[a] requires a 100 % scaling factor since the proprietary high collapse curve is not dependent on actual test specimen dimensions or material yield strength. Curve 4[a] and Curve 5[a] require a 95 % bi-axial scaling factor since both curves are based on actual test specimen dimensions and material yield strength. LP 23_a95 through LP 25_a95 are based on the proprietary high collapse curve (Curve 3[a]), therefore, a 100 % scaling factor applies (no scaling). TLE LP 22_a95 and LP 26_a95 require special consideration in this example, and the resulting test loads for each curve shall be compared to ensure that the test specimen is tested to as high a load or combination of loads as safely practical. For LP 27_a95, external pressure is based on the actual VME curve (Curve 4[a]); therefore, a 95 % scaling factor applies.

The CEE[a] and TLE[a] for LP 22_a95 could be based on either the proprietary high collapse curve (Curve 3[a]) or the actual API collapse curve (Curve 5[a]). As shown in Table D.14, Curve 5[a] results in a higher compressive test load but a lower external pressure test load than Curve 3[a]. Since the test specimen is specifically being tested on a high collapse pipe grade, Curve 3[a] has been chosen for LP 22_a95, and a 100 % scaling factor applies.

Table D.14—Potential LP 22_a95 TLE[a] Load Points Based on Curve 3[a], Curve 4[a], and Curve 5[a]

Potential CEE[a]	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Scaling Factor
	Axial Point (kips)	Pressure Point (psi)	Axial Load (kips)	Pressure Load (psi)	
Curve 3[a]	**−1710**	**−9140**	**−1710**	**−9140**	**A = 100 %**
Curve 4[a]	−1840	−12,950	−1748	−12,303	A = 95 %
Curve 5[a]	−1840	−8057	−1748	−7654	A = 95 %

Even though the CEE[a] for LP 26_a95 is defined by the actual API collapse curve (Curve 5[a]), the highest TLE[a] combination of loads that is safely practical is based on the proprietary high collapse curve (Curve 3[a]). As shown in Table D.15, Curve 3[a] results in a test pressure higher than that generated by Curve 5[a], and Curve 3[a] results in a test pressure lower than that generated by Curve 4[a]. Since the CEE is defined as the Min [Curve 4[a], Max (Curve 3[a], Curve 5[a])], LP 26_a95 uses the proprietary high collapse curve (Curve 3[a]) and a 100 % bi-axial scaling factor.

Table D.15—Potential LP 26_a95 TLE[a] Load Points Based on Curve 3[a], Curve 4[a], and Curve 5[a]

Potential CEE[a]	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Scaling Factor
	Axial Point (kips)	Pressure Point (psi)	Axial Load (kips)	Pressure Load (psi)	
Curve 3[a]	**1301**	**−4755**	**1301**	**−4755**	**A = 100 %**
Curve 4[a]	1369	−5440	1301	−5168	A = 95 %
Curve 5[a]	1369	−4973	1301	−4724	A = 95 %

Example calculations for LP 13_a95:

LP 13_a95 CEE[a] F_a = 0.90/0.95 * CEE[a] t = 0.90/0.95 * 1942 = 1840 kips

LP 13_a95 CEE[a] p_i = 100 % CEE[a] p_i @ LP 13_a95 CEE[a] F_a = 11,796 psi

LP 13_a95 TLE[a] F_a = 0.95 * LP 13_a95 CEE[a] t = 0.95 * 1840 = 1748 kips

LP 13_a95 TLE[a] p_i = 0.95 * LP 13_a95 CEE[a] p_i = 0.95 * 13,003 = 11,206 psi

Example calculations for LP 25_a95 (for Curve 3[a], A = 1.00):

LP 25_a95 CEE[a] F_a = 0.33/A * CEE[a] t = 0.33/1.00 * 1942 = 641 kips

LP 25_a95 CEE[a] p_o = 100 % CEE[a] p_o @ LP 25_a95 CEE[a] F_a = −7811 psi

LP 25_a95 TLE[a] F_a = A * LP 25_a95 CEE[a] F_a = 1.00 * 641 = 641 kips

LP 25_a95 TLE[a] p_o = A * LP 25_a95 CEE[a] p_o = 1.00 * −7811 = −7811 psi

Example calculations for LP 27_a95 (for Curve 1[a], A = 0.95):

LP 27_a95 CEE F_a = 0.90/A * CEE[a] t = 0.90/0.95 * 1942 = 1840 kips

LP 27_a95 CEE[a] p_o = 100 % CEE[a] p_o @ LP 27_a95 CEE[a] F_a = −1214 psi

LP 27_a95 TLE[a] F_a = A * LP 27_a95 CEE[a] F_a = 0.95 * 1840 = 1748 kips

LP 27_a95 TLE[a] p_o = A * LP 27_a95 CEE[a] p_o = 0.95 * −1214 = −1154 psi

Based on the CEE[a] defined by the manufacturer, Table D.16 summarizes the resulting CEE[a] points and TLE[a] 95 % load points at ambient temperature. Figure D.17 depicts plots of the CEE[a] and CEE[a] points and the TLE[a] and TLE[a] load points. The vectors passing through the CEE[a] and TLE[a] LP are not included in order to improve clarity.

Table D.16—95 % CEE[a] Points and TLE[a] Load Points at Ambient Temperature

Load Point	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)	
	Axial Point F_a (kips)	Pressure Point p_i or p_o (psi)	Axial Load F_a (kips)	Pressure Load p_i or p_o (psi)
10_a95	1942	0	1748	0
11_a95	N/A	N/A	1748	2802
12_a95	N/A	N/A	1748	5603
13_a95	1840	11,796	1748	11,206
14_a95	1635	12,964	1553	12,316
15_a95	834	14,296	792	13,581
16_a95	0	12,981	0	12,332
17_a95	−511	11,170	−485	10,612
18_a95	−1022	8534	−971	8108
19_a95	−1533	4751	−1456	4513
20_a95	−1840	1464	−1748	1391
21_a95	−1942	0	−1748	0
22_a95	−1710	−9140	−1710	−9140
23_a95	−971	−9140	−971	−9140
24_a95	0	−9140	0	−9140
25_a95	641	−7811	641	−7811
26_a95	1301	−4755	1301	−4755
27_a95	1840	−1214	1748	−1154

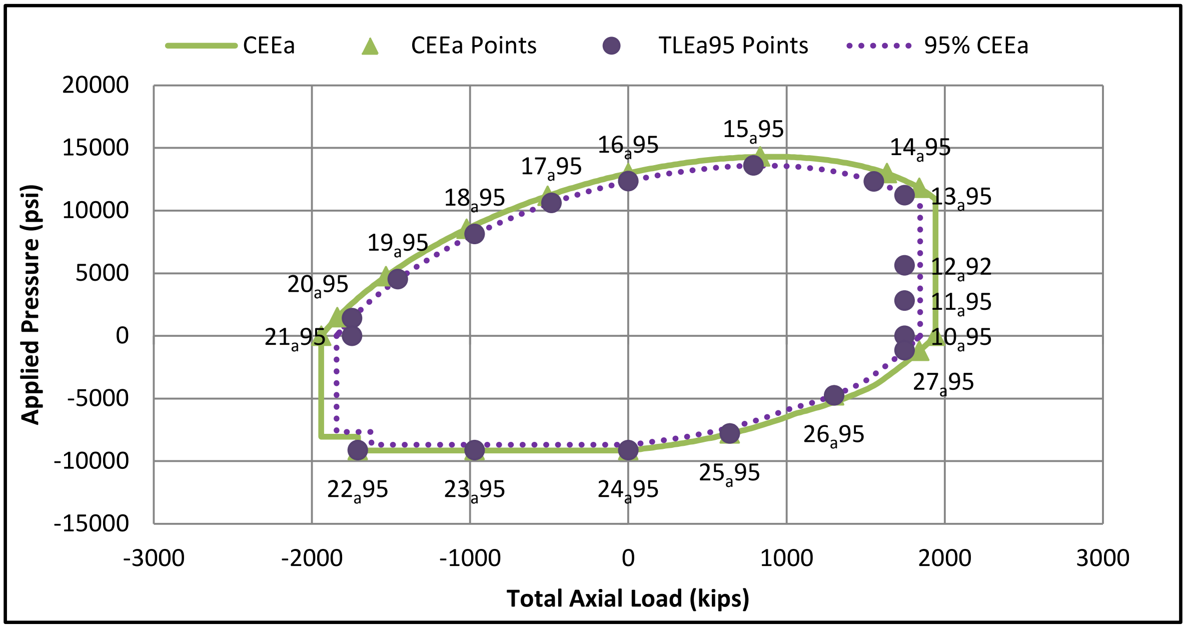


Figure D.17—CEE[a] Points and 95 % TLE[a] Load Points at Ambient Temperature

D.5.5 CEE[a] Points and 90 % TLE[a] Load Points at Ambient Temperature

Refer to the equations for load points 10_a90 through 27_a90 in Table 8 to calculate CEE[a] F_a and p_i or p_o and TLE[a] F_a and p_i or p_o.

For CEE[a] LP 10_a90 through LP 27_a90, LP 10_a90 and LP 13_a90 through LP 27_a90 lie on the CEE[a]. LP 11_a90 and LP 12_a90 are a function of LP 13_a90.

NOTE LP 10_a90 and LP 27_a90 are the same point, and LP 20_a90 and LP 21_a90 are the same point.

For TLE[a] LP 10_a90 through LP 21_a90, LP 10_a90 and LP 13_a90 through LP 21_a90 are bi-axially scaled to the CEE[a] point indicated in Table 8 based on the specified 90 % bi-axial scaling factor. LP 11_a90 and LP 12_a90 are based on TLE[a] LP 13_a90 and do not require bi-axial scaling.

TLE[a] LP 22_a90 through LP 27_a90 are bi-axially scaled to the CEE[a] point indicated in Table 8; however, the scaling factor is dependent on the controlling reference curve. Curve 3[a] requires a 100 % scaling factor since the proprietary high collapse curve is not dependent on actual test specimen dimensions or material yield strength. Curve 4[a] and 5[a] require a 90 % bi-axial scaling factor since both curves are based on actual test specimen dimensions and material yield strength. LP 23_a90 through LP 25_a90 are based on the proprietary high collapse curve (Curve 3[a]); therefore, a 100 % scaling factor applies (no scaling). TLE LP 22_a90 and 26_a90 require special consideration in this example, and the resulting test loads for each curve shall be compared to ensure that the test specimen is tested to as high a load or combination of loads as safely practical. For LP 27_a90, external pressure is based on the actual VME curve (Curve 4[a]) because none of the API collapse curves are defined at this level of axial load. At this point, CEE[a] p_o = zero.

The CEE[a] and TLE[a] for LP 22_a90 could be based on either the proprietary high collapse curve (Curve 3[a]) or the actual API collapse curve (Curve 5[a]). As shown in Table D.17, Curve 5[a] results in a higher compressive load but a lower external pressure than Curve 3[a]. Since the test specimen is specifically being tested on a high collapse pipe grade, Curve 3[a] has been chosen for LP 22_a90, and a 100 % scaling factor applies.

Table D.17—Potential LP 22_a90 TLE[a] Load Points Based on Curve 3[a], Curve 4[a], and Curve 5[a]

Potential CEE[a]	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Scaling Factor
	Axial Point (kips)	Pressure Point (psi)	Axial Load (kips)	Pressure Load (psi)	
Curve 3[a]	**−1710**	**−9140**	**−1710**	**−9140**	**B = 100 %**
Curve 4[a]	−1942	−12,388	−1748	−11,149	B = 90 %
Curve 5[a]	−1942	−8057	−1748	−7251	B = 90 %

Even though the CEE[a] for LP 26_a90 is defined by the actual API collapse curve (Curve 5[a]), the highest TLE[a] combination of loads that is safely practical is based on the actual VME curve (Curve 4[a]). As shown in Table D.18, Curve 3[a] results in a test pressure higher than that generated by Curve 5[a], and Curve 4[a] results in a test pressure lower than that generated by Curve 3[a]. Since the CEE is defined as the Min [Curve 4[a], Max (Curve 3[a], Curve 5[a])], LP 26_a90 uses the actual VME curve (Curve 4[a]) and a 90 % bi-axial scaling factor.

Table D.18—Potential LP 26_a90 TLE[a] Load Points Based on Curve 3[a], Curve 4[a], and Curve 5[a]

Potential CEE[a]	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Scaling Factor
	Axial Point (kips)	Pressure Point (psi)	Axial Load (kips)	Pressure Load (psi)	
Curve 3[a]	1301	−4755	1301	−4755	B = 100 %
Curve 4[a]	**1446**	**−4859**	**1301**	**−4373**	**B = 90 %**
Curve 5[a]	1446	−4589	1301	−4130	B = 90 %

Example calculations for LP 13_a90:

LP 13_a90 CEE[a] F_a = 0.90/0.90 * CEE[a] t = 0.90/0.90 * 1942 = 1942 kips

LP 13_a90 CEE[a] p_i = 100 % CEE[a] p_i @ LP 13_a90 CEE[a] F_a = 10,906 psi

LP 13_a90 TLE[a] F_a = 0.90 * LP 13^a90 CEE[a] F_a = 0.90 * 1942 = 1748 kips

LP 13_a90 TLE[a] p_i = 0.90 * LP 13_a90 CEE[a] p_i = 0.90 * 13,003 = 11,206 psi

Example calculations for LP 25_a90 (for Curve 3[a], B = 1.00):

LP 25_a90 CEE[a] F_a = 0.33/B * CEE[a] t = 0.33/1.00 * 1942 = 641 kips

LP 25_a90 CEE[a] p_o = 100 % CEE[a] p_o @ LP 25_a90 CEE[a] F_a = −7811 psi

LP 25_a90 TLE[a] F_a = B * LP 25_a90 CEE[a] t = 1.00 * 641 = 641 kips

LP 25_a90 TLE[a] p_o = B * LP 25_a90 CEE[a] p_o = 1.00 * −7811 = −7811 psi

Example calculations for LP 29_a90:

LP 29_a90 CEE[a] F_a = Not Applicable

LP 29_a90 CEE[a] p_i = Not Applicable

LP 29_a90 TLE[a] p_i = 0.20 * LP 14_a90 TLE[a] p_i = 0.20 * 11,267 = 2253 psi

LP 29_a90 F_{CEPL} = LP 29_a90 TLE[a] p_i * (π/4 * d_{avg}^2) = 2253 * (π/4 * 8.617^2) = 132 kips

LP 29_a90 TLE[a] F_a = LP 28_a90 TLE[a] F_a + LP 29_a90 F_{CEPL} = 896 + 132 = 1028 kips

Based on the CEE[a] defined by the manufacturer, Table D.19 summarizes the resulting CEE[a] points and TLE[a] 90 % load points at ambient temperature. Figure D.18 depicts plots of the CEE[a] and CEE[a] points and the TLE[a] and TLE[a] load points.

Table D.19—90 % CEE[a] Points and TLE[a] Load Points at Ambient Temperature

Load Point	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)	
	Axial Point F_a (kips)	Pressure Point p_i or p_o (psi)	Axial Load F_a (kips)	Pressure Load p_i or p_o (psi)
10_a90	1942	0	1748	0
11_a90	N/A	N/A	1748	2454
12_a90	N/A	N/A	1748	4908
13_a90	1942	10,906	1748	9815
14_a90	1726	12,519	1553	11,267
15_a90	834	14,296	750	12,866
16_a90	0	12,981	0	11,683
17_a90	−539	11,047	−485	9942
18_a90	−1079	8181	−971	7363
19_a90	−1618	3949	−1456	3554
20_a90	−1942	0	−1748	0
21_a90	−1942	0	−1748	0

Table D.19—90 % CEE[a] Points and TLE[a] Load Points at Ambient Temperature (Continued)

Load Point	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)	
	Axial Point F_a (kips)	Pressure Point p_i or p_o (psi)	Axial Load F_a (kips)	Pressure Load p_i or p_o (psi)
22_a90	−1710	−9140	−1710	−9140
23_a90	−971	−9140	−971	−9140
24_a90	0	−9140	0	−9140
25_a90	641	−7811	641	−7811
26_a90	1446	−4859	1301	−4373
27_a90	1942	0	1748	0
28_a90	N/A	N/A	896	0
29_a90	N/A	N/A	1028	2253
30_a90	N/A	N/A	702	11,267
31_a90	N/A	N/A	176	2253

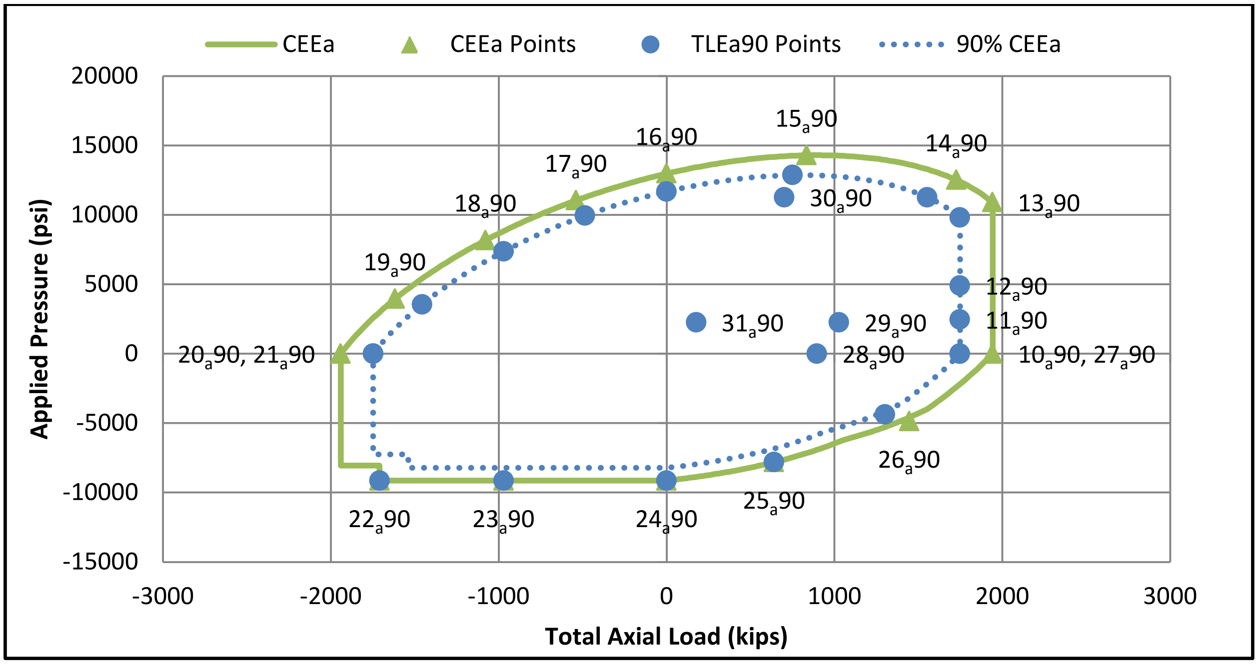


Figure D.18—CEE[a] Points and 90 % TLE[a] Load Points at Ambient Temperature

D.5.6 TLE Load Point at 150 °F (65 °C)

LP 13_{Cycle} shall be established at 150 °F (65 °C) by linear interpolation between TLE ambient and TLE elevated as defined in Table 7. For that purpose, a $K_{150°}$ factor is linearly interpolated from K_{temp} based on a maximum temperature of 150 °F (65 °C). This factor can be used to interpolate pipe body reference curves from ambient ones using the same methodology presented in D.4 replacing K_{temp} by $K_{150°}$. Assuming that, for this example, the ambient temperature material yield strength was determined at 75 °F (23.8 °C), the resulting formula for the calculated $K_{150°}$ is as follows:

$$K_{150°} = 1 - [(1 - K_{temp}) * (150 - 75)/(\text{Max Temp} - 75)]$$

Based on the parameters described in Table D.12, the $K_{150°}$ is:

$$K_{150°} = 1 – [(1 – 0.8864) * (150 – 75)/(383 – 75)] = 0.9723$$

From Table 7, LP 13_{Cycle} is linearly interpolated between LP 13_e90, defined in Table D.23, and LP 13_a90, defined in Table D.19, using $K_{150°}$ as follows:

LP 13_{Cycle} TLE F_a = LP 13_e90 TLE^e F_a + ($K_{150°}$ – K_{temp})/(1 – K_{temp}) * (LP 13_a90 TLE^a F_a – LP 13_e90 TLE^e F_a) = 1549 + (0.9723 – 0.8864)/(1 – 0.8864) * (1748 – 1549) = 1549 + 0.7565 * 199 = 1699 kips

LP 13_{Cycle} TLE p_i = LP 13_e90 TLE^e p_i + ($K_{150°}$ – K_{temp})/(1 – K_{temp}) * (LP 13_a90 TLE^a p_i – LP 13_e90 TLE^e p_i) = 8700 + (0.9723 – 0.8864)/(1 – 0.8864) * (9815 – 8700) = 1549 + 0.7565 * 1115 = 9544 psi

Table D.20 summarizes the resulting TLE load point at 150 °F (65 °C).

Table D.20—TLE Load Point at 150 °F (65 °C)

Load Point	Test Load Envelope (TLE)	
	Axial Load F_a (kips)	Pressure Load p_i or p_o (psi)
13_{Cycle}	1699	9544

D.5.7 CEE^e Points and 90 % TLE^e Load Points at Elevated Temperature

Refer to the equations for load points 10_e through 27_e in Table 8 to calculate the CEE^e F_a and p_i or p_o and the TLE^e F_a and p_i or p_o. The manufacturer has the responsibility for defining the CEE^e. As a result, the CEE^e may be independent of the CEE^a.

In this example, the CEE^e is related to the CEE^a by the difference in material yield strengths at ambient and elevated temperature, so CEE^e axial LP 10_e through LP 21_e are established by multiplying each CEE^a F_a by the elevated temperature scaling factor.

From Table D.12:

— CEE^e t = CEE^a t * $K_{383°}$ = 1942 * 0.8864 = 1721 kips;

— CEE^e c = CEE^a c * $K_{383°}$ = −1942 * 0.8864 = −1721 kips.

For CEE^e LP 10_e through LP 27_e, LP 10_e and LP 13_e through LP 27_e lie on the CEE^e. LP 11_e and LP 12_e are a function of LP 13_e.

NOTE LP 10_e and LP 27_e are the same point, and LP 20_e and LP 21_e are the same point.

For TLE^e LP 10_e through LP 21_e, LP 10_e and LP 13_e through LP 21_e are bi-axially scaled to the CEE^e point indicated in Table 8 based on the specified 90 % bi-axial scaling factor. LP 11_e and LP 12_e are based on TLE^e LP 13_e and do not require bi-axial scaling.

TLE^e LP 22_e through LP 27_e are bi-axially scaled to the CEE^e point indicated in Table 8; however, the scaling factor depends on the controlling reference curve. Curve 3^e requires a 100 % scaling factor since the proprietary high collapse curve does not depend on actual test specimen dimensions or material yield strength. Curves 4^e and 5^e require a 90 % bi-axial scaling factor since both curves are based on actual test specimen dimensions and material yield strength. LP 23_e through LP 25_e is based on the proprietary high collapse curve (Curve 3^e); therefore, a 100 % scaling factor applies (no scaling). As before, TLE LP 22_e and LP 26_e require special consideration in this example, and the resulting test loads for each curve shall be compared to ensure that the test specimen is tested to as high a load or combination of loads as safely practical. LP 27_e is based on the actual VME curve (Curve 4^e) because none of the API collapse curves are defined at this level of axial load. At this point, CEE^a p_o = zero.

The CEE^e and TLE^e for LP 22_e could be based on either the proprietary high collapse curve (Curve 3^e) or the actual API collapse curve (Curve 5^e). As shown in Table D.21, Curve 5^e results in a higher compressive load but a lower external pressure than Curve 3^e. Since the test specimen is specifically being tested on a high collapse pipe grade, Curve 3^e has been chosen for LP 22_e, and a 100 % scaling factor applies.

Table D.21—Potential LP 22_e TLE^e Load Points Based on Curve 3^e, Curve 4^e, and Curve 5^e

Potential CEE^e	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Scaling Factor
	Axial Point (kips)	Pressure Point (psi)	Axial Load (kips)	Pressure Load (psi)	
Curve 3^e	**−1516**	**−8102**	**−1516**	**−8102**	**B = 100 %**
Curve 4^e	−1721	−10,980	−1549	−9882	B = 90 %
Curve 5^e	−1721	−7142	−1549	−6428	B = 90 %

Even though the CEE^e for LP 26_e is defined by the actual API collapse curve (Curve 5^e), the highest TLE^e combination of loads that is safely practical is based on the actual VME curve (Curve 4^e). As shown in Table D.22, Curve 3^e results in a test pressure higher than that generated by Curve 5^e, and Curve 4^e results in a test pressure lower than that generated by Curve 3^e. Since the CEE is defined as the Min [Curve 4^e, Max (Curve 3^e, Curve 5^e)], LP 26_a90 uses the actual VME curve (Curve 4^e) and a 90 % bi-axial scaling factor.

Table D.22—Potential LP 26_e TLE^e Load Points Based on Curve 3^e, Curve 4^e, and Curve 5^e

Potential CEE^e	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)		Scaling Factor
	Axial Point (kips)	Pressure Point (psi)	Axial Load (kips)	Pressure Load (psi)	
Curve 3^e	1153	−4215	1153	−4215	B = 100 %
Curve 4^e	**1281**	**−4307**	**1153**	**−3876**	**B = 90 %**
Curve 5^e	1281	−4068	1153	−3661	B = 90 %

Example calculations for LP 13_e:

LP 13_e CEE^e F_a = 0.90/0.90 * CEE^e t = 0.90/0.90 * 1721 = 1721 kips

LP 13_e CEE^e p_i = 100 % CEE^e p_i @ LP 13_e CEE^e F_a = 9667 psi

LP 13_e TLE^e F_a = 0.90 * LP 13_e CEE^e t = 0.90 * 1721 = 1549 kips

LP 13_e TLE^e p_i = 0.90 * LP 13_e CEE^e p_i = 0.90 * 9667 = 8700 psi

Example calculations for LP 25_e (for Curve 4e, B = 1.00):

LP 25_e CEE^e F_a = 0.33/B * CEE^e t = 0.33/1.00 * 1721 = 568 kips

LP 25_e CEE^e p_o = 100 % CEE^e p_o @ LP 25_e CEE^e F_a = −6897 psi

LP 25_e TLE^e F_a = B * LP 25_e CEE^e F_a = 1.00 * 568 = 568 kips

LP 25_e TLE^e p_o = B * LP 25_e CEE^e p_o = 1.00 * −6897 = −6897 psi

Based on the CEE^e defined by the manufacturer, Table D.23 summarizes the resulting CEE^e points and TLE^e 90 % load points at elevated temperature. Figure D.19 depicts plots of the CEE^e and CEE^e points and the TLE^e and TLE^e load points.

D.6 CAL IV Load Schedules

D.6.1 General

As shown in Figure 3, the load schedules are based on the ambient and elevated temperature TLE. The following sections define the load schedules for the CAL IV Series A, Series B, and Series C tests based on the TLE load points defined in D.5 and D.6. The load schedules in this annex have been developed in the same sequence as the sequence of testing for CAL IV as required by Figure 7. Recommended test schedule load paths are given. The load paths are given for informational purposes, as there may be more than one acceptable load path for a given load point. In addition, some sequentially defined load points have exactly the same loads; these redundant load steps have not been removed.

Table D.23—90 % CEE^e Points and TLE^e Load Points at Elevated Temperature

Load Point	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)	
	Axial Point F_a (kips)	Pressure Point p_i or p_o (psi)	Axial Load F_a (kips)	Pressure Load p_i or p_o (psi)
10_e	1721	0	1549	0
11_e	N/A	N/A	1549	2175
12_e	N/A	N/A	1549	4350
13_e	1721	9667	1549	8700
14_e	1530	11,097	1377	9987
15_e	739	12,672	665	11,405
16_e	0	11,506	0	10,355
17_e	−478	9792	−430	8813
18_e	−956	7251	−861	6526
19_e	−1434	3500	−1291	3150
20_e	−1721	0	−1549	0
21_e	−1721	0	−1549	0
22_e	−1516	−8102	−1516	−8102
23_e	−861	−8102	−861	−8102
24_e	0	−8102	0	−8102
25_e	568	−6924	568	−6924
26_e	1281	−4307	1153	−3876
27_e	1721	0	1549	0

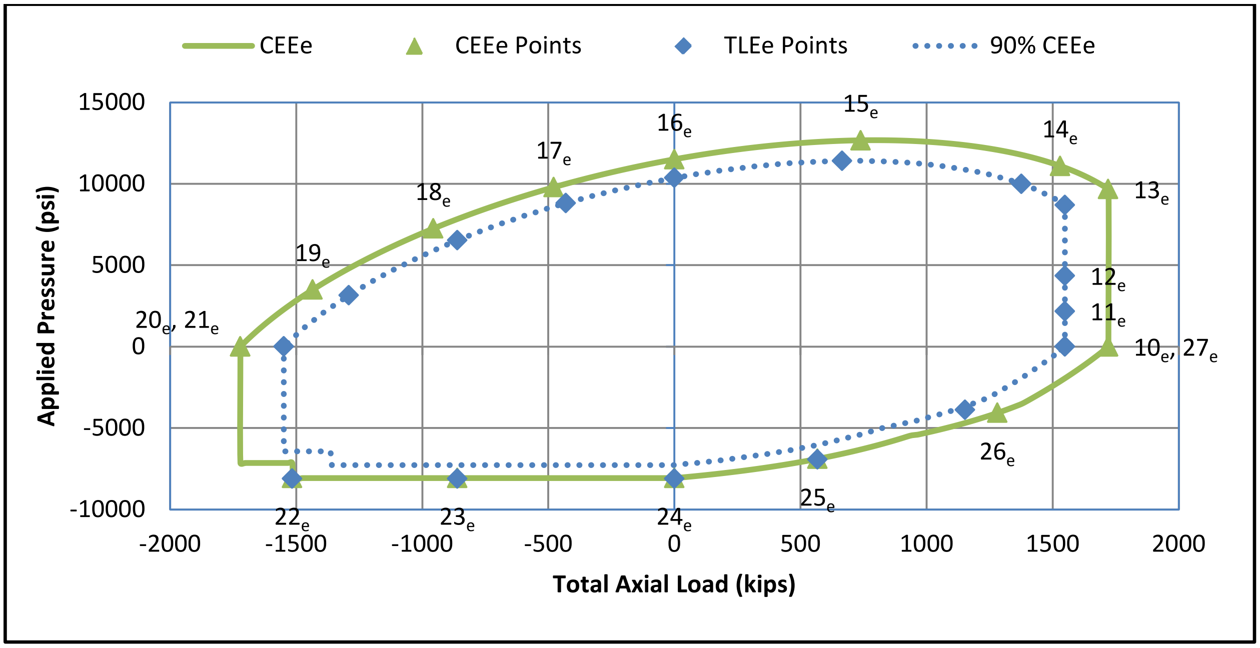


Figure D.19—90 % CEE[e] Points and TLE[e] Load Points at Elevated Temperature

D.6.2 TS-B Load Schedules

D.6.2.1 General

The specific load steps to complete CAL IV TS-B as required by 7.3.4 and Table 11 are shown in Tables D.25 through D.28 and Figures D.20 through D.23. To allow for more clarity and sense of purpose, TS-B has been broken down into four test sequences for this example.

The following assumptions were used in determining the CAL IV Series B load schedules.

a) The actual average pipe D_i (d_{avg}) used to calculate the capped-end pressure load (CEPL) for internal pressure load steps is 8.617 in.

b) Equivalent bending load is based on the bending stress at the D_o of the pipe. The measured maximum average D_o (D_{avg}) and actual average D_i (d_{avg}) are used to calculate the equivalent bending load.

c) The pipe parameters used to calculate the CAL IV TS-B load schedules are listed in Table D.24.

NOTE Depending on the connection design, the D_i used for CEPL calculations may not be equal to the average pipe D_i, particularly for internally shouldered connections.

Table D.24—Example Pipe Parameters Used to Calculate Load Schedules

Specified OD	Specified Wall	SMYS	D_{avg}	t_{min}	t_{avg}	AMYS[a]	K_{temp}	HC Rating	E
9.625 in.	0.545 in.	110,000 psi	9.697 in.	0.507 in.	0.540 in.	125,000 psi	0.8864	9140 psi	30×10^6 psi

D.6.2.2 Derivation of Formulas Used in Specimen Pipe Body Bending Calculations

TLE load points including bending require special consideration. It is the intent of the specification to test the defined TLE load point F_a and p_i.

$$F_a = F_i + F_{CEPL} \pm F_b \tag{D.1}$$

As a result, the frame load (F_i) shall be adjusted based on the bending equivalent axial force (F_b) such that F_a is maintained at the specified load. As specified in 7.3.4 a), the bending load (F_b) shall be limited to avoid overloading on the extrados or intrados side of the pipe, depending on the specific load point.

For CEE points and TLE load points 13b and 14b, F_a is defined on the extrados side of the pipe (F_{ae}). However, for the purposes of calculating the allowable bending load (F_b), the allowable axial load on the intrados side of the pipe (F_{ai}) shall also be calculated for each TLE load point.

For CEE points add TLE load points 16b through 20b, F_a is defined on the intrados side of the pipe (F_{ai}). However, for the purposes of calculating the allowable bending load (F_b), the allowable axial load on the extrados side of the pipe (F_{ae}) shall also be calculated for each TLE load point.

$$F_{ae} = F_i + F_{CEPL} + F_b \tag{D.2}$$

$$F_{ai} = F_i + F_{CEPL} - F_b \tag{D.3}$$

For the purposes of this example, the connection is considered to be transparent to the pipe body under bending, and the bending force applied to the connection is the same as for the pipe.

NOTE This assumption may not be correct for specific connections, especially flush and semi-flush connections; additional calculations may be required to ensure proper loading of the connection (e.g. the CEE may be different for loads with bending than without bending).

To determine the bending stress in the specimen pipe body, Equation (6) is taken directly from API 5C3. The equation is subject to change and shall be verified with the latest edition of API 5C3 prior to usage.

$$\sigma_b = \pm M_b\, r/I = \pm\, E_{cr} \tag{6}$$

The maximum pipe bending stress is at $r = D_{avg}/2$. As a result, the radius of curvature (c) resulting from a specified pipe bending stress can be found by restating Equation (6) as follows:

$$c = (2 * \sigma_b)/(E * D_{avg}) \tag{D.4}$$

The units for c are in radians/unit length. If σ_b and E are expressed in psi and r is expressed in inches, c is expressed in radians per inch. Traditionally, c has been expressed in units of °/100 ft and referred to as "dogleg." As a result, unit conversion is required to convert c to D_{leg}.

$$D_{leg} = c * (1200 * 180/\pi), \text{ with } D_{leg} \text{ in units of °/100 ft and in units of radians/inch} \tag{D.5}$$

and

$$F_b = \pm\sigma_b * A_p = \pm\, E_{cr} * A_p = \pm\, D_{leg}/(1200 * 180/\pi) * E * D_{avg}/2 * A_p \tag{D.6}$$

$$D_{leg} = |F_b| * (1200 * 180/\pi)/(E * D_{avg}/2 * A_p) \tag{D.7}$$

NOTE Equation (4) (below) from 5.9.3.4 is used to calculate the bending equivalent axial force in kips and is the same as the Equation (D.7).

$$F_b = 2.284566\, x\, 10^{-8} * \left(t_{ave} D_{avg}^2 - t_{avg}^2 D_{avg}\right) * E * D_{leg} \tag{4}$$

where

F_b bending equivalent axial force (kips);

t_{avg} average wall thickness of test specimen pipe body based on actual measurements (inches);

D_{avg} maximum average OD of test specimen pipe body based on actual measurements (inches);

D_{leg} effective dogleg severity (deg°/100 ft);

E elastic modulus of the pipe body material (psi) (see 5.5.2).

Equation (4) from 5.9.3.4 was derived using the following.

$$\sigma_{axial} = \sigma_{Bending} \tag{D.8}$$

$$\frac{F_b}{A} = \frac{M * c}{I} \tag{D.9}$$

$$F_b = \frac{M * OD * A}{2I} \tag{D.10}$$

$$M[ft - lbs] = 1.212\ x\ 10^{-6} * E * I * D_{leg} \tag{D.11}$$

$$F_b = \frac{1.212\ x\ 10^{-6} * E * I * D_{leg} * OD * A * 12}{2I} \tag{D.12}$$

$$A = \frac{\pi}{4}(OD^2 - ID^2) \tag{D.13}$$

$$A = \frac{\pi}{4}[OD^2 - (OD - 2t)^2] \tag{D.14}$$

$$F_b = \frac{1.212\ x\ 10^{-6} * E * I * D_{leg} * \pi * [OD^2 - (OD - 2t)^2] * OD * 12}{8I} \tag{D.15}$$

As specified in this RP, the TLE bending is limited to the lesser of:

a) D_{leg} = 20°/100 ft,

b) F_b = ±40 % * (F_t – F_c)/2,

c) F_b = ±40 % * (CEE$_t$ – CEE$_c$)/2, or

d) F_b = ±(TLE F_{ae} – TLE F_{ai})/2.

For this example, the elastic modulus (E) from API 5C3, Annex F is used; however, the actual elastic modulus at ambient temperature (E^a) and actual elastic modulus at elevated temperature (E^e) may be determined and used in the calculations in accordance with 5.5.1.

D.6.2.3 TS-B 80 % Level at Ambient Temperature without Bending (QI, QII)

As shown in Figure D.20 and Table D.25, the CAL IV test protocol begins with TS-B, which includes a series of QI/QII load points in the CCW direction at an 80 % level at ambient temperature. No bending is applied and hold periods are 2 minutes, indicating that the intent of this test sequence is to mechanically exercise the connection at a moderate level in the event that a gross sealability issue surfaces. It is not the intent of this test sequence to evaluate the connection for absolute sealability. Sealability evaluation shall be by one of the leak detection methods described in 5.7.

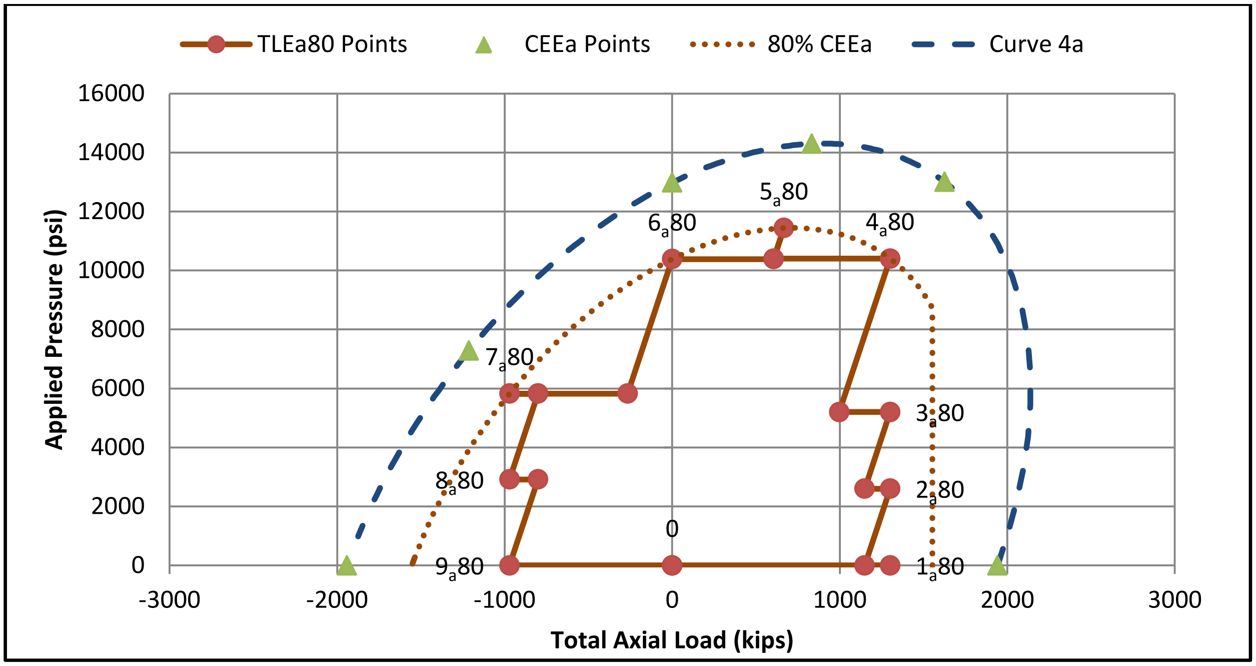


Figure D.20—B^a 80 % (QI, QII), TS-B Load Steps 1 to 19

Table D.25—TS-B 80 % Level at Ambient Temperature

Begin CAL IV TS-B with B^a 80 % (QI, QII) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Connection Bending Load (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Dogleg (°/100')**	**CAL IV** **Temperature (°F)**	**Hold Time (min)**	**Direction**
1	0	0	0	0	0	0	0.0	Ambient		CCW (80 % Level) See Table 11, Table D.13, and Figure D.20
2	1_a80	1301	0	0	1301	0	0.0	Ambient	2	
3	Transition	1149	0	0	1149	0	0.0	Ambient		
4	2_a80	1301	152	0	1149	2601	0.0	Ambient	2	
5	Transition	1149	152	0	998	2601	0.0	Ambient		
6	3_a80	1301	303	0	998	5201	0.0	Ambient	2	
7	Transition	998	303	0	694	5201	0.0	Ambient		
8	4_a80	1301	607	0	694	10,402	0.0	Ambient	2	
9	Transition	607	607	0	0	10,402	0.0	Ambient		
10	5_a80	667	667	0	0	11,437	0.0	Ambient	2	
11	Transition	606	606	0	0	10,385	0.0	Ambient		
12	6_a80	0	606	0	−606	10,385	0.0	Ambient	2	
13	Transition	−266	340	0	−606	5826	0.0	Ambient		
14	7_a80	−971	340	0	−1311	5826	0.0	Ambient	2	
15	Transition	−801	340	0	−1141	5826	0.0	Ambient		
16	8_a80	−971	170	0	−1141	2913	0.0	Ambient	2	
17	Transition	−801	170	0	−971	2913	0.0	Ambient		
18	9_a80	−971	0	0	−971	0	0.0	Ambient	2	
19	0	0	0	0	0	0	0.0	Ambient		
End of B^a 80 % (QI, QII)										

D.6.2.4 TS-B 95 % Level at Ambient Temperature without Bending (QI, QII, QI)

As shown in Figure D.21 and Table D.26, CAL IV TS-B testing continues with a series of QI/QII load points in the CCW and CW direction (to evaluate load path dependency) at a 95 % level at ambient temperature. Still no bending loads are applied, and the majority of the hold points require sealability evaluation. Sealability evaluation shall be by one of the leak-detection methods described in 5.7.

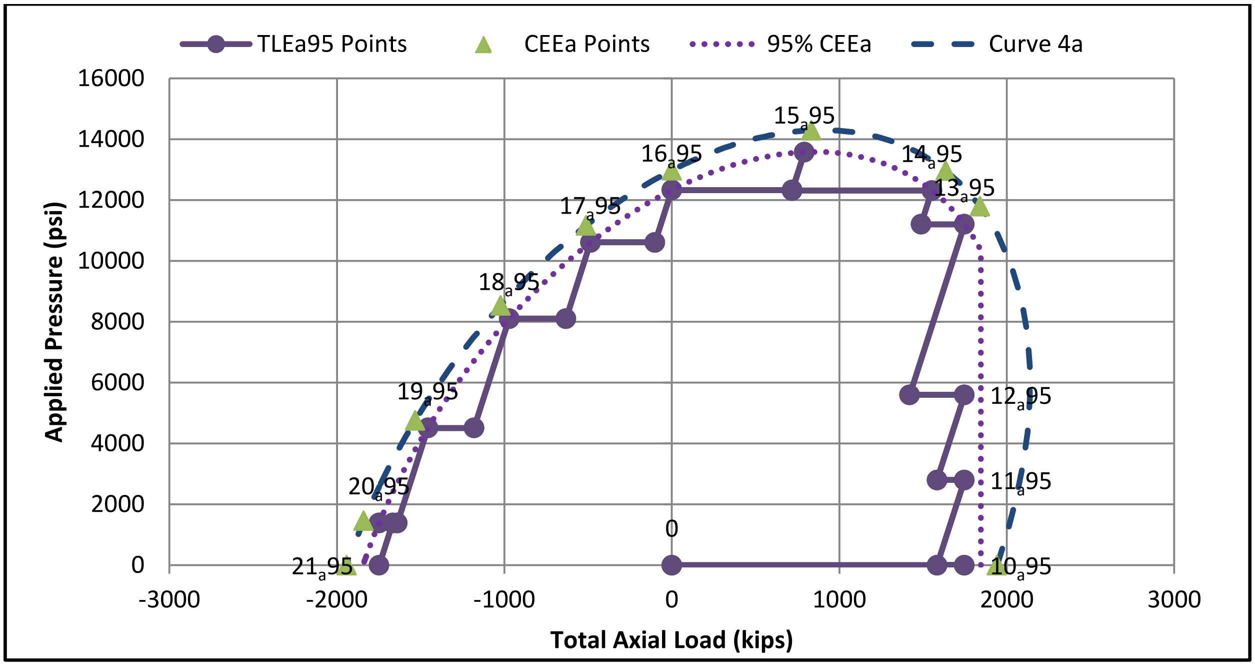


Figure D.21—B^a 95 % (QI, QII, QI), TS-B Load Steps 20 to 66

Table D.26—TS-B 95 % Level at Ambient Temperature Without Bending

Continue CAL IV TS-B with B^a 95 % (QI, QII, QI) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Connection Bending Load (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Dogleg (°/100')**	**CAL IV Temperature (°F)**	**Hold Time (min)**	**Direction**
20	0	0	0	0	0	0	0.0	Ambient		CCW (95 % Level) See Table 11, Table D.16, and Figure D.21
21	10_a95	1748	0	0	1748	0	0.0	Ambient	2	
22	Transition	1584	0	0	1584	0	0.0	Ambient		
23	11_a95	1748	163	0	1584	2802	0.0	Ambient	5	
24	Transition	1584	163	0	1421	2802	0.0	Ambient		
25	12_a95	1748	327	0	1421	5603	0.0	Ambient	5	
26	Transition	1421	327	0	1094	5603	0.0	Ambient		
27	13_a95	1748	654	0	1094	11,206	0.0	Ambient	5	
28	Transition	1489	654	0	835	11,206	0.0	Ambient		
29	14_a95	1553	718	0	835	12,316	0.0	Ambient	5	
30	Transition	718	718	0	0	12,316	0.0	Ambient		
31	15_a95	792	792	0	0	13,581	0.0	Ambient	5	

Table D.26—TS-B 95 % Level at Ambient Temperature Without Bending (Continued)

Continue CAL IV TS-B with B^a 95 % (QI, QII, QI) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	LP	Total Load (kips)	CEPL (kips)	Connection Bending Load (kips)	Frame Load (kips)	Pressure (psi)	Dogleg (°/100')	CAL IV Temperature (°F)	Hold Time (min)	Direction
32	Transition	719	719	0	0	12,332	0.0	Ambient		CCW (95 % Level) See Table 11, Table D.16, and Figure D.21
33	16_a95	0	719	0	−719	12,332	0.0	Ambient	5	
34	Transition	−100	619	0	−719	10,612	0.0	Ambient		
35	17_a95	−485	619	0	−1104	10,612	0.0	Ambient	5	
36	Transition	−631	473	0	−1104	8108	0.0	Ambient		
37	18_a95	−971	473	0	−1444	8108	0.0	Ambient	5	
38	Transition	−1181	263	0	−1444	4513	0.0	Ambient		
39	19_a95	−1456	263	0	−1720	4513	0.0	Ambient	5	
40	Transition	−1638	81	0	−1720	1391	0.0	Ambient		
41	20_a95	−1748	81	0	−1829	1391	0.0	Ambient	5	
42	Transition	−1667	81	0	−1748	1391	0.0	Ambient		
43	21_a95	−1748	0	0	−1748	0	0.0	Ambient	2	
44	Transition	−1667	81	0	−1748	1391	0.0	Ambient		CW (95 % Level) See Table 11, Table D.16, and Figure D.21
45	20_a95	−1748	81	0	−1829	1391	0.0	Ambient	5	
46	Transition	−1638	81	0	−1720	1391	0.0	Ambient		
47	19_a95	−1456	263	0	−1720	4513	0.0	Ambient	5	
48	Transition	−1181	263	0	−1444	4513	0.0	Ambient		
49	18_a95	−971	473	0	−1444	8108	0.0	Ambient	5	
50	Transition	−631	473	0	−1104	8108	0.0	Ambient		
51	17_a95	−485	619	0	−1104	10,612	0.0	Ambient	5	
52	Transition	−100	619	0	−719	10,612	0.0	Ambient		
53	16_a95	0	719	0	−719	12,332	0.0	Ambient	5	
54	Transition	719	719	0	0	12,332	0.0	Ambient		
55	15_a95	792	792	0	0	13,581	0.0	Ambient	5	
56	Transition	718	718	0	0	12,316	0.0	Ambient		
57	14_a95	1553	718	0	835	12,316	0.0	Ambient	5	
58	Transition	1489	654	0	835	11,206	0.0	Ambient		
59	13_a95	1748	654	0	1094	11,206	0.0	Ambient	5	
60	Transition	1421	327	0	1094	5603	0.0	Ambient		
61	12_a95	1748	327	0	1421	5603	0.0	Ambient	5	
62	Transition	1584	163	0	1421	2802	0.0	Ambient		
63	11_a95	1748	163	0	1584	2802	0.0	Ambient	5	
64	Transition	1584	0	0	1584	0	0.0	Ambient		
65	10_a95	1748	0	0	1748	0	0.0	Ambient	2	
66	0	0	0	0	0	0	0.0	Ambient		
End of B^a 95 % (QI, QII, QI)										

D.6.2.5 TS-B 90 % Level at Elevated Temperature with Bending (QI, QII, QI)

As shown in Figure D.22 and Table D.27, CAL IV TS-B continues with internal pressure testing. Elevated temperature and bending are now introduced with a series of QI/QII load points in the CCW and CW direction (to evaluate load path dependency) at a 90 % level. The majority of the hold points require sealability evaluation. Sealability evaluation shall be by one of the leak-detection methods described in 5.7.

For Table D.27, the transition load points shall be changed immediately preceding and following these load points to ensure proper transitions between load points.

The bending load for load points except LP $16b_e$ is 20.0°/100 ft in accordance with 7.3.4 a) 1). The bending load for LP $16b_e$ had to be reduced to 19.8°/100 ft to avoid overloading the pipe on the extrados side of the pipe based on the calculation method shown in D.6.2.2 in accordance with 7.3.4 a) 4).

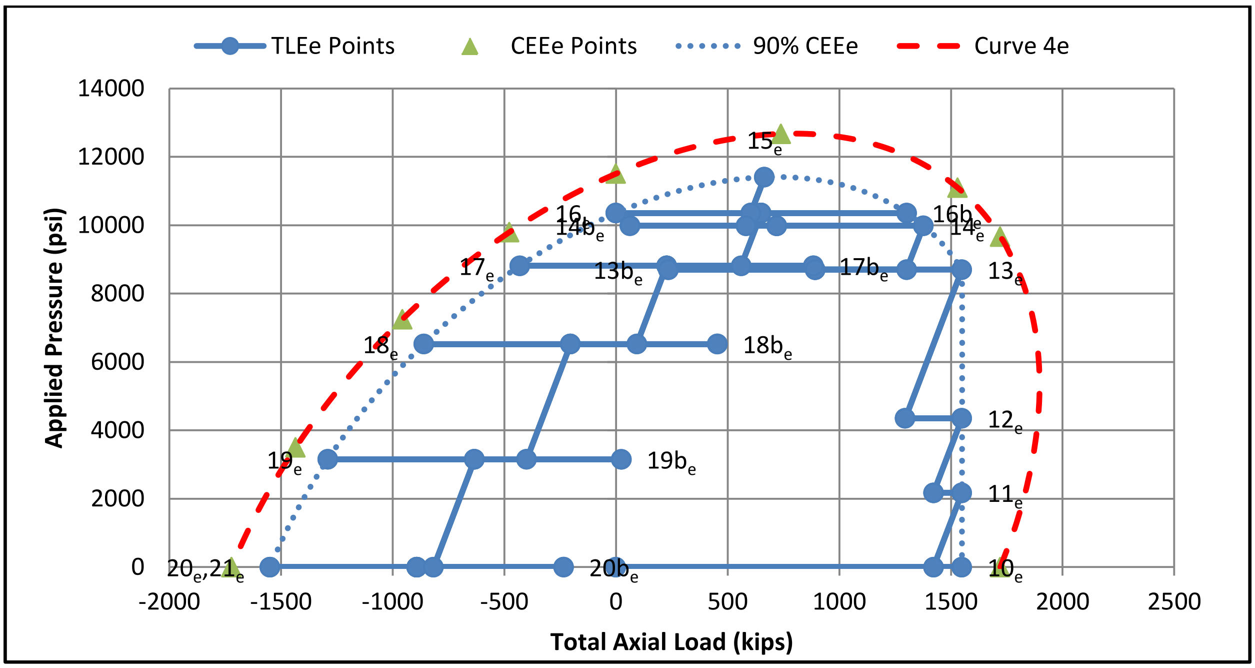


Figure D.22—B^e_b 90 % (QI, QII, QI), TS-B Load Steps 67 to 155

Table D.27—TS-B 90 % Level at Elevated Temperature with Bending

Continue CAL IV TS-B with B^e_b 90 % (QI, QII, QI) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Connection Bending Load (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Dogleg (°/100')**	**CAL IV Temperature (°F)**	**Hold Time (min)**	**Direction**
67	0	0	0	0	0	0	0.0	Heat-up		CCW (90 % Level) See Table 11, Table D.23, and Figure D.22
68	10_e	1549	0	0	1549	0	0.0	356	2	
69	Transition	1422	0	0	1422	0	0.0	356		
70	11_e	1549	127	0	1422	2175	0.0	356	5	
71	Transition	1422	127	0	1295	2175	0.0	356		
72	12_e	1549	254	0	1295	4350	0.0	356	5	
73	Transition	1295	254	0	1042	4350	0.0	356		
74	13_e	1549	507	0	1042	8700	0.0	356	15	
75	Transition	892	507	0	384	8700	0.0	356		

Table D.27—TS-B 90 % Level at Elevated Temperature with Bending (Continued)

Continue CAL IV TS-B with B^e_b 90 % (QI, QII, QI) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Connection Bending Load (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Dogleg (°/100')**	**CAL IV Temperature (°F)**	**Hold Time (min)**	**Direction**
76	$13b_e$	1549	507	657	384	8700	20.0	356	15	CCW (90 % Level) See Table 11, Table D.23, and Figure D.22
77	Transition	892	507	0	384	8700	0.0	356		
78	Transition	1302	507	0	795	8700	0.0	356		
79	14_e	1377	582	0	795	9987	0.0	356	10	
80	Transition	720	582	0	137	9987	0.0	356		
81	$14b_e$	1377	582	657	137	9987	20.0	356	60	
82	Transition	720	582	0	137	9987	0.0	356		
83	Transition	582	582	0	0	9987	0.0	356		
84	15_e	665	665	0	0	11,405	0.0	356	15	
85	Transition	604	604	0	0	10,355	0.0	356		
86	16_e	0	604	0	−604	10,355	0.0	356	10	
87	Transition	651	604	0	47	10,355	0.0	356		
88	$16b_e$	0	604	−651	47	10,355	19.8	356	10	
89	Transition	651	604	0	47	10,355	0.0	356		
90	Transition	561	514	0	47	8813	0.0	356		
91	17_e	−430	514	0	−944	8813	0.0	356	10	
92	Transition	227	514	0	−287	8813	0.0	356		
93	$17b_e$	−430	514	−657	−287	8813	20.0	356	10	
94	Transition	227	514	0	−287	8813	0.0	356		
95	Transition	94	381	0	−287	6526	0.0	356		
96	18e	−861	381	0	−1241	6526	0.0	356	10	
97	Transition	−203	381	0	−584	6526	0.0	356		
98	$18b_e$	−861	381	−657	−584	6526	20.0	356	10	
99	Transition	−203	381	0	−584	6526	0.0	356		
100	Transition	−400	184	0	−584	3150	0.0	356		
101	19_e	−1291	184	0	−1475	3150	0.0	356	10	
102	Transition	−634	184	0	−817	3150	0.0	356		
103	$19b_e$	−1291	184	−657	−817	3150	20.0	356	10	
104	Transition	−634	184	0	−817	3150	0.0	356		
105	Transition	−817	0	0	−817	0	0.0	356		
106	20_e	−1549	0	0	−1549	0	0.0	356	2 [a]	
107	Transition	−892	0	0	−892	0	0.0	356		
108	$20b_e$	−1549	0	−657	−892	0	20.0	356	5 [b]	
109	Transition	−892	0	0	−892	0	0.0	356		
110	Transition	−892	0	0	−892	0	0.0	356		
111	21_e	−1549	0	0	−1549	0	0.0	356	2	

Table D.27—TS-B 90 % Level at Elevated Temperature with Bending (Continued)

Continue CAL IV TS-B with B^e_b 90 % (QI, QII, QI) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Connection Bending Load (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Dogleg (°/100')**	**CAL IV Temperature (°F)**	**Hold Time (min)**	**Direction**
112	Transition	−892	0	0	−892	0	0.0	356		CW (90 % Level) See Table 11, Table D.23, and Figure D.22
113	$20b_e$ [c]	−1549	0	−657	−892	0	20.0	356	5 [b]	
114	Transition	−892	0	0	−892	0	0.0	356		
115	Transition	−892	0	0	−892	0	0.0	356		
116	20_e [c]	−1549	0	0	−1549	0	0.0	356	2 [a]	
117	Transition	−817	0	0	−817	0	0.0	356		
118	Transition	−634	184	0	−817	3150	0.0	356		
119	$19b_e$ [c]	−1291	184	−657	−817	3150	20.0	356	10	
120	Transition	−634	184	0	−817	3150	0.0	356		
121	19_e [c]	−1291	184	0	−1475	3150	0.0	356	10	
122	Transition	−400	184	0	−584	3150	0.0	356		
123	Transition	−203	381	0	−584	6526	0.0	356		
124	$18b_e$ [c]	−861	381	−657	−584	6526	20.0	356	60	
125	Transition	−203	381	0	−584	6526	0.0	356		
126	18_e [c]	−861	381	0	−1241	6526	0.0	356	10	
127	Transition	94	381	0	−287	6526	0.0	356		
128	Transition	227	514	0	−287	8813	0.0	356		
129	$17b_e$ [c]	−430	514	−657	−287	8813	20.0	356	10	
130	Transition	227	514	0	−287	8813	0.0	356		
131	17_e [c]	−430	514	0	−944	8813	0.0	356	10	
132	Transition	561	514	0	47	8813	0.0	356		
133	Transition	651	604	0	47	10,355	0.0	356		
134	$16b_e$ [c]	0	604	−651	47	10,355	19.8	356	10	
135	Transition	651	604	0	47	10,355	0.0	356		
136	16_e [c]	0	604	0	−604	10,355	0.0	356	10	
137	Transition	604	604	0	0	10,355	0.0	356		
138	15_e	665	665	0	0	11,405	0.0	356	15	
139	Transition	582	582	0	0	9987	0.0	356		
140	Transition	720	582	0	137	9987	0.0	356		
141	$14b_e$ [c]	1377	582	657	137	9987	20.0	356	10	
142	Transition	720	582	0	137	9987	0.0	356		
143	14_e [c]	1377	582	0	795	9987	0.0	356	10	
144	Transition	1302	507	0	795	8700	0.0	356		
145	Transition	892	507	0	384	8700	0.0	356		
146	$13b_e$ [c]	1549	507	657	384	8700	20.0	356	60	
147	Transition	892	507	0	384	8700	0.0	356		

Table D.27—TS-B 90 % Level at Elevated Temperature with Bending (Continued)

Continue CAL IV TS-B with B^e_b 90 % (QI, QII, QI) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Connection Bending Load (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Dogleg (°/100')**	**CAL IV Temperature (°F)**	**Hold Time (min)**	**Direction**
148	13_e [c]	1549	507	0	1042	8700	0.0	356	10	CW (90 % Level) See Table 11, Table D.23, and Figure D.22
149	Transition	1295	254	0	1042	4350	0.0	356		
150	12_e	1549	254	0	1295	4350	0.0	356	5	
151	Transition	1422	127	0	1295	2175	0.0	356		
152	11_e	1549	127	0	1422	2175	0.0	356	5	
153	Transition	1422	0	0	1422	0	0.0	356		
154	10_e	1549	0	0	1549	0	0.0	356	2	
155	0	0	0	0	0	0	0.0	356		
End of B^e_b 90 % (QI, QII, QI)										

[a] Since there is no pressure at this load point, the hold time was reduced from 10 minutes to 2 minutes.

[b] Since there is no pressure at this load point, the hold time was reduced from 10 minutes to 5 minutes.

[c] If bending had been controlled by the equivalent stress based curvature control method (5.9.3.4.4), the bending load point would have been conducted after the corresponding load point without bending.

D.6.2.6 TS-B 90 % Level at Ambient Temperature with Bending (QI, QII, QI)

As shown in Figure D.23 and Table D.28, CAL IV TS-B testing concludes with a series of QI/QII load points in the CCW and CW direction (to evaluate load path dependency) with bending at a 90 % level at ambient temperature. The test sequence from ambient temperature to elevated temperature and back to ambient temperature is a critical aspect of the testing. The majority of the hold points require sealability evaluation. Sealability evaluation shall be by one of the leak-detection methods described in 5.7.

NOTE The D_{leg} for load points with bending is 20.0°/100 ft in accordance with 7.3.4.3 a) 1).

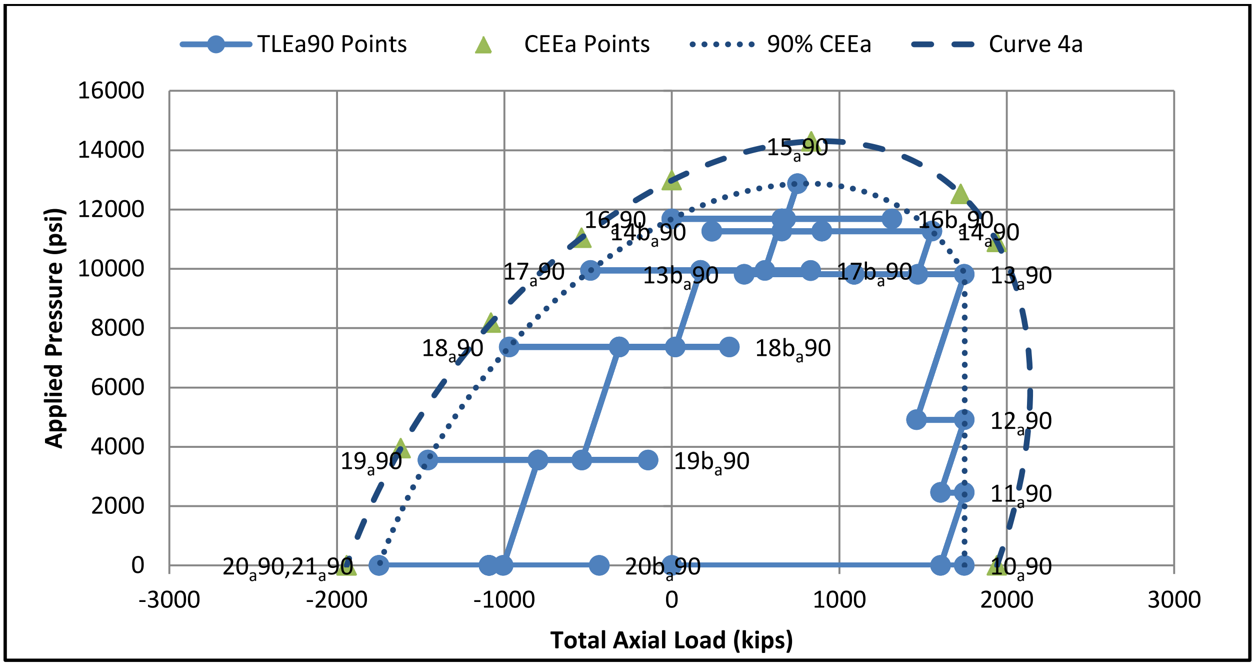


Figure D.23—B^a_b 90 % (QI, QII, QI), TS-B Load Steps 156 to 244

Table D.28—TS-B 90 % Level at Ambient Temperature with Bending

Complete CAL IV TS-B with B^a_b 90 % (QI, QII, QI) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Connection Bending Load (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Dogleg (°/100')**	**CAL IV Temperature (°F)**	**Hold Time (min)**	**Direction**
156	0	0	0	0	0	0	0.0	Cooldown		CCW (90 % Level) See Table 11, Table D.19, and Figure D.23
157	10_a90	1748	0	0	1748	0	0.0	Ambient	2	
158	Transition	1605	0	0	1605	0	0.0	Ambient		
159	11_a90	1748	143	0	1605	2454	0.0	Ambient	5	
160	Transition	1605	143	0	1461	2454	0.0	Ambient		
161	12_a90	1748	286	0	1461	4908	0.0	Ambient	5	
162	Transition	1461	286	0	1175	4908	0.0	Ambient		
163	13_a90	1748	572	0	1175	9815	0.0	Ambient	10	
164	Transition	1090	572	0	518	9815	0.0	Ambient		
165	$13b_a90$	1748	572	657	518	9815	20.0	Ambient	10	
166	Transition	1090	572	0	518	9815	0.0	Ambient		
167	Transition	1469	572	0	896	9815	0.0	Ambient		
168	14_a90	1553	657	0	896	11,267	0.0	Ambient	10	
169	Transition	896	657	0	239	11,267	0.0	Ambient		
170	$14b_a90$	1553	657	657	239	11,267	20.0	Ambient	10	
171	Transition	896	657	0	239	11,267	0.0	Ambient		
172	Transition	657	657	0	0	11,267	0.0	Ambient		

Table D.28—TS-B 90 % Level at Ambient Temperature with Bending (Continued)

Complete CAL IV TS-B with B^{a}_{b} 90 % (QI, QII, QI) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Connection Bending Load (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Dogleg (°/100')**	**CAL IV Temperature (°F)**	**Hold Time (min)**	**Direction**
173	15_a90	750	750	0	0	12,866	0.0	Ambient	60	CCW (90 % Level) See Table 11, Table D.19, and Figure D.23
174	Transition	681	681	0	0	11,683	0.0	Ambient		
175	16_a90	0	681	0	−681	11,683	0.0	Ambient	10	
176	Transition	657	681	0	−24	11,683	0.0	Ambient		
177	$16b_a90$	0	681	−657	−24	11,683	20.0	Ambient	10	
178	Transition	657	681	0	−24	11,683	0.0	Ambient		
179	Transition	556	580	0	−24	9942	0.0	Ambient		
180	17_a90	−485	580	0	−1065	9942	0.0	Ambient	10	
181	Transition	172	580	0	−408	9942	0.0	Ambient		
182	$17b_a90$	−485	580	−657	−408	9942	20.0	Ambient	10	
183	Transition	172	580	0	−408	9942	0.0	Ambient		
184	Transition	21	429	0	−408	7363	0.0	Ambient		
185	18_a90	−971	429	0	−1400	7363	0.0	Ambient	10	
186	Transition	−314	429	0	−743	7363	0.0	Ambient		
187	$18b_a90$	−971	429	−657	−743	7363	20.0	Ambient	10	
188	Transition	−314	429	0	−743	7363	0.0	Ambient		
189	Transition	−536	207	0	−743	3554	0.0	Ambient		
190	19_a90	−1456	207	0	−1664	3554	0.0	Ambient	10	
191	Transition	−799	207	0	−1006	3554	0.0	Ambient		
192	$19b_a90$	−1456	207	−657	−1006	3554	20.0	Ambient	10	
193	Transition	−799	207	0	−1006	3554	0.0	Ambient		
194	Transition	−1006	0	0	−1006	0	0.0	Ambient		
195	20_a90	−1748	0	0	−1748	0	0.0	Ambient	2 [a]	
196	Transition	−1090	0	0	−1090	0	0.0	Ambient		
197	$20b_a90$	−1748	0	−657	−1090	0	20.0	Ambient	5 [b]	
198	Transition	−1090	0	0	−1090	0	0.0	Ambient		
199	Transition	−1090	0	0	−1090	0	0.0	Ambient		
200	21_a90	−1748	0	0	−1748	0	0.0	Ambient	2	

Table D.28—TS-B 90 % Level at Ambient Temperature with Bending (Continued)

Complete CAL IV TS-B with B^a_b 90 % (QI, QII, QI)
Internal Pressure Leak Detection System for TS-B and TS-C

Load Step	LP	Total Load (kips)	CEPL (kips)	Connection Bending Load (kips)	Frame Load (kips)	Pressure (psi)	Dogleg (°/100')	CAL IV Temperature (°F)	Hold Time (min)	Direction
201	Transition	−1090	0	0	−1090	0	0.0	Ambient		CW (90 % Level) See Table 11, Table D.19, and Figure D.23
202	$20b_a90$ [c]	−1748	0	−657	−1090	0	20.0	Ambient	5 [b]	
203	Transition	−1090	0	0	−1090	0	0.0	Ambient		
204	Transition	−1090	0	0	−1090	0	0.0	Ambient		
205	20_a90 [c]	−1748	0	0	−1748	0	0.0	Ambient	2 [a]	
206	Transition	−1006	0	0	−1006	0	0.0	Ambient		
207	Transition	−799	207	0	−1006	3554	0.0	Ambient		
208	$19b_a90$ [c]	−1456	207	−657	−1006	3554	20.0	Ambient	10	
209	Transition	−799	207	0	−1006	3554	0.0	Ambient		
210	19_a90 [c]	−1456	207	0	−1664	3554	0.0	Ambient	10	
211	Transition	−536	207	0	−743	3554	0.0	Ambient		
212	Transition	−314	429	0	−743	7363	0.0	Ambient		
213	$18b_a90$ [c]	−971	429	−657	−743	7363	20.0	Ambient	10	
214	Transition	−314	429	0	−743	7363	0.0	Ambient		
215	18_a90 [c]	−971	429	0	−1400	7363	0.0	Ambient	10	
216	Transition	21	429	0	−408	7363	0.0	Ambient		
217	Transition	172	580	0	−408	9942	0.0	Ambient		
218	$17b_a90$ [c]	−485	580	−657	−408	9942	20.0	Ambient	10	
219	Transition	172	580	0	−408	9942	0.0	Ambient		
220	$17b_a90$ [c]	−485	580	0	−1065	9942	0.0	Ambient	10	
221	Transition	556	580	0	−24	9942	0.0	Ambient		
222	Transition	657	681	0	−24	11,683	0.0	Ambient		
223	$16b_a90$ [c]	0	681	−657	−24	11,683	20.0	Ambient	60	
224	Transition	657	681	0	−24	11,683	0.0	Ambient		
225	16_a90 [c]	0	681	0	−681	11,683	0.0	Ambient	10	
226	Transition	681	681	0	0	11,683	0.0	Ambient		
227	15_a90	750	750	0	0	12,866	0.0	Ambient	10	
228	Transition	657	657	0	0	11,267	0.0	Ambient		
229	Transition	896	657	0	239	11,267	0.0	Ambient		
230	$14b_a90$ [c]	1553	657	657	239	11,267	20.0	Ambient	10	
231	Transition	896	657	0	239	11,267	0.0	Ambient		
232	14_a90 [c]	1553	657	0	896	11,267	0.0	Ambient	10	
233	Transition	1469	572	0	896	9815	0.0	Ambient		
234	Transition	1090	572	0	518	9815	0.0	Ambient		

Table D.28—TS-B 90 % Level at Ambient Temperature with Bending (Continued)

Complete CAL IV TS-B with B^{a}_{b} 90 % (QI, QII, QI) Internal Pressure Leak Detection System for TS-B and TS-C										
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Connection Bending Load (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Dogleg (°/100')**	**CAL IV Temperature (°F)**	**Hold Time (min)**	**Direction**
235	$13b_a90$ [c]	1748	572	657	518	9815	20.0	Ambient	10	CW (90 % Level) See Table 11, Table D.19, and Figure D.23
236	Transition	1090	572	0	518	9815	0.0	Ambient		
237	13_a90 [c]	1748	572	0	1175	9815	0.0	Ambient	10	
238	Transition	1461	286	0	1175	4908	0.0	Ambient		
239	12_a90	1748	286	0	1461	4908	0.0	Ambient	5	
240	Transition	1605	143	0	1461	2454	0.0	Ambient		
241	11_a90	1748	143	0	1605	2454	0.0	Ambient	5	
242	Transition	1605	0	0	1605	0	0.0	Ambient		
243	10_a90	1748	0	0	1748	0	0.0	Ambient	2	
244	0	0	0	0	0	0	0.0	Ambient		
End of CAL IV TS-B										

[a] Since there is no pressure at this load point, the hold time was reduced to 2 minutes.

[b] Since there is no pressure at this load point, the hold time was reduced to 5 minutes.

NOTE This reduces the hold time for Load Step 197 from 60 minutes to 5 minutes.

[c] If bending had been controlled by the equivalent stress based curvature control method (5.9.3.4.4), the bending load point would have been conducted after the corresponding load point without bending.

D.6.3 TS-C Load Schedule

D.6.3.1 General

The specific load steps to complete CAL IV TS-C as required by 7.3.5 and Table 13 are shown in Tables D.30 and D.31 and Figures D.24 and D.25. To allow for more clarity and sense of purpose, TS-C has been broken down into two test sequences for this example.

The following assumptions were used in determining the CAL IV Series C load schedules:

a) the actual average pipe D_i (d_{avg}) used to calculate the CEPL for internal pressure load steps is 8.617 in., and

b) the pipe parameters used to calculate the CAL IV TS-C load schedules are listed in Table D.29.

NOTE Depending on the connection design, the D_i used for CEPL calculations may not be equal to the average pipe D_i, particularly for internally shouldered connections.

Table D.29—Example Pipe Parameters Used to Calculate Series C Load Schedules

Specified OD	**Specified Wall**	**SMYS**	D_{avg}	t_{min}	t_{avg}	**AMYS**[a]	K_{temp}
9.625 in.	**0.545** in.	**110,000** psi	**9.697** in.	**0.507** in.	**0.540** in.	**125,000** psi	**0.8864**

D.6.3.2 TS-C 10 Thermal Cycles (TC1 to TC10)

As shown in Figure D.24 and Table D.30, CAL IV testing continues with TS-C. TS-C begins by heating the test specimen to the target elevated temperature and applying a constant tension and internal pressure load (LP 14_e) with an hour hold period. While maintaining the constant loading, the test specimen is cooled down and then cycled between ambient and elevated temperature 10 times. The hold points at ambient and elevated temperature require sealability evaluation. Sealability evaluation shall be by one of the leak-detection methods described in 5.7.

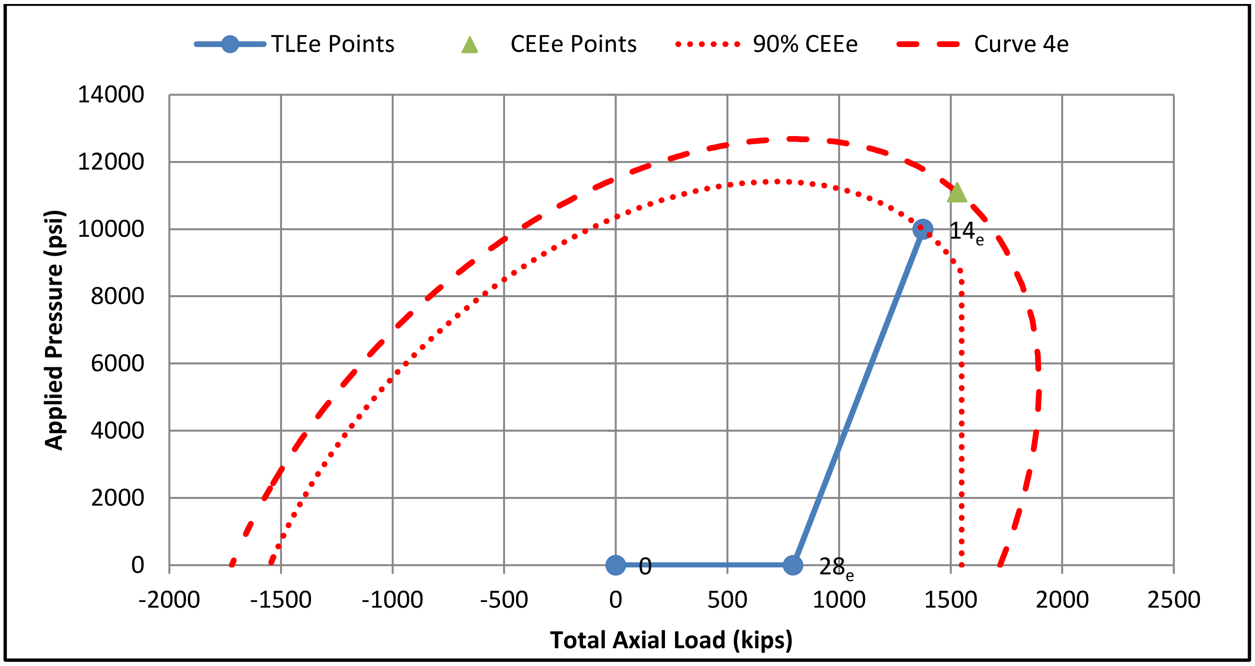


Figure D.24—Ten Thermal Cycles, TS-C Load Steps 1 to 44

Table D.30—CAL IV Series C Thermal Cycle Load Schedule

Begin CAL IV TS-C with 10 Thermal Cycles Internal Pressure Leak Detection System for TS-B and TS-C								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Load Step Description**
1	0	0	0	0	0	Heat-up		
2	0	0	0	0	0	356		
3	28_e	795	0	795	0	356		
4	14_e	1377	582	795	9987	356	60	
5	14_e	1377	582	795	9987	Cooldown		TC1 See Table 13, Table D.23, and Figure D.24
6	14_e	1377	582	795	9987	≤125	5	
7	14_e	1377	582	795	9987	Heat-up		
8	14e	1377	582	795	9987	356	5	
9	14_e	1377	582	795	9987	Cooldown		TC2 See Table 13, Table D.23, and Figure D.24
10	14_e	1377	582	795	9987	≤125	5	
11	14_e	1377	582	795	9987	Heat-up		
12	14_e	1377	582	795	9987	356	5	

Table D.30—CAL IV Series C Thermal Cycle Load Schedule (Continued)

Begin CAL IV TS-C with 10 Thermal Cycles Internal Pressure Leak Detection System for TS-B and TS-C								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Load Step Description**
13	14_e	1377	582	795	9987	Cooldown		TC3 See Table 13, Table D.23, and Figure D.24
14	14_e	1377	582	795	9987	≤125	5	
15	14_e	1377	582	795	9987	Heat-up		
16	14_e	1377	582	795	9987	356	5	
17	14_e	1377	582	795	9987	Cooldown		TC4 See Table 13, Table D.23, and Figure D.24
18	14_e	1377	582	795	9987	≤125	5	
19	14_e	1377	582	795	9987	Heat-up		
20	14_e	1377	582	795	9987	356	5	
21	14_e	1377	582	795	9987	Cooldown		TC5 See Table 13, Table D.23, and Figure D.24
22	14_e	1377	582	795	9987	≤125	5	
23	14_e	1377	582	795	9987	Heat-up		
24	14_e	1377	582	795	9987	356	5	
25	14_e	1377	582	795	9987	Cooldown		TC6 See Table 13, Table D.23, and Figure D.24
26	14_e	1377	582	795	9987	≤125	5	
27	14_e	1377	582	795	9987	Heat-up		
28	14_e	1377	582	795	9987	356	5	
29	14_e	1377	582	795	9987	Cooldown		TC7 See Table 13, Table D.23, and Figure D.24
30	14_e	1377	582	795	9987	≤125	5	
31	14_e	1377	582	795	9987	Heat-up		
32	14_e	1377	582	795	9987	356	5	
33	14_e	1377	582	795	9987	Cooldown		TC8 See Table 13, Table D.23, and Figure D.24
34	14_e	1377	582	795	9987	≤125	5	
35	14_e	1377	582	795	9987	Heat-up		
36	14_e	1377	582	795	9987	356	5	
37	14_e	1377	582	795	9987	Cooldown		TC9 See Table 13, Table D.23, and Figure D.24
38	14_e	1377	582	795	9987	≤125	5	
39	14_e	1377	582	795	9987	Heat-up		
40	14_e	1377	582	795	9987	356	5	
41	14_e	1377	582	795	9987	Cooldown		TC10 See Table 13, Table D.23, and Figure D.24
42	14_e	1377	582	795	9987	≤125	5	
43	14_e	1377	582	795	9987	Heat-up		
44	14_e	1377	582	795	9987	356	5	
End of TS-C 10 Thermal Cycles								

D.6.3.3 TS-C Five Mechanical Cycles (MC1–MC5)

As shown in Figure D.25 and Table D.31, CAL IV TS-C concludes with a series of five mechanical cycles at ambient temperature. The intended path for these mechanical cycles is in the CCW direction with a hold point at high tension and high internal pressure (LP 14_a90) that requires sealability evaluation. The other points passed through during the mechanical cycles do not require absolute sealability evaluation. Sealability evaluation shall be by one of the leak-detection methods described in 5.7.

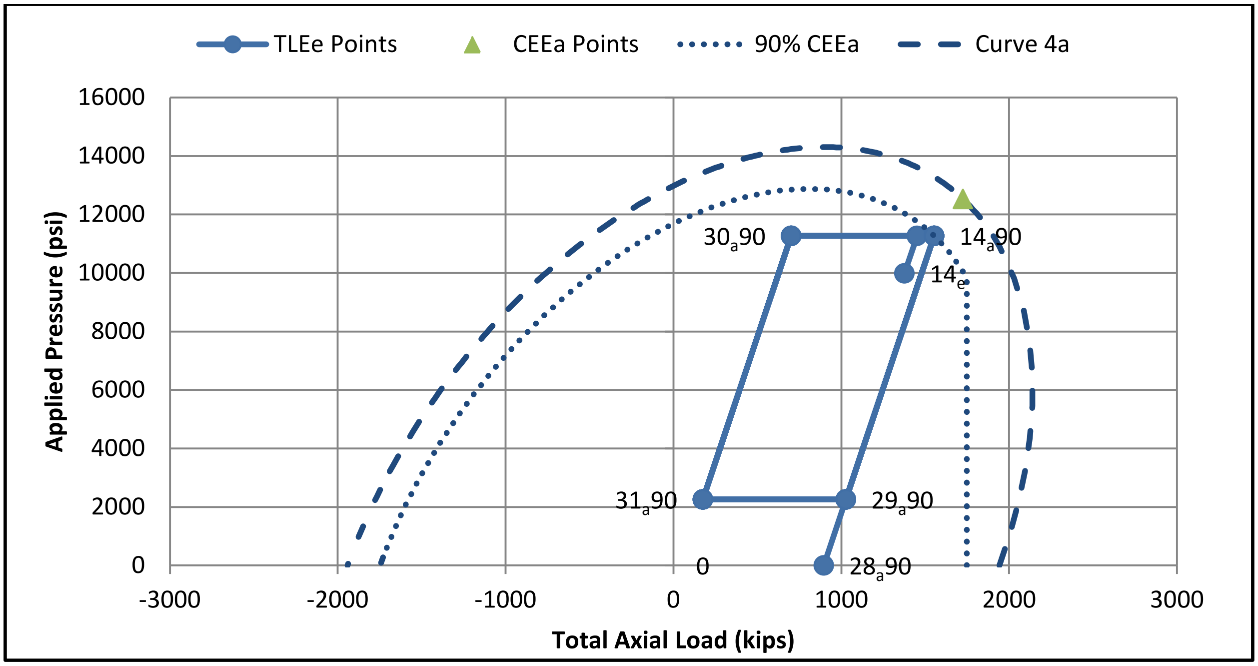


Figure D.25—Five Mechanical Cycles, TS-C Load Steps 45 to 69

Table D.31—CAL IV Series C Mechanical Cycle Load Schedule

Continue CAL IV TS-C with Five Mechanical Cycles Internal Pressure Leak Detection System for TS-B and TS-C								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Load Step Description**
45	14_e	1377	582	795	9987	≤95		Transition
46	Transition	1452	657	795	11,267	≤95		
47	14_a90	1553	657	896	11,267	≤95	5	
48	30_a90	702	657	45	11,267	≤95	2	MC1 See Table 13, Table D.19, and Figure D.25
49	31_a90	176	131	45	2253	≤95	2	
50	29_a90	1028	131	896	2253	≤95	2	
51	14_a90	1553	657	896	11,267	≤95	5	
52	30_a90	702	657	45	11,267	≤95	2	MC2 See Table 13, Table D.19, and Figure D.25
53	31_a90	176	131	45	2253	≤95	2	
54	29_a90	1028	131	896	2253	≤95	2	
55	14_a90	1553	657	896	11,267	≤95	5	
56	30_a90	702	657	45	11,267	≤95	2	MC3 See Table 13, Table D.19, and Figure D.25
57	31_a90	176	131	45	2253	≤95	2	
58	29_a90	1028	131	896	2253	≤95	2	
59	14_a90	1553	657	896	11,267	≤95	5	
60	30_a90	702	657	45	11,267	≤95	2	MC4 See Table 13, Table D.19, and Figure D.25
61	31_a90	176	131	45	2253	≤95	2	
62	29_a90	1028	131	896	2253	≤95	2	
63	14_a90	1553	657	896	11,267	≤95	5	

Table D.31—CAL IV Series C Mechanical Cycle Load Schedule (Continued)

Continue CAL IV TS-C with Five Mechanical Cycles Internal Pressure Leak Detection System for TS-B and TS-C								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Load Step Description**
64	30_a90	702	657	45	11,267	≤95	2	MC5 See Table 13, Table D.19, and Figure D.25
65	31_a90	176	131	45	2253	≤95	2	
66	29_a90	1028	131	896	2253	≤95	2	
67	14_a90	1553	657	896	11,267	≤95	5	
68	Transition	896	0	896	0	≤95		
69	0	0	0	0	0	≤95		
End of CAL IV TS-C								

D.6.4 TS-A Load Schedule

D.6.4.1 General

The specific load steps to complete a CAL IV Series A test as required by 7.3.3 and Table 9 are shown in Table D.33 through D.42 and Figures D.26 through D.35. To allow for more clarity and sense of purpose, TS-A has been broken down into 10 test sequences for this example.

The following assumptions were used in determining the CAL IV Series A load schedules.

a) The actual average pipe D_i (d_{avg}) used to calculate the CEPL for internal pressure load steps is 8.617 in.

b) The external pressure chamber seals on the test specimen pipe D_o. If the external pressure chamber seals on a surface that is not actual pipe D_o, the axial load would need to be adjusted due to the CEPL to ensure that the specified total load is applied.

c) The pipe parameters used to calculate the CAL IV TS-A load schedules are listed in Table D.32.

NOTE Depending on the connection design, the D_i used for CEPL calculations may not be equal to the average pipe D_i, particularly for internally shouldered connections.

Table D.32—Example Pipe Parameters Used to Calculate Series A Load Schedules

Specified OD	**Specified Wall**	**SMYS**	D_{avg}	t_{min}	t_{avg}	**AMYS**[a]	$K_{383°}$	$K_{150°}$	**HC Rating**
9.625 in.	**0.545** in.	**110,000** psi	**9.697** in.	**0.507** in.	**0.540** in.	**125,000** psi	**0.8864**	0.9723	**9140** psi

NOTE $K_{150°}$ has been rounded; refer to D.5.6 for the exact formula.

D.6.4.2 TS-A 90 % Level at Elevated Temperature (QI, QII)

As shown in Figure D.26 and Table D.33, CAL IV testing continues with TS-A. TS-A begins with internal pressure testing at elevated temperature. A series of QI/QII load points is executed in the CCW direction at a 90 % level. The majority of the hold points require sealability evaluation. If the testing is conducted with the external pressure vessel installed, sealability evaluation shall be by the pressure-drop method (see 5.8.2 and Figure 16). Otherwise, one of the leak-detection methods described in 5.7 shall be used.

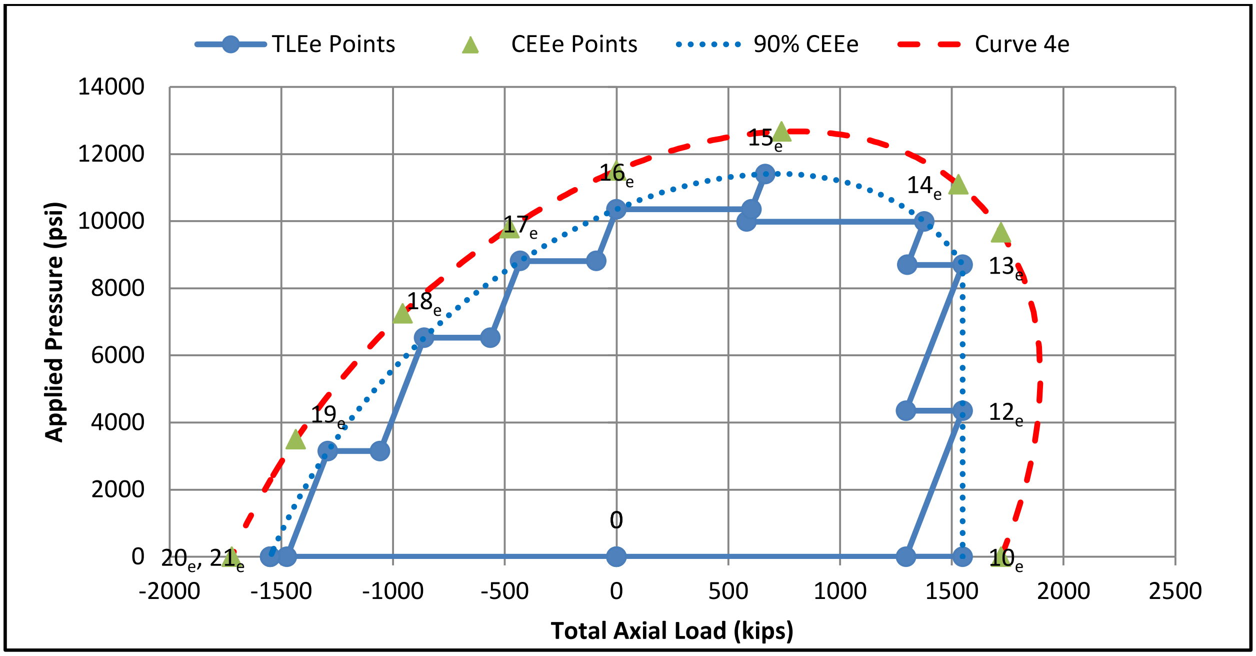


Figure D.26—A^e 90 % (QI, QII), TS-A Load Steps 1 to 24

Table D.33—TS-A 90 % Level at Elevated Temperature (QI, QII)

Begin CAL IV TS-A with A^e 90 % (QI, QII) Leak Detection for TS-A at Elevated Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
1	0	0	0	0	0	Heat-up		CCW (90 % Level) See Table 9, Table D.23, and Figure D.26
2	0	0	0	0	0	356		
3	10_e	1549	0	1549	0	356	2	
4	Transition	1295	0	1295	0	356		
5	12_e	1549	254	1295	4350	356	10	
6	Transition	1295	254	1042	4350	356		
7	13_e	1549	507	1042	8700	356	10	
8	Transition	1302	507	795	8700	356		
9	14_e	1377	582	795	9987	356	10	
10	Transition	582	582	0	9987	356		
11	15_e	665	665	0	11,405	356	10	
12	Transition	604	604	0	10,355	356		
13	16_e	0	604	−604	10,355	356	60	
14	Transition	−90	514	−604	8813	356		
15	17_e	−430	514	−944	8813	356	10	
16	Transition	−564	381	−944	6526	356		
17	18_e	−861	381	−1241	6526	356	10	
18	Transition	−1057	184	−1241	3150	356		
19	19_e	−1291	184	−1475	3150	356	10	

Table D.33—TS-A 90 % Level at Elevated Temperature (QI, QII) (Continued)

Begin CAL IV TS-A with A^e 90 % (QI, QII) Leak Detection for TS-A at Elevated Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
20	Transition	−1475	0	−1475	0	356		CCW (90 % Level) See Table 9, Table D.23, and Figure D.26
21	20e	−1549	0	−1549	0	356	2 [a]	
22	Transition	−1549	0	−1549	0	356		
23	21e	−1549	0	−1549	0	356	2	
24	0	0	0	0	0	356		
End of A^e 90 % (QI, QII) Switch from Internal Pressure to External Pressure Testing								

[a] Since there is no pressure at this load point, the hold time was reduced from 10 minutes to 2 minutes.

D.6.4.3 TS-A 90 % Level at Elevated Temperature (QIII, QIV) and (QIV, QIII)

As shown in Figure D.27 and Table D.34, CAL IV TS-A continues with external pressure testing at elevated temperature. A series of QIII/QIV load points is executed first in the CCW and then in the CW direction (to evaluate load path dependency) at a 90 % level. The majority of the hold points require sealability evaluation. Sealability evaluation shall be by the pressure-drop method (see 5.8.2 and Figure 17). The system should remain closed to prevent hot fluid from escaping the external pressure chamber.

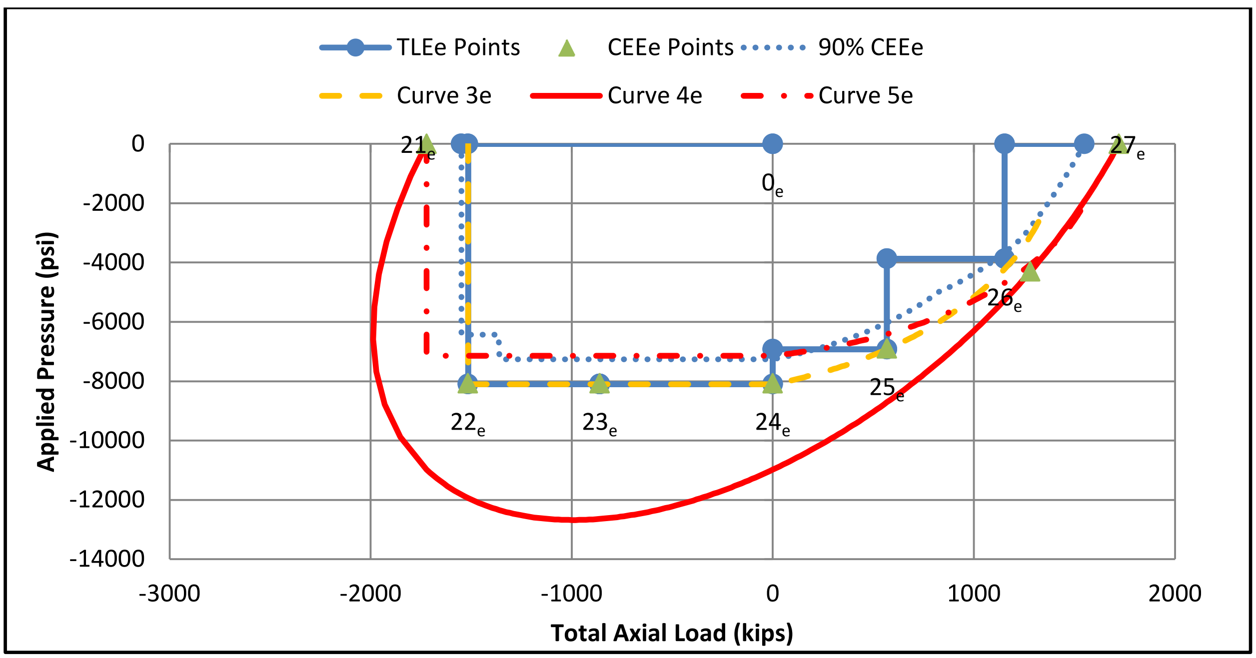


Figure D.27—A^e 90 % (QIII, QIV) and A^e 90 % (QIV, QIII), TS-A Load Steps 25 to 51

Table D.34—TS-A 90 % Level at Elevated Temperature (QIII, QIV) and (QIV, QIII)

Continue CAL IV TS-A with A^e 90 % (QIII, QIV) and A^e 90 % (QIV, QIII) Leak Detection for TS-A at Elevated Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
25	0	0	0	0	0	356		CCW (90 % Level) See Table 9, Table D.23, and Figure D.27
26	21_e	−1549	0	−1549	0	356	2	
27	Transition	−1516	0	−1516	0	356		
28	22_e	−1516	0	−1516	−8102	356	60	
29	Transition	−861	0	−861	−8102	356		
30	23_e	−861	0	−861	−8102	356	10	
31	Transition	−861	0	−861	−8102	356		
32	24_e	0	0	0	−8102	356	10	
33	Transition	0	0	0	−6924	356		
34	25_e	568	0	568	−6924	356	10	
35	Transition	568	0	568	−3876	356		
36	26_e	1153	0	1153	−3876	356	10	
37	Transition	1153	0	1153	0	356		
38	27_e	1549	0	1549	0	356	2	
39	Transition	1153	0	1153	0	356		CW (90 % Level) See Table 9, Table D.23, and Figure D.27
40	26_e	1153	0	1153	−3876	356	10	
41	Transition	568	0	568	−3876	356		
42	25_e	568	0	568	−6924	356	10	
43	Transition	0	0	0	−6924	356		
44	24_e	0	0	0	−8102	356	60	
45	Transition	−861	0	−861	−8102	356		
46	23_e	−861	0	−861	−8102	356	10	
47	Transition	−861	0	−861	−8102	356		
48	22_e	−1516	0	−1516	−8102	356	10	
49	Transition	−1516	0	−1516	0	356		
50	21_e	−1549	0	−1549	0	356	2	
51	0	0	0	0	0	356		
End of A^e 90 % (QIII, QIV) and A^e 90 % (QIV, QIII) Switch from External Pressure to Internal Pressure Testing								

D.6.4.4 TS-A 90 % Level at Elevated Temperature (QII, QI)

As shown in Figure D.28 and Table D.35, CAL IV TS-A continues with internal pressure testing at elevated temperature. A series of QI/QII load points is executed in the CW direction. The majority of the hold points require sealability evaluation. This testing can be performed with the external pressure vessel installed and sealability evaluation is by the pressure-drop method (see 5.8.2 and Figure 16). However, the external pressure vessel may be removed so that one of the leak-detection methods described in 5.7 may be used.

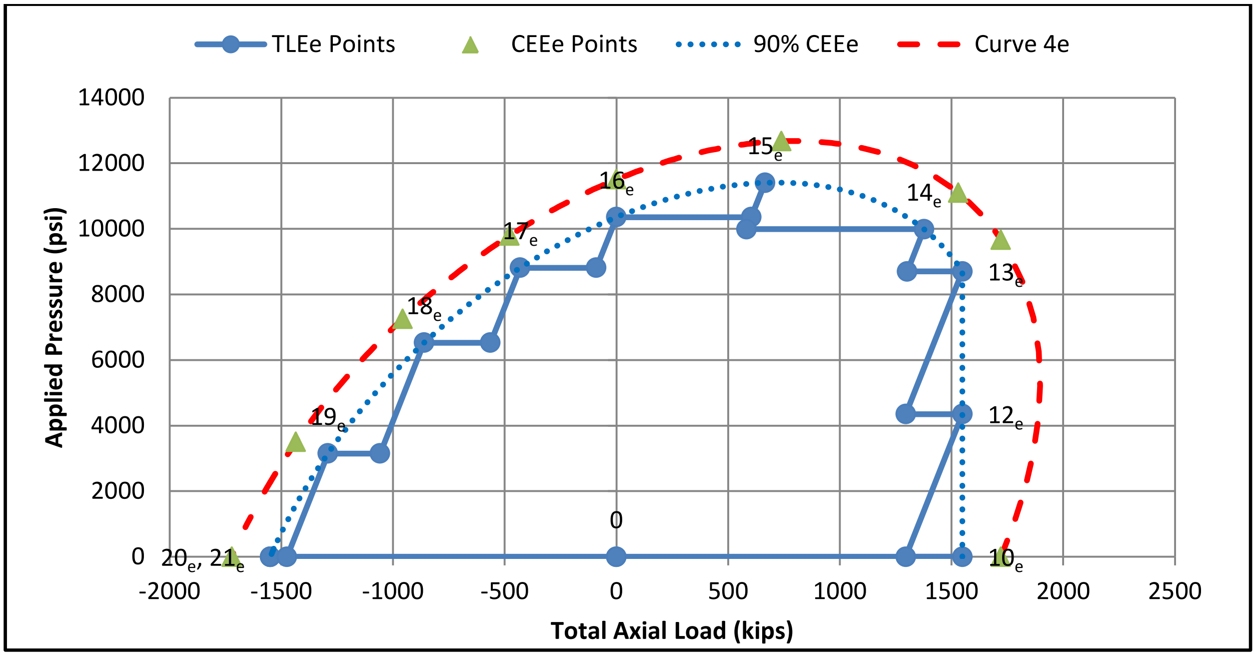


Figure D.28—A^e 90 % (QIII, QIV) and A^e 90 % (QIV, QIII), TS-A Load Steps 52 to 74

Table D.35—TS-A 90 % Level at Elevated Temperature (QII, QI)

Continue TS-A with A^e 90 % (QII, QI) Leak Detection for TS-A at Elevated Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
52	0	0	0	0	0	356		CW (90 % Level) See Table 9, Table D.23, and Figure D.28
53	21_e	−1549	0	−1549	0	356	2	
54	Transition	−1549	0	−1549	0	356		
55	20_e	−1549	0	−1549	0	356	2 [a]	
56	Transition	−1475	0	−1475	0	356		
57	19_e	−1291	184	−1475	3150	356	10	
58	Transition	−1057	184	−1241	3150	356		
59	18_e	−861	381	−1241	6526	356	60	
60	Transition	−564	381	−944	6526	356		
61	17_e	−430	514	−944	8813	356	10	
62	Transition	−90	514	−604	8813	356		
63	16_e	0	604	−604	10,355	356	10	
64	Transition	604	604	0	10,355	356		
65	15_e	665	665	0	11,405	356	10	
66	Transition	582	582	0	9987	356		
67	14_e	1377	582	795	9987	356	60	
68	Transition	1302	507	795	8700	356		

Table D.35—TS-A 90 % Level at Elevated Temperature (QII, QI) (Continued)

Continue TS-A with A^e 90 % (QII, QI) Leak Detection for TS-A at Elevated Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
69	13_e	1549	507	1042	8700	356	10	CW (90 % Level) See Table 9, Table D.23, and Figure D.28
70	Transition	1295	254	1042	4350	356		
71	12_e	1549	254	1295	4350	356	10	
72	Transition	1295	0	1295	0	356		
73	10_e	1549	0	1549	0	356	2	
74	0	0	0	0	0	356		
End of A^e 90 % (QII, QI)								

[a] Since there is no pressure at this load point, the hold time was reduced from 10 minutes to 2 minutes.

D.6.4.5 TS-A 90 % Level 5 QI to QIII Cycles

As shown in Figure D.29 and Table D.36, CAL IV TS-A continues with load and temperature cycling (five cycles) between QI at ambient temperature [≤150 °F (65 °C)] and QIII at elevated temperature. The hold points in QI and QIII require sealability evaluation. This testing can be performed with the external pressure vessel installed, and sealability evaluation is by the pressure drop method (see 5.8.2 and Figure 16). However, the external pressure vessel may be removed so that one of the leak-detection methods described in 5.7 may be used. For external pressure testing, sealability evaluation shall be by the pressure-drop method (see 5.8.2 and Figure 17). The system should remain closed to prevent hot fluid from escaping the external pressure chamber.

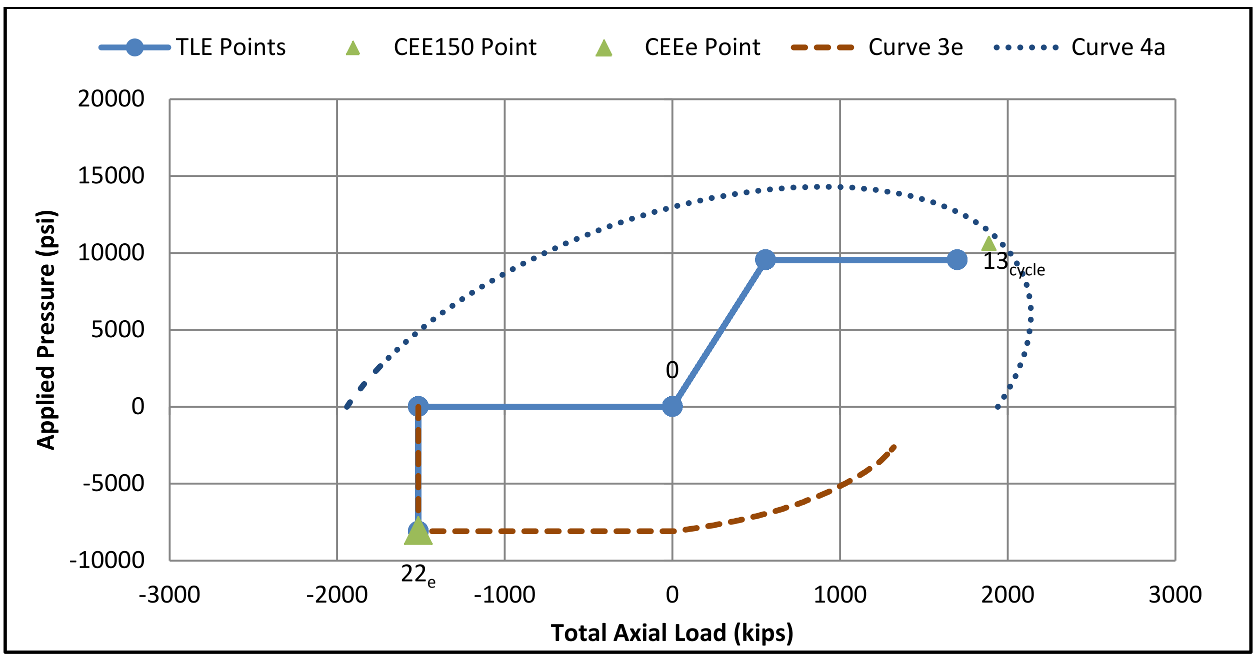


Figure D.29—A^e 90 % 5 QI-QIII Cycles, TS-A Load Steps 75 to 125

Table D.36—TS-A 90 % Level 5 QI-QIII Cycles

Continue CAL IV TS-A with 90 % 5 QI-QIII Cycles Leak Detection for TS-A at Elevated Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
75	0	0	0	0	0	Cooldown		Cycle 1 (90 % Level) See Table 9, Table D.20, Table D.23, and Figure D.29
76	Transition	557	557	0	9544	150		
77	13_{cycle}	1699	557	1143	9544	150	15	
78	Transition	557	557	0	9544	150		
79	0	0	0	0	0	150		
80	0	0	0	0	0	Heat-up		
81	Transition	–1516	0	–1516	0	356		
82	22_e	–1516	0	–1516	8102	356	15	
83	Transition	–1516	0	–1516	0	356		
84	0	0	0	0	0	356		
85	0	0	0	0	0	Cooldown		Cycle 2 (90 % Level) See Table 9, Table D.20, Table D.23, and Figure D.29
86	Transition	557	557	0	9544	150		
87	13_{cycle}	1699	557	1143	9544	150	15	
88	Transition	557	557	0	9544	150		
89	0	0	0	0	0	150		
90	0	0	0	0	0	Heat-up		
91	Transition	–1516	0	–1516	0	356		
92	22_e	–1516	0	–1516	–8102	356	15	
93	Transition	–1516	0	–1516	0	356		
94	0	0	0	0	0	356		
95	0	0	0	0	0	Cooldown		Cycle 3 (90 % Level) See Table 9, Table D.20, Table D.23, and Figure D.29
96	Transition	557	557	0	9544	150		
97	13_{cycle}	1699	557	1143	9544	150	15	
98	Transition	557	557	0	9544	150		
99	0	0	0	0	0	150		
100	0	0	0	0	0	Heat-up		
101	Transition	–1516	0	–1516	0	356		
102	22_e	–1516	0	–1516	–8102	356	15	
103	Transition	–1516	0	–1516	0	356		
104	0	0	0	0	0	356		

Table D.36—TS-A 90 % Level 5 QI-QIII Cycles (Continued)

Load Step	LP	Total Load (kips)	CEPL (kips)	Frame Load (kips)		Pressure (psi)	Temperature (°F)	Hold Time (min)	Direction
Continue CAL IV TS-A with 90 % 5 QI-QIII Cycles Leak Detection for TS-A at Elevated Temperature									
105	0	0	0	0	0	Cooldown		Cycle 4 (90 % Level) See Table 9, Table D.20, Table D.23, and Figure D.29	
106	Transition	557	557	0	9544	150			
107	13_{cycle}	1699	557	1143	9544	150	15		
108	Transition	557	557	0	9544	150			
109	0	0	0	0	0	150			
110	0	0	0	0	0	Heat-up			
111	Transition	–1516	0	–1516	0	356			
112	22_e	–1516	0	–1516	–8102	356	15		
113	Transition	–1516	0	–1516	0	356			
114	0	0	0	0	0	356			
115	0	0	0	0	0	Cooldown		Cycle 5 (90 % Level) See Table 9, Table D.20, Table D.23, and Figure D.29	
116	Transition	557	557	0	9544	150			
117	13_{cycle}	1699	557	1143	9544	150	15		
118	Transition	557	557	0	9544	150			
119	0	0	0	0	0	150			
120	0	0	0	0	0	Heat-up			
121	Transition	–1516	0	–1516	0	356			
122	22_e	–1516	0	–1516	–8102	356	15		
123	Transition	–1516	0	–1516	0	356			
124	0	0	0	0	0	356			
125	0	0	0	0	0	Cooldown			
End of QI-QIII Cycles Switch Leak Detection System to Ambient Temperature Method									

D.6.4.6 TS-A 90 % Level at Ambient Temperature (QI, QII)

As shown in Figure D.30 and Table D.37, CAL IV TS-A continues with internal pressure testing at ambient temperature. A series of QI/QII load points is executed in the CCW direction at a 90 % level. The majority of the hold points require sealability evaluation. This testing can be performed with the external pressure vessel installed, and sealability evaluation is by the water column method (see 5.8.1 and Figure 14). However, the external pressure vessel may be removed so that one of the leak-detection methods described in 5.7 may be used.

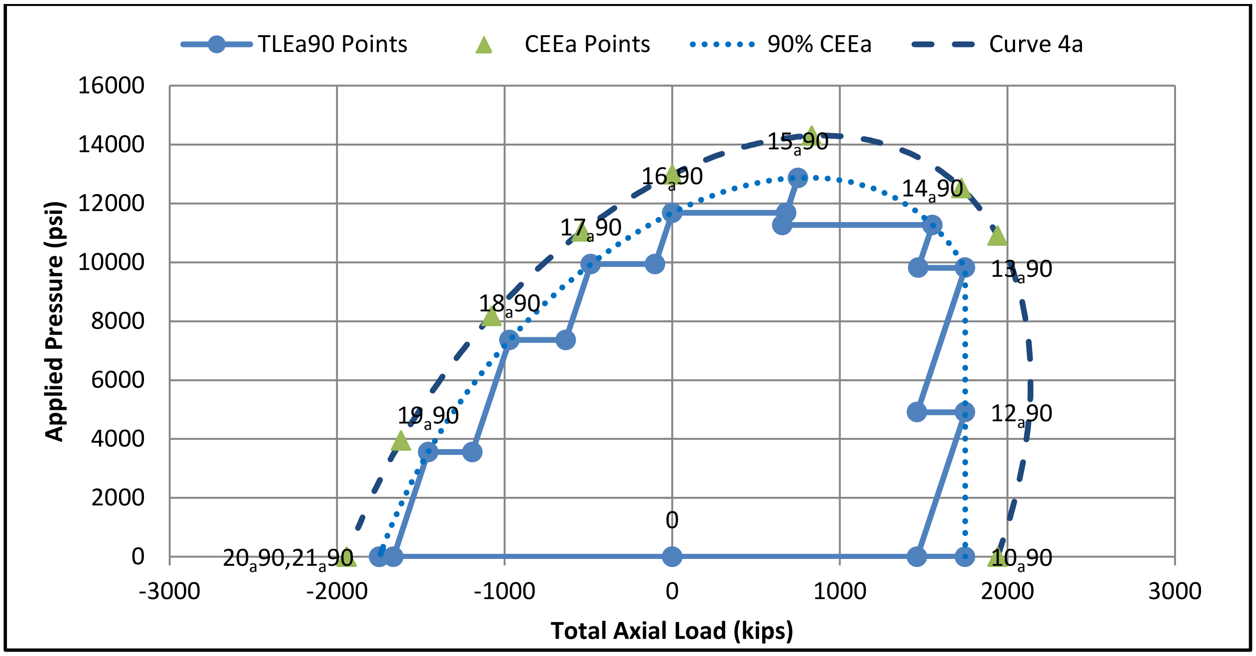


Figure D.30—A^a 90 % (QI, QII), TS-A Load Steps 126 to 148

Table D.37—TS-A 90 % Level at Ambient Temperature (QI, QII)

Continue CAL IV TS-A with A^a 90 % (QI, QII) Leak Detection for TS-A at Ambient Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
126	0	0	0	0	0	Ambient		CCW (90 % Level) See Table 9, Table D.19, and Figure D.30
127	10_a90	1748	0	1748	0	Ambient	2	
128	Transition	1461	0	1461	0	Ambient		
129	12_a90	1748	286	1461	4908	Ambient	10	
130	Transition	1461	286	1175	4908	Ambient		
131	13_a90	1748	572	1175	9815	Ambient	10	
132	Transition	1469	572	896	9815	Ambient		
133	14_a90	1553	657	896	11,267	Ambient	10	
134	Transition	657	657	0	11,267	Ambient		
135	15_a90	750	750	0	12,866	Ambient	10	
136	Transition	681	681	0	11,683	Ambient		
137	16_a90	0	681	–681	11,683	Ambient	60	
138	Transition	−102	580	–681	9942	Ambient		
139	17_a90	−485	580	–1065	9942	Ambient	10	
140	Transition	−636	429	–1065	7363	Ambient		
141	18_a90	−971	429	–1400	7363	Ambient	10	
142	Transition	−1193	207	–1400	3554	Ambient		

Table D.37—TS-A 90 % Level at Ambient Temperature (QI, QII) (Continued)

Continue CAL IV TS-A with A^a 90 % (QI, QII) Leak Detection for TS-A at Ambient Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
143	19_a90	−1456	207	−1664	3554	Ambient	10	
144	Transition	−1664	0	–1664	0	Ambient		
145	20_a90	−1748	0	–1748	0	Ambient	2 [b]	
146	Transition	−1748	0	–1748	0	Ambient		
147	21_a90	−1748	0	–1748	0	Ambient	2	
148	0	0	0	0	0	Ambient		
End of A^a 90 % (QI, QII) Switch from Internal Pressure to External Pressure Testing								

[b] Since there is no pressure at this load point, the hold time was reduced from 10 minutes to 2 minutes.

D.6.4.7 TS-A 90 % Level at Ambient Temperature (QIII, QIV) & (QIV, QIII)

As shown in Figure D.31 and Table D.38, CAL IV TS-A continues with external pressure testing. A series of QIII/QIV load points is executed first in the CCW and then in the CW direction (to evaluate load path dependency) at a 90 % level. The majority of the hold points require sealability evaluation. Sealability evaluation shall be by the water-column method (see 5.8.1 and Figure 14).

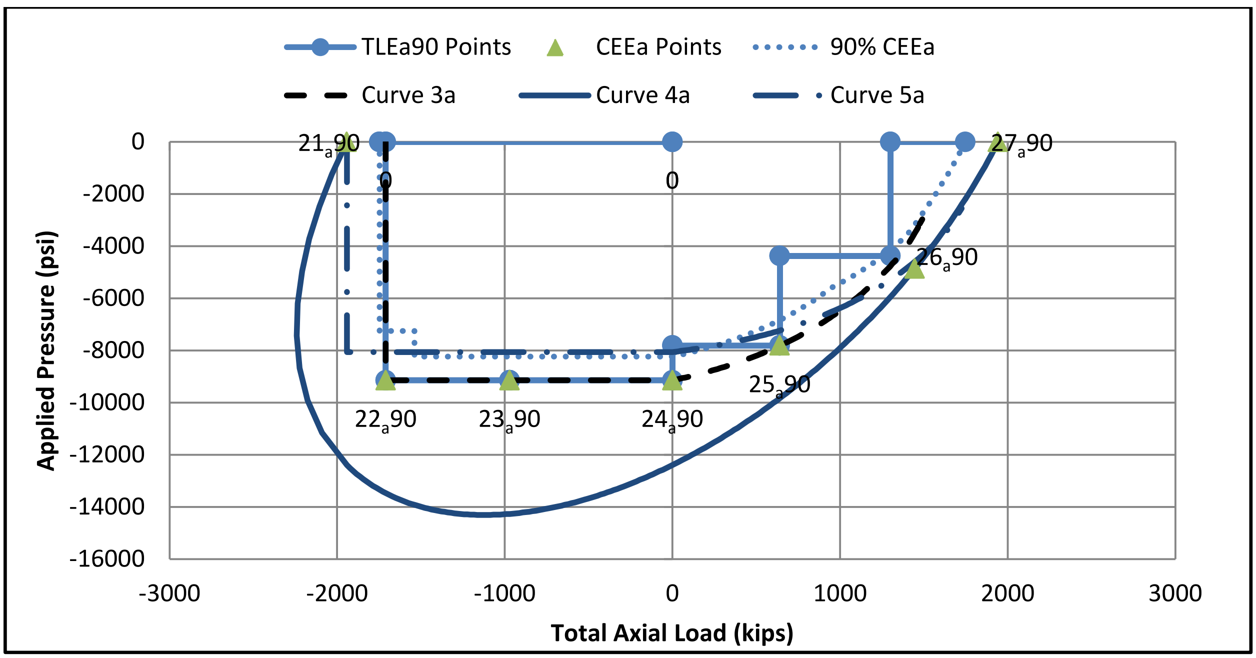


Figure D.31—A^a 90 % (QIII, QIV) and A^a 90 % (QIV, QIII), TS-A Load Steps 149 to 175

Table D.38—TS-A 90 % Level at Ambient Temperature (QIII, QIV) and (QIV, QIII)

Continue CAL IV TS-A with A^a 90 % (QIII, QIV) and A^a 90 % (QIV, QIII) Leak Detection for TS-A at Ambient Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
149	0	0	0	0	0	Ambient		CCW (90 % Level) See Table 9, Table D.19, and Figure D.31
150	21_a90	−1748	0	−1748	0	Ambient	2	
151	Transition	−1710	0	−1710	0	Ambient		
152	22_a90	−1710	0	−1710	−9140	Ambient	60	
153	Transition	−971	0	−971	−9140	Ambient		
154	23_a90	−971	0	−971	−9140	Ambient	10	
155	Transition	−971	0	−971	−9140	Ambient		
156	24_a90	0	0	0	−9140	Ambient	10	
157	Transition	0	0	0	−7811	Ambient		
158	25_a90	641	0	641	−7811	Ambient	10	
159	Transition	641	0	641	−4373	Ambient		
160	26_a90	1301	0	1301	−4373	Ambient	10	
161	Transition	1301	0	1301	0	Ambient		
162	27_a90	1748	0	1748	0	Ambient	2	
163	Transition	1301	0	1301	0	Ambient		CW (90 % Level) See Table 9, Table D.19, and Figure D.31
164	26_a90	1301	0	1301	−4373	Ambient	10	
165	Transition	641	0	641	−4373	Ambient		
166	25_a90	641	0	641	−7811	Ambient	10	
167	Transition	0	0	0	−7811	Ambient		
168	24_a90	0	0	0	−9140	Ambient	60	
169	Transition	−971	0	−971	−9140	Ambient		
170	23_a90	−971	0	−971	−9140	Ambient	10	
171	Transition	−971	0	−971	−9140	Ambient		
172	22_a90	−1710	0	−1710	−9140	Ambient	10	
173	Transition	−1710	0	−1710	0	Ambient		
174	21_a90	−1748	0	–1748	0	Ambient	2	
175	0	0	0	0	0	Ambient		
End of Begin A^a 90 % (QIII, QIV) and A^a 90 % (QIV, QIII) Switch from External Pressure to Internal Pressure Testing								

D.6.4.8 TS-A 90 % Level at Ambient Temperature (QII, QI)

As shown in Figure D.32 and Table D.39, CAL IV TS-A continues with internal pressure testing. A series of QI/QII load points is executed in the CW direction to allow evaluation of load path dependency at a 90 % level. The majority of the hold points require sealability evaluation. This testing can be performed with the external pressure vessel installed, and sealability evaluation is by the water-column method (see 5.8.1 and Figure 14). However, the external pressure vessel may be removed so that one of the leak-detection methods described in 5.7 may be used. Successful completion of each test through the end of this test sequence demonstrates the test specimen's compliance for CAL IV at a 90 % level.

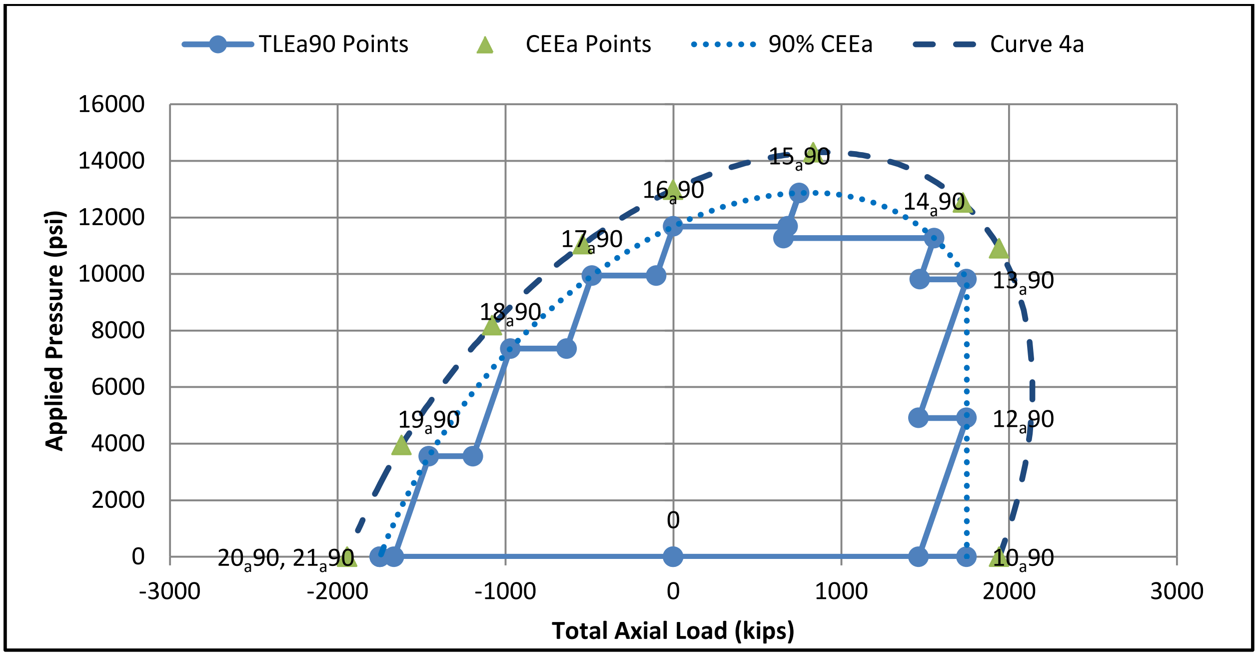


Figure D.32—A^a 90 % (QI, QII), TS-A Load Steps 176 to 198

Table D.39—TS-A 90 % Level at Ambient Temperature (QII, QI)

Continue CAL IV TS-A with A^a 90 % (QII, QI) Leak Detection for TS-A at Ambient Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
176	0	0	0	0	0	Ambient		CW (90 % Level) See Table 9, Table D.19, and Figure D.32
177	21_a90	−1748	0	−1748	0	Ambient	2	
178	Transition	−1748	0	−1748	0	Ambient		
179	20_a90	−1748	0	−1748	0	Ambient	2[b]	
180	Transition	−1664	0	−1664	0	Ambient		
181	19_a90	−1456	207	−1664	3554	Ambient	10	
182	Transition	−1193	207	−1400	3554	Ambient		
183	18_a90	−971	429	−1400	7363	Ambient	60	
184	Transition	−636	429	−1065	7363	Ambient		
185	17_a90	−485	580	−1065	9942	Ambient	10	
186	Transition	−102	580	−681	9942	Ambient		
187	16_a90	0	681	−681	11,683	Ambient	10	
188	Transition	681	681	0	11,683	Ambient		
189	15_a90	750	750	0	12,866	Ambient	10	
190	Transition	657	657	0	11,267	Ambient		
191	14_a90	1553	657	896	11,267	Ambient	60	
192	Transition	1469	572	896	9815	Ambient		
193	13_a90	1748	572	1175	9815	Ambient	10	

Table D.39—TS-A 90 % Level at Ambient Temperature (QII, QI) (Continued)

Continue CAL IV TS-A with A^{a} 90 % (QII, QI) Leak Detection for TS-A at Ambient Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
194	Transition	1461	286	1175	4908	Ambient		CW (90 % Level)
195	12_a90	1748	286	1461	4908	Ambient	10	
196	Transition	1461	0	1461	0	Ambient		See Table 9, Table D.19, and Figure D.32
197	10_a90	1748	0	1748	0	Ambient	2	
198	0	0	0	0	0	Ambient		
End of TS-A 90 % Level								
[b] Since there is no pressure at this load point, the hold time was reduced from 10 minutes to 2 minutes.								

D.6.4.9 TS-A 95 % Level at Ambient Temperature (QI, QII)

To demonstrate connection performance at a 95 % level, CAL IV TS-A continues with internal pressure testing as shown in Figure D.33 and Table D.40. A series of QI/QII load points is executed in the CCW direction at a 95 % level. The majority of the hold points require sealability evaluation. This testing can be performed with the external pressure vessel installed, and sealability evaluation is by the water-column method (see 5.8.1 and Figure 14). However, the external pressure vessel may be removed so that one of the leak-detection methods described in 5.7 may be used.

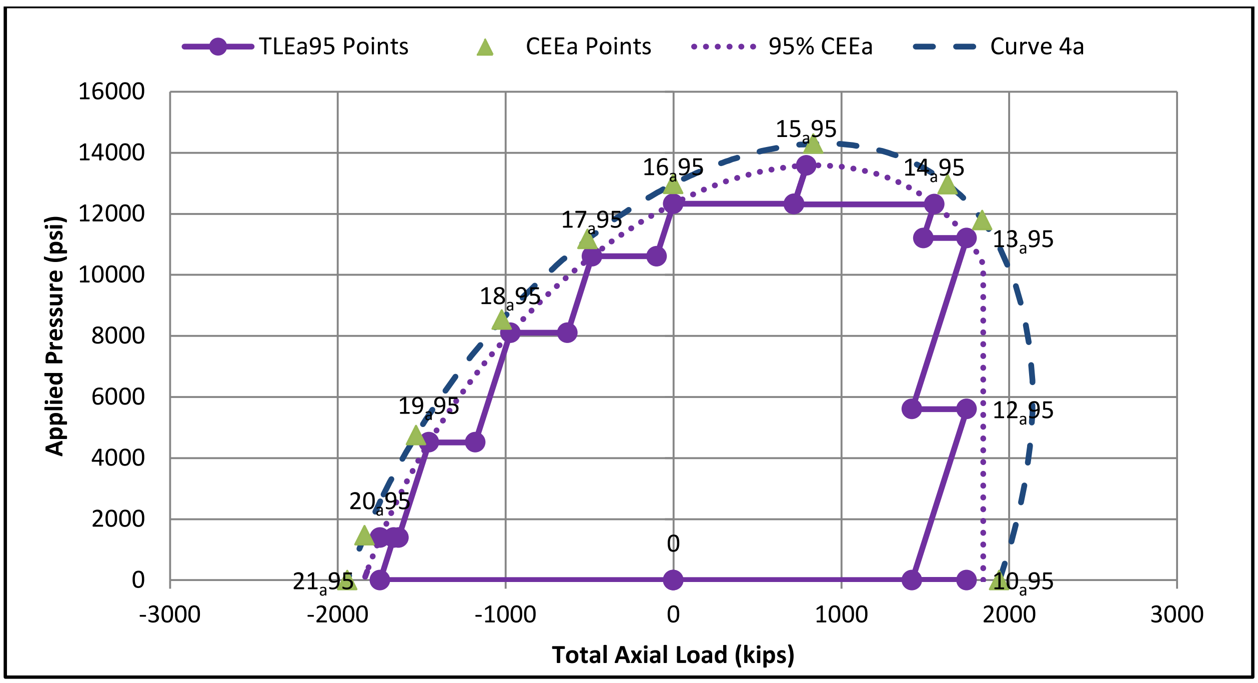


Figure D.33—A^{a} 95 % (QI, QII), TS-A Load Steps 199 to 221

Table D.40—TS-A 95 % Level at Ambient Temperature (QI, QII)

Continue TS-A with A^{a} 95 % (QI, QII) Leak Detection for TS-A at Ambient Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
199	0	0	0	0	0	Ambient		CCW (95 % Level) See Table 9, Table D.16, and Figure D.33
200	10_a95	1748	0	1748	0	Ambient	2	
201	Transition	1421	0	1421	0	Ambient		
202	12_a95	1748	327	1421	5603	Ambient	10	
203	Transition	1421	327	1094	5603	Ambient		
204	13_a95	1748	654	1094	11,206	Ambient	10	
205	Transition	1489	654	835	11,206	Ambient		
206	14_a95	1553	718	835	12,316	Ambient	10	
207	Transition	718	718	0	12,316	Ambient		
208	15_a95	792	792	0	13,581	Ambient	10	
209	Transition	719	719	0	12,332	Ambient		
210	16_a95	0	719	−719	12,332	Ambient	60	
211	Transition	−100	619	−719	10,612	Ambient		
212	17_a95	−485	619	−1104	10,612	Ambient	10	
213	Transition	−631	473	−1104	8108	Ambient		
214	18_a95	−971	473	−1444	8108	Ambient	10	
215	Transition	−1181	263	−1444	4513	Ambient		
216	19_a95	−1456	263	−1720	4513	Ambient	10	
217	Transition	−1638	81	−1720	1391	Ambient		
218	20_a95	−1748	81	−1829	1391	Ambient	10	
219	Transition	−1667	81	−1748	1391	Ambient		
220	21_a95	−1748	0	−1748	0	Ambient	2	
221	0	0	0	0	0	Ambient		
End of A^{a} 95 % (QI, QII) Switch from Internal Pressure to External Pressure Testing								

D.6.4.10 TS-A 95 % Level at Ambient Temperature (QIII, QIV) & (QIV, QIII)

As shown in Figure D.34 and Table D.41, CAL IV TS-A continues with external pressure testing. A series of QIII/QIV load points is executed first in the CCW and then in the CW direction (to evaluate load path dependency) at a 95 % level. The majority of the hold points require sealability evaluation. Sealability evaluation shall be by the water-column method (see 5.8.1 and Figure 14).

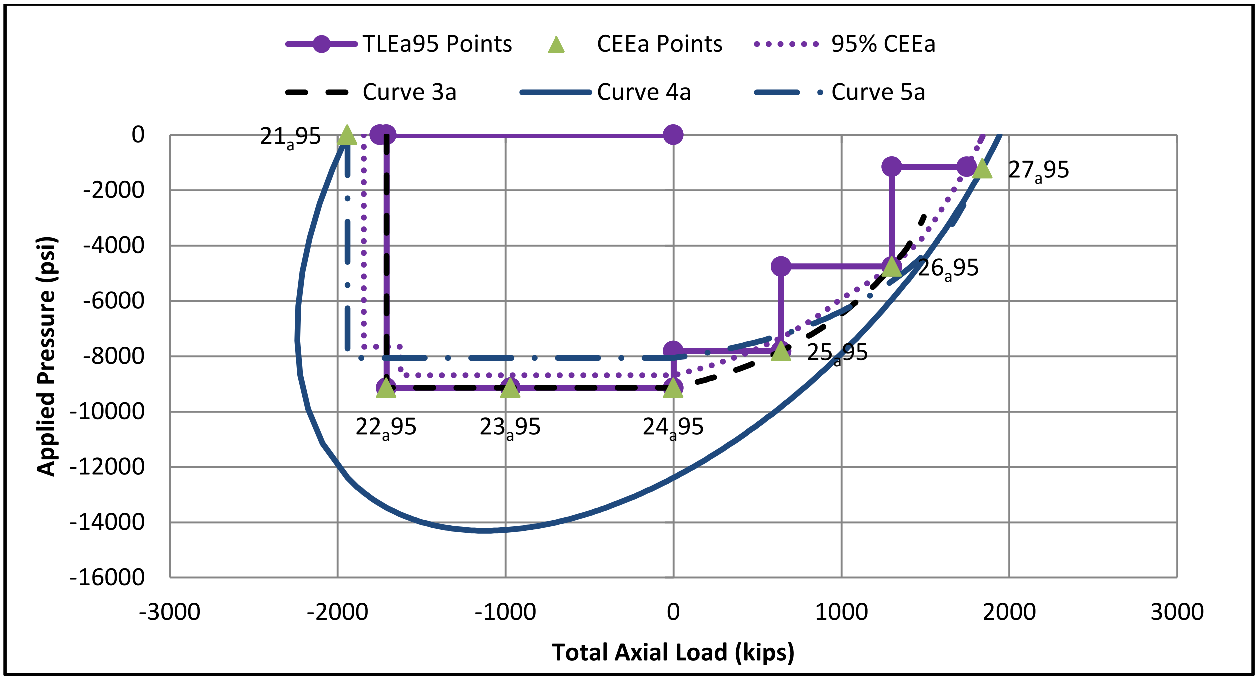


Figure D.34—A^a 95 % (QIII, QIV) and A^a 95 % (QIV, QIII), TS-A Load Steps 222 to 248

Table D.41—TS-A 95 % Level at Ambient Temperature (QIII, QIV) and (QIV, QIII)

Continue CAL IV TS-A with A^a 95 % (QIII, QIV) and A^a 95 % (QIV, QIII) Leak Detection for TS-A at Ambient Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
222	0	0	0	0	0	Ambient		CCW (95 % Level) See Table 9, Table D.16, and Figure D.34
223	21_a95	−1748	0	−1748	0	Ambient	2	
224	Transition	−1710	0	−1710	0	Ambient		
225	22_a95	−1710	0	−1710	−9140	Ambient	60	
226	Transition	−971	0	−971	−9140	Ambient		
227	23_a95	−971	0	−971	−9140	Ambient	10	
228	Transition	−971	0	−971	−9140	Ambient		
229	24_a95	0	0	0	−9140	Ambient	10	
230	Transition	0	0	0	−7811	Ambient		
231	25_a95	641	0	641	−7811	Ambient	10	
232	Transition	641	0	641	−4755	Ambient		
233	26_a95	1301	0	1301	−4755	Ambient	10	
234	Transition	1301	0	1301	−1154	Ambient		
235	27_a95	1748	0	1748	−1154	Ambient	2	

Table D.41—TS-A 95 % Level at Ambient Temperature (QIII, QIV) and (QIV, QIII) (Continued)

Continue CAL IV TS-A with A^a 95 % (QIII, QIV) and A^a 95 % (QIV, QIII) Leak Detection for TS-A at Ambient Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
236	Transition	1301	0	1301	−1154	Ambient		CW (95 % Level) See Table 9, Table D.16, and Figure D.34
237	26_a95	1301	0	1301	−4755	Ambient	10	
238	Transition	641	0	641	−4755	Ambient		
239	25_a95	641	0	641	−7811	Ambient	10	
240	Transition	0	0	0	−7811	Ambient		
241	24_a95	0	0	0	−9140	Ambient	60	
242	Transition	−971	0	−971	−9140	Ambient		
243	23_a95	−971	0	−971	−9140	Ambient	10	
244	Transition	−971	0	−971	−9140	Ambient		
245	22_a95	−1710	0	−1710	−9140	Ambient	10	
246	Transition	−1710	0	−1710	0	Ambient		
247	21_a95	−1748	0	−1748	0	Ambient	2	
248	0	0	0	0	0	Ambient		
End of A^a 95 % (QIII, QIV) and A^a 95 % (QIV, QIII) Switch from External Pressure to Internal Pressure Testing								

D.6.4.11 TS-A 95 % Level at Ambient Temperature (QII, QI)

As shown in Figure D.35 and Table D.42, CAL IV TS-A concludes with internal pressure testing. A series of QI/QII load points is executed in the CW direction, which allows evaluation of load path dependency at a 95 % level. The majority of the hold points require sealability evaluation. This testing can be performed with the external pressure vessel installed, and sealability evaluation is by the water-column method (see 5.8.1 and Figure 14). However, the external pressure vessel may be removed so that one of the leak-detection methods described in 5.7 may be used.

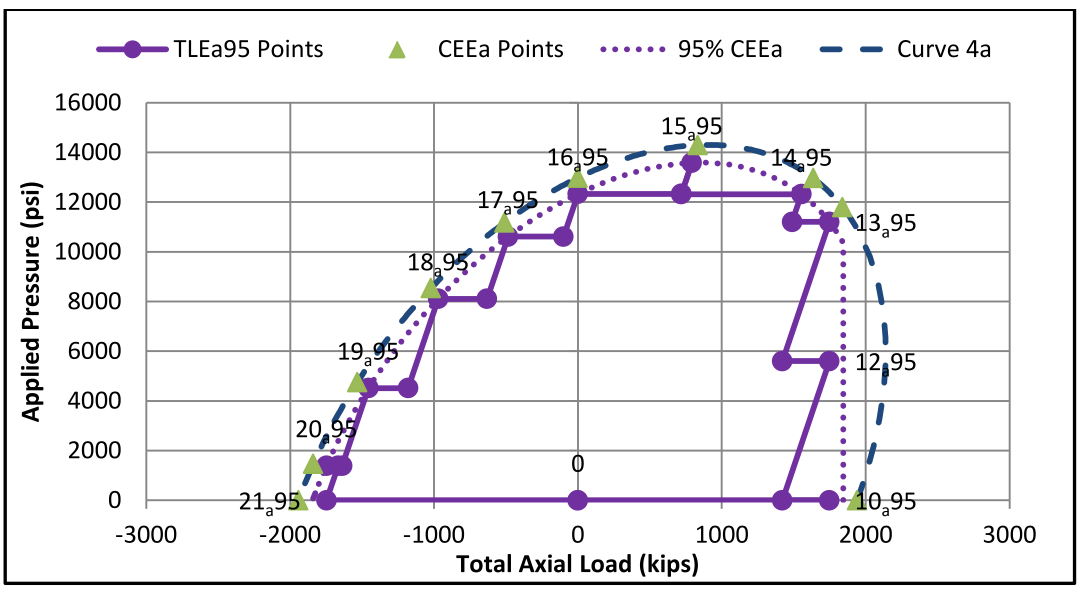


Figure D.35—A^a 95 % (QI, QII), TS-A Load Steps 249 to 271

Table D.42—TS-A 95 % Level at Ambient Temperature (QII, QI)

Continue CAL IV TS-A with A^a 95 % (QII, QI) Leak Detection for TS-A at Ambient Temperature								
Load Step	**LP**	**Total Load (kips)**	**CEPL (kips)**	**Frame Load (kips)**	**Pressure (psi)**	**Temperature (°F)**	**Hold Time (min)**	**Direction**
249	0	0	0	0	0	Ambient		CW (95 % Level) See Table 9, Table D.16, and Figure D.35
250	21a95	−1748	0	−1748	0	Ambient	2	
251	Transition	−1667	81	−1748	1391	Ambient		
252	20a95	−1748	81	−1829	1391	Ambient	10	
253	Transition	−1638	81	−1720	1391	Ambient		
254	19a95	−1456	263	−1720	4513	Ambient	10	
255	Transition	−1181	263	−1444	4513	Ambient		
256	18a95	−971	473	−1444	8108	Ambient	60	
257	Transition	−631	473	−1104	8108	Ambient		
258	17a95	−485	619	−1104	10,612	Ambient	10	
259	Transition	−100	619	−719	10,612	Ambient		
260	16a95	0	719	−719	12,332	Ambient	10	
261	Transition	719	719	0	12,332	Ambient		
262	15a95	792	792	0	13,581	Ambient	10	
263	Transition	718	718	0	12,316	Ambient		
264	14a95	1553	718	835	12,316	Ambient	60	
265	Transition	1489	654	835	11,206	Ambient		
266	13a95	1748	654	1094	11,206	Ambient	10	
267	Transition	1421	327	1094	5603	Ambient		
268	12a95	1748	327	1421	5603	Ambient	10	
269	Transition	1421	0	1421	0	Ambient		
270	10a95	1748	0	1748	0	Ambient	2	
271	0	0	0	0	0	Ambient		
End of CAL IV TS-A								

D.7 Other Examples

D.7.1 General

The following sections provide additional examples for calculation of the test specimen pipe body reference curves, CEE points, and TLE loads points based on different pipe and connection parameters to highlight specific situations that could be encountered.

D.7.2 5½ in. 35.30 lb T-95 Generic T&C Connection

D.7.2.1 General

This section details the inputs for developing the test specimen pipe body reference curves, CEE and CEE points, and TLE and TLE load points for a hypothetical 5½ in. 35.30 lb T-95 T&C connection at ambient temperature. Standard API collapse rating is used in this example. The connection is assumed to be a generic T&C connection with internal metal-to-metal seal and torque shoulder.

D.7.2.2 Test Specimen Pipe Body Reference Curves

The pipe body reference curves at ambient temperature are calculated in accordance with D.4 based on the input parameters shown in Table D.43. The resulting reference curves are shown in Figure D.36.

Table D.43—Example Pipe Parameters used to Calculate Reference Curves at Ambient Temperature

Specified OD	Specified Wall	SMYS	D_{avg}	t_{min}	t_{avg}	AMYS[a]
5½ in.	0.687 in.	95,000 psi	5.541 in.	0.632 in.	0.680 in.	102,500 psi

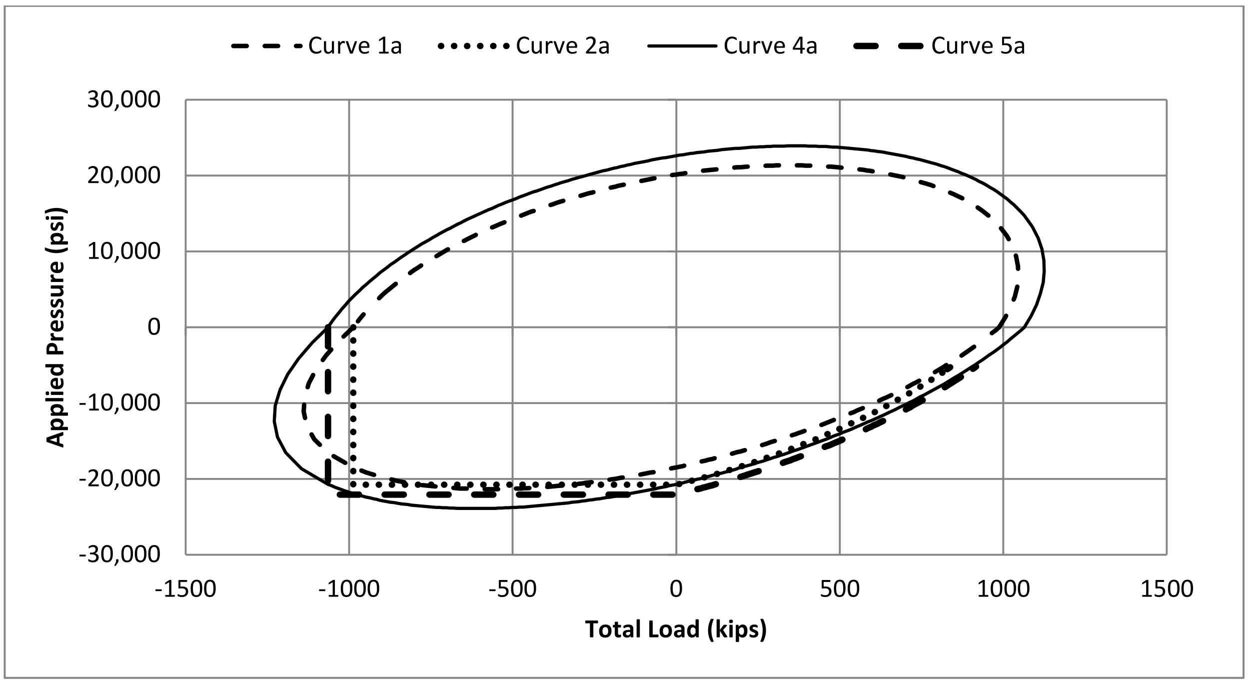


Figure D.36—Test Specimen Pipe Body Reference Curves (Curves 1[a], 2[a], 4[a], and 5[a])

Regarding Figure D.36, the nominal API collapse and actual API collapse curves (Curves 2[a] and 5[a]) exceed 100 % VME in some regions of the diagram. This risk occurs most often for pipes using the Yield Strength Collapse Pressure Equation (35). Caution should be used to ensure that load points do not exceed the specified percentage of VME yield.

D.7.2.3 CEE[a] and TLE[a]

When developing the CEE, the hypothetical manufacturer limited compression with a vertical truncation in QII and QIII to prevent yielding the connection torque shoulder. Based on the actual connection dimensions and material yield strength, compression was limited to 60 % of the actual specimen pipe body capacity (F_c); however, the tension capacity remained 100 % of the actual pipe body capacity (F_t).

Therefore, for this example:

— CEE[a] $t = A_p$ * AMYS[a] = 10.3845 * 102,500/1000 = 1064 kips;

— CEE[a] c = −60 % * A_p * AMYS[a] = −60 % * 10.3845 * 102,500 = −639 kips.

For internal pressure (p_i), the CEE[a] was defined as 100 % of the test specimen pipe body actual VME curve (Curve 4[a]) at loads between CEE[a] c and CEE[a] t. For external pressure (p_o), the CEE was defined as 100 % of the lesser of the test specimen pipe body actual VME curve (Curve 4[a]) and the specimen actual API collapse curve (Curve 5[a]) at loads between CEE[a] c and CEE[a] t. Since CEE points are based on actual connection dimensions and material yield strength, bi-axial scaling was used for TLE[a] load points. Table D.44 summarizes the resulting CEE[a] points and TLE[a] load points at ambient temperature, and Figure D.37 plots the CEE[a] and TLE[a] points.

Table D.44—CEE[a] Points and TLE[a] Load Points

Load Point	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)	
	Axial Point F_a (kips)	Pressure Point p_i or p_o (psi)	Axial Load F_a (kips)	Pressure Load p_i or p_o (psi)
1_a80	1064	14,715	713	0
2_a80	N/A	N/A	713	3995
3_a80	N/A	N/A	713	7989
4_a80	891	19,973	713	15,978
5_a80	328	23,905	263	19,124
6_a80	0	22,619	0	18,095
7_a80	−399	18,390	−319	14,712
8_a80	N/A	N/A	−319	7356
9_a80	−639	0	−319	0
10_a95	1064	14,715	958	0
11_a95	N/A	N/A	958	4043
12_a95	N/A	N/A	958	8085
13_a95	1008	17,021	958	16,170
14_a95	896	19,878	852	18,884
15_a95	328	23,905	312	22,710
16_a95	0	22,619	0	21,488
17_a95	−168	21,204	−160	20,144
18_a95	−336	19,264	−319	18,300
19_a95	−504	16,738	−479	15,901
20_a95	−605	14,891	−575	14,147
21_a95	−639	0	−575	0
22_a95	−605	−23,919	−575	−20,967
23_a95	−336	−23,196	−319	−20,967
24_a95	0	−20,715	0	−19,679
25_a95	370	−16,158	351	−15,350
26_a95	751	−9098	713	−8643
27_a95	1008	−2031	958	−1929
10_a90	1064	0	958	0
11_a90	1064	14,715	958	3311

Table D.44—CEE[a] Points and TLE[a] Load Points (Continued)

Load Point	Connection Evaluation Envelope (CEE)		Test Load Envelope (TLE)	
	Axial Point F_a (kips)	Pressure Point p_i or p_o (psi)	Axial Load F_a (kips)	Pressure Load p_i or p_o (psi)
12_a90	1064	14,715	958	6622
13_a90	1064	14,715	958	13,243
14_a90	946	18,793	852	16,914
15_a90	328	23,905	295	21,514
16_a90	0	22,619	0	20,357
17_a90	−177	21,110	−160	18,999
18_a90	−355	19,013	−319	17,112
19_a90	−532	16,252	−479	14,627
20_a90	−639	14,211	−575	12,790
21_a90	−639	0	−575	0
22_a90	−639	−23,914	−575	−20,768
23_a90	−355	−23,286	−319	−20,768
24_a90	0	−20,715	0	−18,644
25_a90	390	−15,845	351	−14,261
26_a90	792	−8125	713	−7312
27_a90	1064	0	958	0
28_a90	N/A	N/A	619	0
29_a90	N/A	N/A	666	3383
30_a90	N/A	N/A	263	16,914
31_a90	N/A	N/A	77	3383

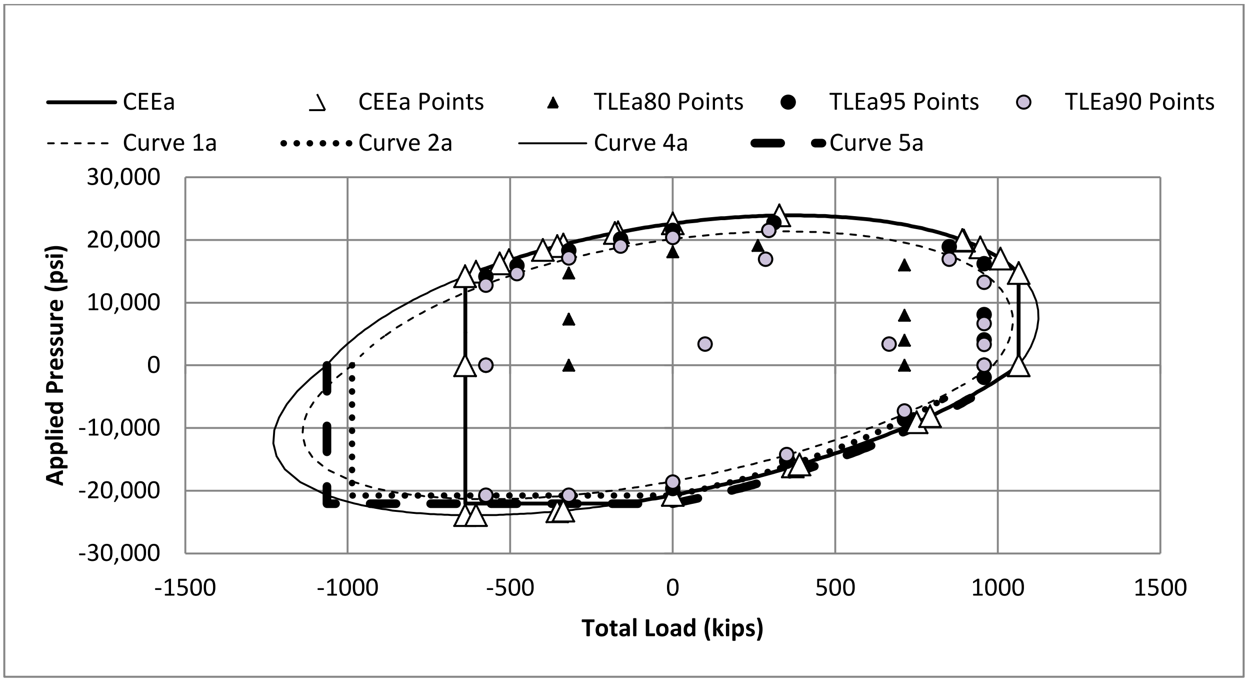


Figure D.37—CEE[a] Points and TLE[a] Load Points

D.7.3 18⅝ in. 87.50 lb L-80 Generic Flush Connection

D.7.3.1 General

This section details the inputs for developing the test specimen pipe body reference curves, CEE and CEE points, and TLE and TLE load points for a hypothetical 18⅝ in. 87.50 lb L-80 flush connection at ambient temperature. Standard API collapse rating is used in this example. The connection is assumed to be a generic Flush connection with internal metal-to-metal seals and an external torque shoulder.

D.7.3.2 Test Specimen Pipe Body Reference Curves

The pipe body reference curves at ambient temperature are calculated in accordance with D.2 based on the input parameters shown in Table D.45. The resulting reference curves are shown in Figure D.38.

Table D.45—Example Pipe Parameters Used to Calculate Reference Curves at Ambient Temperature

Specified OD	Specified Wall	SMYS	D_{avg}	t_{min}	t_{avg}	AMYS[a]
18.625 in.	0.435 in.	80,000 psi	18.765 in.	0.400 in.	0.432 in.	87,500 psi

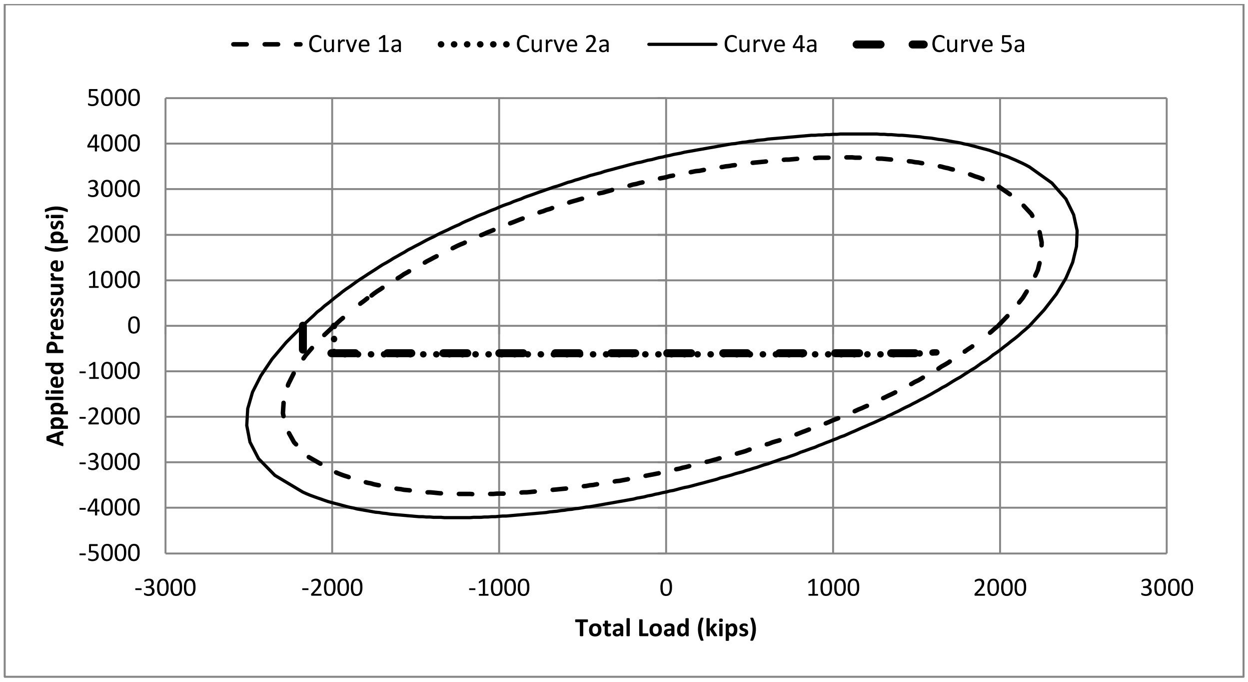


Figure D.38—Test Specimen Pipe Body Reference Curves (Curves 1[a], 2[a], 4[a], and 5[a])

D.7.3.3 CEE[a] and TLE[a]

Because this hypothetical flush connection is machined into the wall of the pipe body, the connection is not 100 % efficient relative to the pipe body. Nominal connection performance is based on minimum API pipe performance properties defined in API 5C3. The manufacturer provided the nominal tension, compression, internal pressure, and external pressure ratings of the connection based on the pipe dimensions and yield strength used to define the nominal VME and nominal API collapse curves (Curve 1[a] and Curve 2[a]) shown in Table D.46.

Table D.46—Nominal CEE

Rating	Uni-axial Tension	Uni-axial Compression	Uni-axial Internal Pressure	Uni-axial External Pressure
CEE point	10_a90	21_a90	6_a80, 16_a90, 16_a95	24_a90, 24_a95
Nominal pipe	1989 kips	−1989 kips	3266 psi	−627 psi
Nominal connection	1233 kips	−756 kips	3266 psi	−627 psi
Nominal efficiency	62 %	38 %	100 %	100 %

However, the hypothetical manufacturer has stipulated that actual connection performance is impacted by actual connection dimensions and material strengths. Some potential considerations include the following.

a) The actual average OD is greater than the nominal pipe OD. As a result, the box could be thicker than the nominal design, which could change the actual tension rating of the box.

b) The average ID is greater than the nominal pipe ID. As a result, the pin could be thinner than the nominal design, which could change the actual tension rating of the pin.

c) The average OD is greater than the nominal pipe OD. As a result, the external torque shoulder could be larger than the nominal design, which could change the actual compression rating.

d) The dimensional and yield strength inputs for the actual pipe result in changes to the pipe pressure ratings; however, the dimensional factors may not impact the connection ratings in the same manner, which could change the actual internal pressure rating and the actual external pressure rating relative to the actual specimen.

After review of the actual connection dimensions, the tension capacity was reduced to 60 % of the actual pipe body capacity (F_t); however, the compression rating was increased to 40 % of the actual specimen pipe body capacity (F_c). Neither the internal pressure capacity nor the external pressure capacity was linearly dependent on the actual specimen pipe body capacity. The functions for developing the internal pressure capacity and external pressure capacity based on actual pipe dimensions were disclosed to the user; however, the methodology for developing these ratings is beyond the scope of this RP. As a result, to avoid confusion the formulas are not presented. The hypothetical CEE points pertaining to the nominal connection ratings are summarized in Table D.47, while Figure D.39 shows the full CEE diagram.

Table D.47—Actual CEE[a]

Rating	Uni-axial Tension	Uni-axial Compression	Uni-axial Internal Pressure	Uni-axial External Pressure
CEE point	10_a90	21_a90	6_a80, 16_a90, 16_a95	24_a90, 24_a95
Actual pipe	2177 kips	−2177 kips	3726 psi	−600 psi
Actual connection	1306 kips	−871 kips	3572 psi	−627 psi
Actual efficiency	60 %	40 %	96 %	105 %

NOTE The specimen actual API collapse (600 psi) is less than the nominal API collapse (627 psi)—this risk occurs most often with pipe sizes using the elastic collapse pressure equation.

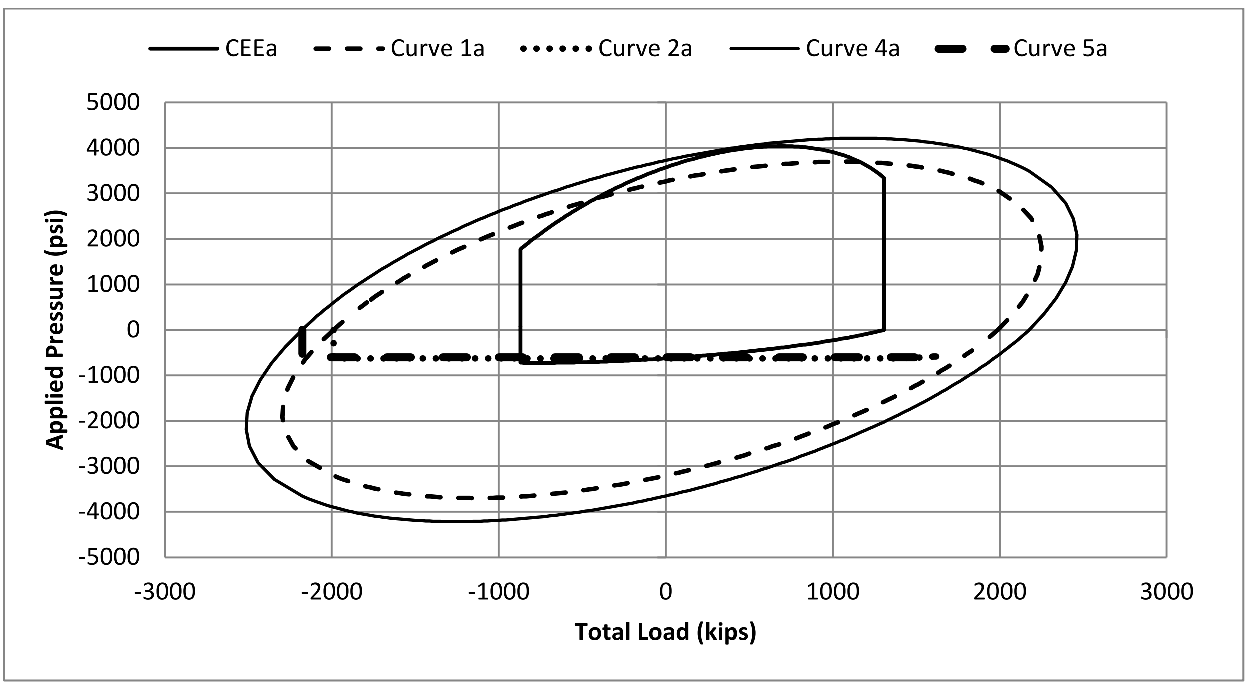


Figure D.39—Specimen CEE[a]

Annex E
(informative)

Frame Load Range Determination

Assume that a 2000 kN frame is calibrated from 100 kN to 2000 kN. Table E.1 depicts the average of two passes and percent error of the indicated frame loads.

Table E.1—Typical Results from Frame Load Range Determination (100 kN to 2000 kN)

		Indicated Load (kN)	Actual Load (kN)	Error (kN)	Error (%)
Calibration Run 1	Load Up	105.0	100.0	5.0	4.76
		201.0	200.0	1.0	0.50
		400.5	400.0	0.5	0.12
		599.0	600.0	–1.0	–0.17
		797.5	800.0	–2.5	–0.31
		999.5	1000.0	–0.5	–0.05
		1201.5	1200.0	1.5	0.12
		1404.0	1400.0	4.0	0.28
		1606.0	1600.0	6.0	0.37
		1797.0	1800.0	–3.0	–0.17
		1991.0	2000.0	–9.0	–0.45
	Load Down	1991.0	2000.0	–9.0	–0.45
		1798.0	1800.0	–2.0	–0.11
		1605.0	1600.0	5.0	0.31
		1403.0	1400.0	3.0	0.21
		1201.0	1200.0	1.0	0.08
		1001.0	1000.0	1.0	0.10
		799.0	800.0	–1.0	–0.13
		601.0	600.0	1.0	0.17
		399.0	400.0	–1.0	–0.25
		201.0	200.0	1.0	0.50
		104.0	100.0	4.0	3.85

Table E.1—Typical Results from Frame Load Range Determination (100 kN to 2000 kN) (Continued)

		Indicated Load (kN)	Actual Load (kN)	Error (kN)	Error (%)
Calibration Run 2	Load Up	104.0	100.0	4.0	3.85
		202.0	200.0	2.0	0.99
		401.5	400.0	1.5	0.37
		598.0	600.0	–2.0	–0.33
		798.5	800.0	–1.5	–0.19
		999.1	1000.0	–0.9	–0.09
		1201.0	1200.0	1.0	0.08
		1403.0	1400.0	3.0	0.21
		1605.0	1600.0	5.0	0.31
		1798.0	1800.0	–2.0	–0.11
		1992.0	2000.0	–8.0	–0.40
	Load Down	1992.0	2000.0	–8.0	–0.40
		1797.0	1800.0	–3.0	–0.17
		1603.0	1600.0	3.0	0.19
		1401.0	1400.0	1.0	0.07
		1204.0	1200.0	4.0	0.33
		1003.0	1000.0	3.0	0.30
		797.0	800.0	–3.0	–0.38
		603.0	600.0	3.0	0.50
		400.5	400.0	0.5	0.12
		200.5	200.0	0.5	0.25
		103.0	100.0	3.0	2.91

NOTE At 100 kN, the percent error is greater than ±1.0 %; therefore, the usable loading range is 200 kN to 2000 kN.

Annex F
(informative)

Product Line Validation

F.1 General Considerations

Manufacturers and users can both benefit from extrapolation/interpolation of salient performance parameters of a connection design fully tested to requirements of a specific API 5C5 CAL over a range of D, D/t, grades, etc. It is recognized that full-scale physical testing on every diameter, mass (label: weight) and grade is not practical and not necessary. Further, various users may have differing internal standards for accomplishing product line validations; therefore, it is important that the thread design company reach agreement with the user(s) prior to beginning a product line validation. While manufacturers often make use of FEA in routine connection design and in correlation and comparison with tested designs, relying entirely on FEA may not be sufficient due to the limitations in predicting leakage of a metal seal, demonstrating the difference in performance (leakage) between gas and water regarding leak determination as well as the constitutive relationships of leak resistance and thread compound data.

This annex provides a framework for performing a connection product line validation by evaluating a large group of sizes, mass (label: weight), and grades of a single connection design through a combination of testing the selected CAL specified number of connections to the full requirements of the selected API 5C5 CAL, reduced specimen testing to the specific CAL requirements, using analysis, and possibly no testing as agreed to by the user and thread design company.

F.2 Product Line Validation

F.2.1 Principle

A product line is a set of products that are designed with common criteria. See F.3 for the list of common criteria. Product line validation may cover the entire product size and mass (label: weight) range or may be limited to tubing sizes, to casing sizes, or as otherwise determined by the thread design company.

Examples of product line testing concepts are shown schematically in Figures F.1 and F.2. These are only two examples; there are others and the thread design company should reach agreement with their end users before beginning a product line validation program.

In Figures F.1 (numbered circles) and F.2 (filled circles), the six size/weight combinations are tested according to a selected CAL using the procedures described in the main body of this RP (i.e. full-scale tests for the selected CAL). Full-scale physical tests should be performed on heavy wall pipe and light wall pipe and, critical sizes as deemed appropriate by the thread design company and the end user(s), using high strength materials (e.g. API 5CT P-110 or Q-125) to ensure that a high internal pressure rating can be accomplished at data points 1, 2, 3, 4, 5, and 6. In addition to the above full-scale testing, to validate performance of the connection on lower yield strength materials (e.g. API 5CT L-80) a reduced specimen test should be performed at points 1, 3, and 5 in Figure F.1.

F.2.2 Extrapolation/Interpolation

In Figure F.1, the results from the fully tested connections (numbered circles) are then extended to the size-and-mass (label: weight) combinations validated through reduced specimen testing or analysis (open circles with strikethrough). The interpolation region(s) are bounded by the full-scale tested size/weight combinations, by the connections that are validated through analytical or reduced specimen testing, and by the straight lines between the full-scale test points. The end user may also require additional testing or analysis of the connections in the interpolation region(s) denoted by an open circle. Any size/weight combinations that meet the design criteria and that are within this boundary region may be deemed as validated through product line validation.

In Figure F.2, the results from the fully tested connections (filled circles) are then extended to the size-and-mass (label: weight) combinations validated through reduced specimen testing (denoted by an open circle with a “1” in the middle). Connections denoted with a triangle may or may not require any testing or analysis. This is at the option of the user. Connections denoted by an open circle with a “2” in the middle indicate the option of a minimum two-specimen test relative to the original full CAL test to increase the maximum service pressure (due to either increase in grade or wall or decrease in diameter).

The TLE of an interpolated connection should be limited to the lowest percent of pipe body von Mises envelope (PBVME) or CEE, whichever is applicable, and/or API 5C3 collapse of the four points in each interpolated region that represent the full-scale tests (filled circles) to which the size/weight combinations that create the bounded region were successfully tested. The pressure rating of those size/weight combinations extended by interpolation should not be greater than the pressures successfully demonstrated during full-scale testing of the applicable fully tested connections unless there is additional testing, as determined by the user, to validate the increase in pressure.

In each case, the galling tendency of the interpolated connections shall be no more severe than that of the original connections that were fully tested. In some cases, make/break tests may be required to evaluate galling when the material chemistry changes. Or, if anti-galling treatment on the threads changes, make/breaks and reduced specimen testing should be considered.

F.2.3 Grades

Connections validated on a martensitic stainless steel (i.e. 13Cr) would be validated on same-strength carbon steel and may be validated for usage on lower-strength carbon steel grades. The reverse is not necessarily viable. For example, a connection validated on L80 would not be validated on 13Cr80. Reasons for this include: increase in galling tendency, different surface treatment, some thread design companies change tolerances for their product on 13Cr, and differences in stress/strain curves.

Connections validated on high-alloy materials (22Cr, etc.) are validated on same-strength carbon or martensitic stainless steels and may be validated for usage on lower-strength materials. The reverse is not necessarily viable. When changing material grades from high-alloy materials to API carbon grades of material, the thread design company and user are encouraged to, at a minimum, perform make/breaks to confirm no increase in thread or metal seal galling, as it is likely that the surface treatment will change.

When testing connections using anisotropic materials, if the connection has been validated to the highest yield strength of the material (versus specified yield), the same percentage to which this connection was tested can be applied to isotropic materials; and if the connection has been validated to a lower yield strength of the anisotropic material, the test results can be converted to isotropic materials by multiplying by the ratio of the lower yield strength divided by the highest yield strength.

F.2.4 Sizes and Mass

Table F.1 is provided as an example of the sizes to be full-scale tested to satisfy the schematic in Figure F.1.

For the purposes of product line testing, $7^3/_4$ in. connections may be treated as a special weight of $7^5/_8$ in. connections; $9^7/_8$ in. connections may be treated as a special weight of $9^5/_8$ in. connections; and $13^5/_8$ in. connections may be treated as a special weight of $13^3/_8$ in. connections. For other special weight connections, the thread design company and the user should work together to include these connections.

F.2.5 Design Criteria

The thread design company shall have documented product design criteria for the entire claimed product line. Upon request by the user, the product design criteria shall be made available for review. A list of the minimum elements to be included in the design criteria is shown in F.3. Within the interpolation regions, the connection design shall be the same or consistent with the full-scale tested connections. In other words, linear dimensions (lengths, diameters, thicknesses, thread pitch, thread height, and their tolerances, etc.) shall be the same (constant) or shall be bounded by their values in the tested size/weight combinations (consistent).

In order to extend test results across the extrapolation/interpolation region, the connection design criteria shall exhibit performance in the extrapolation/interpolation region that is consistent with those of the fully tested connections. In this context, consistent performance means that the key parameters that determine connection performance are bounded by their values in the size/weight combinations fully tested. These key parameters are shown in F.3 and also include stresses and strains on limiting regions as well as minimum wall cross-section stress (for tensile rating), hoop stress (for burst rating), and seal surface stress (for leak rating).

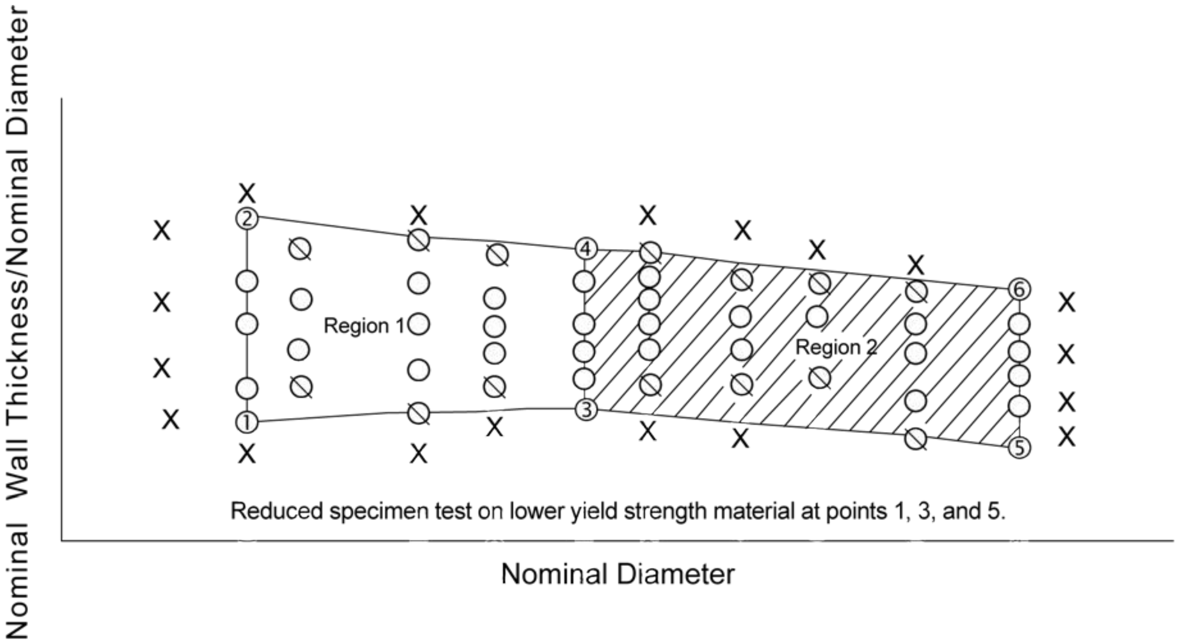
F.2.6 Connection Assessment Levels

The extension of test results across an extrapolation/interpolation region will be valid for the lowest CAL representing the size/weight combinations bounding the interpolation region. For example, in Figure F.1, assume that combinations 1, 2, and 3 are tested to CAL III, combination 4 is tested to CAL IV, and combinations 5 and 6 are tested to CAL II. Then, interpolation region 1 is considered tested to CAL III, and interpolation region 2 is considered tested to CAL II. As a single size, weight, grade combination, combination 4 is a fully tested CAL IV connection, and may be considered for usage by the user as a CAL IV tested connection.

F.2.7 Reduced Specimen Physical Testing for the Interpolated Connections

Reduced specimen physical testing may be employed to further demonstrate and validate consistency or trends in connection performance. For T&C connections, make/break galling testing should be performed on a single worst-case galling specimen (typically Specimen 3). For sealing tests, a minimum of a single worst-case sealing specimen should be tested using the requirements of API 5C5 for the selected CAL.

Figure F.1 is an example of product line testing showing connections validated through full-scale tests and reduced specimen testing and/or analytical methods, with the interpolation region(s) shown.

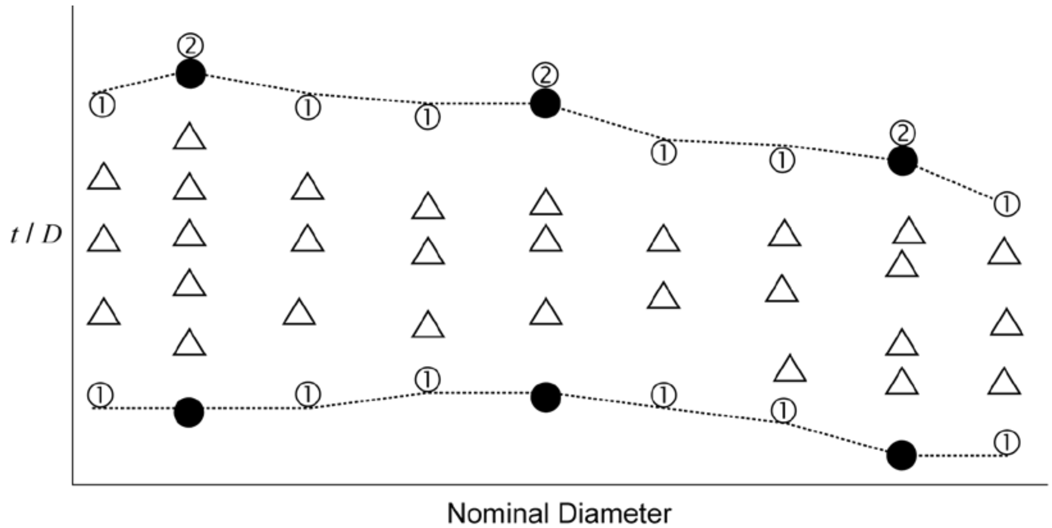


①	Size/weight combinations indicated with a number inside a circle (1, 2, 3, 4, 5, or 6) are fully tested according to selected CAL procedures.
○	Test results are extended to size/weight combinations indicated by an open circle through product line approach. Users may elect to perform reduced specimen testing, analysis, and/or no testing.
X	Test results cannot be extended to size/weight combinations indicated by an X (that is, no extrapolation).
Ø	These size/weight combinations have been subjected to reduced specimen or analytical testing.

Figure F.1—Product Line Validation (Example 1)

Table F.1—Sizes to Be Full-scale Tested to Satisfy the Schematic Shown in Figure F.1

If the following size is tested:		The next larger size to be tested is:	
in.	mm	in.	mm
1.050	26.7	≤1.900	≤48.3
1.315	33.4	≤2.063	≤52.4
1.660	42.2	≤2 $^{3}/_{8}$	≤60.325
1.900	48.3	≤2 $^{7}/_{8}$	≤73.0
2.063	52.4	≤3 $^{1}/_{2}$	≤88.9
2 $^{3}/_{8}$	60.3	≤4	≤101.6
2 $^{7}/_{8}$	73.0	≤4 $^{1}/_{2}$	≤114.3
3 $^{1}/_{2}$	88.9	≤5 $^{1}/_{2}$	≤127.0
4	101.6	≤5 $^{1}/_{2}$	≤139.7
4 $^{1}/_{2}$	114.3	≤6 $^{5}/_{8}$	≤168.3
5	127.0	≤7	≤177.8
5 $^{1}/_{2}$	139.7	≤7 $^{5}/_{8}$ or 7 $^{3}/_{4}$	≤193.7 or 196.8
6 $^{5}/_{8}$	168.3	≤8 $^{5}/_{8}$	≤219.1
7	177.8	≤9 $^{5}/_{8}$ or 9 $^{7}/_{8}$	≤244.5 or 250.8
7 $^{5}/_{8}$ or 7 $^{3}/_{4}$	193.7 or 196.8	≤10 $^{3}/_{4}$	≤273.0
8 $^{5}/_{8}$	219.1	≤11 $^{3}/_{4}$	≤298.45
9 $^{5}/_{8}$ or 9 $^{7}/_{8}$	244.5 or 250.8	≤13 $^{3}/_{8}$ or 13 $^{5}/_{8}$	≤339.7 or 346.1
10 $^{3}/_{4}$	273.0	≤13 $^{3}/_{8}$ or 13 $^{5}/_{8}$	≤ 339.7 or 346.1
11 $^{3}/_{4}$	298.45	≤16	≤406.4
13 $^{3}/_{8}$ or 13 $^{5}/_{8}$	339.7 or 346.1	≤18 $^{5}/_{8}$	≤473.1
16	406.4	≤20	≤508.0
18 $^{5}/_{8}$	473.1	≤20	≤ 508.0



● Fully tested connection to specified CAL; typically, these tests are performed on most commercially used weights and high yield material.

① Minimum of one-specimen test or, by agreement with user, FEA, to change diameters relative to original full CAL test without increasing maximum service pressure of the connection.

② Minimum two-specimen test relative to the original full CAL test to increase the maximum service pressure (due to either increase in grade or wall or decrease in diameter). Typically should be performed only on next heavier weight of a full CAL III tested connection; however, user input from user is needed.

△ This is at option of user (i.e. may be no testing, reduced specimen testing, or FEA).

Figure F.2—Product Line Validation (Example 2)

F.3 Product Design Criteria Elements

The thread design company shall prepare and be prepared to share with the user a completed Annex A, including a list of product drawings numbers and the current revision levels to be included in the size/weight combinations in the product line. The thread design company shall also show the product drawing number and revision level to which each connection was originally tested and document any appropriate differences. Show the following for each size, weight, and grade in the product line design criteria.

a) Analysis of basic connection dimensions and tolerances includes the following:

   1) lead;

   2) taper;

   3) thread height;

   4) thread form;

   5) torque shoulder angle and height;

   6) seal taper (if seal taper angles differ among sizes, amount of drag differential);

   7) seal (pin and box) lengths;

8) pin nose length;

9) distance between face of pin nose to thread start;

10) thread interference/clearance at reference point (pitch diameter, nearest metal seal, and at the box face);

11) effect of gauging methodology on thread interference nearest metal seal and at box face;

12) primary seal interference/clearance;

13) secondary seal interference/clearance;

14) pin nose thickness;

15) box thickness at metal seal;

16) coupling OD and OD profile;

17) critical cross-section areas (pin and box);

18) contact bearing pressure metal seal;

19) metal seal contact pressure profile;

20) distance from pin nose to centerline of seal force;

21) special machining tolerances (if any);

22) anti-galling treatment(s) (pin and box), including any spray-on treatment;

23) makeup torques and makeup speed;

24) thread compounds (type and quantity);

25) production process control plan/quality plan (PCP/QP) with copies of applicable documents (this shall include an attachment to the PCP/QP that lists each sub-tier document with release data and revision level in effect at the time of connection testing);

26) pin seal surface finish (as machined);

27) box seal surface finish (as machined).

b) For seal ring grooved connections include the following:

1) relationship of groove to resilient seal diameter;

2) relationship of groove to resilient seal width;

3) relationship of groove depth to resilient seal thickness;

4) relationship of groove width to thread lead;

5) relationship of groove depth to box thread height;

6) relationship of groove OD to box thread root diameter;

7) box thickness over seal ring groove;

8) interference/clearance between ID of seal ring and box crest diameter;

9) groove location with respect to metal seal;

10) volumetric fill ratio;

11) contact pressure-resilient seal (if available);

12) tornado chart showing effect of thread elements on resilient seal fill.

Annex G
(informative)

Special Application Testing

G.1 General Considerations

This RP covers the testing of connections for the most commonly encountered well conditions. This annex provides guidelines on potential supplemental testing that may be required for the specialized service conditions listed below. For such service conditions, the manufacturer and user should consult and agree.

G.2 Specialized Service Conditions

Listed below are examples of specialized service conditions:

a) application of an counter-clockwise back-off torque while conducting other test sequences;

b) testing of multiple seal connections;

c) thread compound pressure entrapment;

d) extended reach and horizontal well profiles requiring high compression and high torsional resistance;

e) medium- and short-radius well profiles;

f) tension leg platforms, floating facilities, compliant towers;

g) geothermal and steam injection;

h) make and break trials to simulate extreme field assembly/stabbing conditions;

i) surface subsidence, formation compaction, or salt structures;

j) rapid cooling (quenching) of a connection seal;

k) probabilistic connection performance;

l) pile driving of conductors;

m) mechanical connectors for flow lines;

n) high-alloy corrosion-resistant materials with anisotropic material properties;

o) high-temperature wells;

p) sour service wells.

G.3 Testing Considerations for Various Special Applications

G.3.1 Medium-/Short-radius Profile Wells

The trajectory of a medium-/short-radius wellbore is characterized by a high dogleg severity (D_{leg}) profile in excess of 20°/100 ft followed by a near horizontal section. Running of tubing and casing into a well of such a profile will subject the connections to high bending stresses while running through the tight radius section(s).

Such pipe may need to be rotated to work through the frictional and mechanical drag in the well. Rotation in high curvatures can produce fatigue damage to the connection. To confirm a connection's integrity for use in medium-/short-radius wells, it is recommended that connection validation tests include a hydrostatic pressure test (or gas test) with bending to the planned D_{leg} plus a safety margin.

G.3.2 Make and Break Tests to Simulate Field Conditions

The assembly tests described in this RP are conducted with pup joints assembled under well controlled test laboratory conditions. Actual field running can involve more severe conditions due to a variety of effects including the following:

a) field running requires full-length joints (either Range 2 or 3, see API 5CT for tubing and casing);

b) field running involves vertical stabbing and makeup;

c) field running can be conducted under severely varying conditions, including rain, wind, extreme cold, extreme heat, etc.;

d) field running can be affected by misalignments, such as the derrick over the rotary or the rig over the well;

e) field running offshore can be affected by rig movement for floating operations or even fixed offshore structures in deepwater environments;

f) field running of many joints in long strings can certainly be affected by human conditions with regard to doping, stabbing, makeup, final torqueing, etc.;

g) field pulling operations during a work-over require breaking out of connections, which have been affected by both long time exposure and possibly extreme environmental exposure (temperature, hydrocarbons, etc.);

Because of these issues, justification may exist to simulate field running/stabbing for particular projects. For example, a full-size joint or pup joint with a mass (label: weight) representing a full-size joint can be stabbed into a coupling and assembled. This procedure can be repeated with the joint at various angles to simulate incorrect stabbing that can occur due to strong winds. Similarly, make and break tests can be conducted with eccentric masses (label: weights) to simulate misalignment forces. To better simulate breakout conditions for a work-over, connections can be heated between makeups and breakouts to better simulate the degraded state of the thread compound that will be present for the work-over.

G.3.3 Thread Compound Pressure Entrapment

Thread compound pressure build-up within a connection can adversely impact the performance of the connection. It can result in severe plastic deformation of the seal region, makeup torque being absorbed in overcoming the pressure build-up resulting in a reduction of pre-load within the connection.

If it is desired to understand the effects of thread compound quantities on the performance of a connection, the following recommended test procedure should be considered.

a) Drill a port hole into the pin or box member downstream of the primary internal pressure seal to allow the thread pressure in the region to be monitored during makeup. The hole should be tapped to allow a pressure transducer to be connected directly or via a short, rigid pressure line.

b) Prior to assembly, conduct detailed gauging measurements of the seal diameter and bore adjacent to the seal.

c) Apply the thread compound according to the manufacturer's recommended procedure and quantity in order to fill the cavity and the lines to the pressure transducer and pressure gauge with the thread compound.

d) Assemble the connection to the manufacturer's minimum recommended makeup torque.

e) Measure and record the thread compound pressure—an analog or high-speed digital system should be used with the pressure transducer.

f) Break out connection, clean threads and seal, re-gauge connections.

g) Repeat steps c) to f) with the manufacturer's normal makeup torque in place of minimum makeup torque.

h) Repeat steps c) to f) with the manufacturer's maximum makeup torque in place of minimum makeup torque.

i) Repeat steps c) to h) with double the quantity of manufacturer's recommended thread compound.

j) Repeat steps c) to h) with triple the quantity of manufacturer's recommended thread compound.

If plastic deformation is recorded that is excessive for the conditions with the manufacturer's recommended quantity of thread compound, caution in the use of the connection is advised.

If plastic deformation is recorded that is excessive for double or triple the quantity of thread compound, then personnel responsible for running the connection should be made aware of the consequences of overdoping and specialized doping procedures can be considered.

G.3.4 Isolation of Multiple Seals

In the test procedures given in this RP, connections with multiple seals are tested with each seal active without any ports or bleed holes since this is how they should be used. However, for understanding of connection seal redundancy, evaluation of seal independence, etc., some users may desire to test seals individually. For example, each individual seal can be tested with pressure from the primary design direction with other seals disabled.

It is recommended that for connections with multiple seals, only the two innermost seals be tested for internal pressure. Other potential seals are considered extraneous for these tests and should be disabled either by porting between seals or by bypassing seals.

G.3.5 Post-yield Strain Applications

Some reservoirs experience a physical breakdown of the producing formation due to loss of pore pressure. This breakdown causes subsidence of the formation and can produce vertical displacements of the well string. Movement of salt formations can also cause vertical and lateral displacements of the well. These well conditions can create loads well above the pipe yield strength.

Testing for these applications should include high axial compression and bending loads. In some cases, the displacements can completely sever the strings or close the wellbore. Therefore, special considerations should be given to the design of the well.

The near-surface geology of Arctic regions can create well conditions that cause post-yield compression loads on the tubular strings. Arctic regions generally include a layer of frozen soil near the surface known as "permafrost." During the drilling and production of the well, thawing of the permafrost can occur and can cause subsidence of the well. As this happens, the tubular strings are slowly subjected to increasing axial compression that can stress the pipe beyond the material yield strength. In some cases, local buckling can also occur with compression.

Testing of candidate connections should include axial compression that can load the specimen to 2 % or greater strain levels. The specimen will require lateral restraint to prevent gross unstable behavior and buckling. Bending considerations for the well and testing should also be included.

G.3.6 Rapid Cooldown Conditions

Wells with unusually high downhole temperatures cause the production tubing string to operate at higher temperatures than normal. Some operating conditions such as killing the well or acidizing can pump cool liquid down the tubing and cause a rapid cooldown. This cooling can cause the connection pin seal to thermally contract faster than the box and the primary metal seal can sometimes open, causing a connection leak.

Test procedures for evaluating rapid cooldown or quenching have been developed and used by some operators. For wells with unusually high operating temperatures and that could experience such a rapid cooldown of the tubing, consideration should be given to test the tubing connections for this load case.

G.3.7 Stimulation Applications

Some reservoirs benefit from injection of various fluids into the producing formation to improve production, with loads being mechanically controlled from the surface. Unlike other high-pressure applications such as deepwater and high-pressure/high-temperature wells that experience high tension and internal pressure as well as high compression and external pressure as a result of reservoir pressure and temperature during the life of the well, the injection process can also produce maximum tension and pressure loads.

Testing for these applications should include high axial tension, internal pressure, and bending loads with over 20 load cycles involving internal pressure and tension with and without bending. In some cases, the displacement can completely sever the strings. Testing should include elevated temperature of a minimum of 275 °F (135 °C), with bending in excess of 20°/100 ft, cycling to ambient temperature during pressure cycling. Finally, tension with internal pressure increasing to failure should be included to determine the limits of the connection after cycling. In addition, G.3.10 extended reach and horizontal wells test methods may be of interest depending on the need to place the string into position.

G.3.8 Reverse Torque

For applications where reverse torque capacity is required or a contingency, back-off torque resistance evaluation may be requested. As an example, a back-off torque corresponding to 60 % of the makeup torque may be requested. For production tubing applications, the reverse torque can be applied in addition to internal pressure and tension/compression cycling with bending.

Counter-clockwise torsion can be applied using a dead mass (label: weight) fixed on an arm or any other system (e.g. hydraulic). Strain gauges can be placed on the pipe body near the connection to verify that tension is properly applied to the connection before starting the procedure. To facilitate the loading calculation, the stress amount generated by the torsion can be compensated by adjusting loading to ensure that connection stresses remain within yield.

G.3.9 Steam Injection and Geothermal Service

Wells that use steam injected into the reservoir and geothermal wells can produce unusually high axial loads on the tubing and casing strings. The relatively high temperature of the injected steam causes thermal expansion that can stress the tubular string beyond the material yield strength. During the production part of the cycle, the temperature decreases and the string is subject to tension loads that can exceed the yield strength. Geothermal wells exhibit similarly large thermal changes resulting from shut-in periods after steam production cycles.

Tests that load the tubular connections in axial compression and tension are required to evaluate candidate connections. The test should include heating and cooling the specimen to the anticipated well temperatures, while maintaining the ends of the specimen fixed. Internal pressure should also be applied. Bending of the specimen should be considered both for the well service and in the test.

G.3.10 Extended Reach and Horizontal Wells

For extended-reach and horizontal well applications, high torque may be applied to the connection in order to rotate the string and should be to a specific torque range for the connection.

If the standard makeup torque of the connection is selected close to the maximum capacity corresponding to the yielding resistance of the material, no more tests are required. But if there is more than 10 % of safety margin between the maximum makeup torque and the yield torque, some complementary overtorque resistance evaluation may be requested by the user.

As a recommendation, the makeup procedure described in 7.2.2 should be repeated by a makeup at the maximum; therefore, apply the yield makeup torque less 10 %, then break out, clean, and gauge the connection. Report results on Figure B.6, as specified in 7.2.

G.3.11 Pile Driving of Conductors and Associated Connectors

Conductors may be run into pre-drilled holes, water jetted ahead in soft sands/silts, or driven. Pile driving of conductors imparts high magnitudes of shock loadings into the connectors due to the hammer blows. The performance characteristics of the connector shall not be compromised by the shock loadings. To confirm the connector's integrity, it is recommended that the following test sequence be considered:

a) attach strain gauges and accelerometers to the pin and box components;

b) assemble the connector and conduct an internal hydrostatic pressure test;

c) pile-drive the connector/conductor at a rate of 50 blows/minute until 2000 blows have been achieved;

d) visually inspect the connector for damage;

e) re-conduct a hydrostatic pressure test;

f) break out the connector and conduct visual and dimensional inspections of the connector components;

g) record and monitor strain gauge and accelerometer data at each step, and review the data for strains/plastic deformation, etc.

G.3.12 Flowline Connections

Oil country tubular goods (OCTG) connections are specified for use in downhole applications. Another application for connection of similar/same geometry as for OCTG is mechanical connection systems for use on flowlines. There are several loading regimes that shall be accounted for including offshore “S-lay,” “J-lay,” and “J-tube installation,” cyclic loading due to pressure and temperature differentials, bending and cyclic loads on unsupported spans, vortex shedding, and wave loading during installation.

A recommended test procedure to evaluate connections for use as flowline connections includes the following steps:

a) conduct five multiple makes and breaks;

b) assemble to minimum torque;

c) conduct internal hydrostatic pressure test;

d) to simulate pipe lay, conduct a bend test to 80 % yield stress on top surface of pipe body, then reverse bend until 80 % yield stress is achieved on the lower surface of pipe body—this comprises one cycle;

e) conduct a hydrotest to 90 % hoop yield stress;

f) conduct an internal gas pressure test to 80 % hoop yield stress with pipe axially constrained while maintaining internal gas pressure:

   1) cycle temperature from 39 °F to 194 °F (4 °C to 90 °C),

   2) complete 10 cycles;

g) conduct an internal gas pressure test to 80 % hoop yield stress with pipe unconstrained while maintaining internal gas pressure:

   1) cycle temperature from 39 °F to 194 °F (4 °C to 90 °C),

   2) complete 10 cycles.

G.3.13 High-temperature Wells

This protocol may be extended to connection testing at temperatures above 356 °F (180 °C) by adjusting the maximum elevated temperature used in the testing. Above 550 °F (288 °C), creep and relaxation of the material should be considered when evaluating the relevance of the test program.

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