# Dynamic Risers for Floating Production Systems

API STANDARD 2RD
SECOND EDITION, SEPTEMBER 2013

AMERICAN PETROLEUM INSTITUTE

## Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Users of this Standard should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

## Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

The verbal forms used to express the provisions in this recommended practice are as follows:

— the term shall denotes a minimum requirement in order to conform to the standard;

— the term should denotes a recommendation or that which is advised but not required in order to conform to the standard;

— the term may is used to express permission or a provision that is optional;

— the term can is used to express possibility or capability.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 1220 L Street, NW, Washington, DC 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

## Contents


Page

1 Scope . . . . . 1

2 Normative References . . . . . 1

3 Terms, Definitions, Symbols and Abbreviated Terms . . . . . 2
3.1 Terms and Definitions . . . . . 2
3.2 Symbols . . . . . 13
3.3 Abbreviated Terms . . . . . 15

4 Design Loads and Conditions . . . . . 16
4.1 General . . . . . 16
4.2 Loads . . . . . 17
4.3 Design Load Cases . . . . . 17

5 Design Criteria for Rigid Pipe . . . . . 19
5.1 Objective . . . . . 19
5.2 Design Format . . . . . 19
5.3 Capacities of Pipe . . . . . 19
5.4 Design Criteria . . . . . 22

6 Components . . . . . 28
6.1 General . . . . . 28
6.2 Fatigue . . . . . 28
6.3 Pressure-containing Components . . . . . 28

7 Materials . . . . . 29
7.1 Scope . . . . . 29
7.2 General Requirements . . . . . 29
7.3 Steel . . . . . 32
7.4 Other Materials . . . . . 33
7.5 Requirements for Elevated Temperature . . . . . 33
7.6 Requirements for Sour Service . . . . . 33
7.7 Requirements for Strain-based Design . . . . . 33
7.8 Prevention of Brittle Fracture . . . . . 34
7.9 Corrosion Protection . . . . . 35
7.10 Products . . . . . 37
7.11 Manufacture, Welding and Fabrication . . . . . 40
7.12 Examination and Non-destructive Testing (NDT) . . . . . 44

8 Fabrication and Installation . . . . . 45
8.1 General . . . . . 45
8.2 Fabrication . . . . . 46
8.3 Transportation, Shipping and Marine Operations . . . . . 47

9 Riser Integrity Management . . . . . 53
9.1 Introduction . . . . . 53
9.2 Riser Integrity Management Plan . . . . . 53

Annex A (informative) Example TTR Design . . . . . 55

Annex B (informative) Example SCR Design . . . . . 69

Annex C (informative) Supplemental Design Information . . . . . 74

Bibliography . . . . . 75

Page

Figures


1 Hardness Locations in Seamless and Seam Welded Pipe . . . . . 36
2 Hardness Locations for Clad Materials. . . . . 37
A.1 Production Riser Stack-up . . . . . 58


Tables


1 Representative Intact Strength Load Cases . . . . . 18
2 Representative Damaged Strength Load Cases . . . . . 18
3 Representative Fatigue Load Cases . . . . . 18
4 Applicable Material Specifications . . . . . 30
5 Test Temperature for Charpy Impact Testing of Steel and Steel Welds . . . . . 34
6 Carbon and Low-alloy Steel Bolts and Nuts for Pressure-bearing or Main Structural Applications. . . . 38
A.1 Production Riser Load Case Matrix . . . . . 55
A.2 Riser Pipe Sizes and Materials. . . . . 59
A.3 Internal Overpressure Limits for Outer Riser. . . . . 60
A.4 Internal Overpressure Limits for Inner Riser . . . . . 60
A.5 External Overpressure Limits for Outer Riser . . . . . 62
A.6 External Overpressure Limits for Inner Riser . . . . . 63
A.7 Riser Keel and Stress Joints . . . . . 63
A.8 Capacities of the Outer Riser . . . . . 64
A.9 Riser Loads at Bottom of Keel Joint . . . . . 65
B.1 A Typical Load Case Matrix for SCR Design . . . . . 69
B.2 Load Case Matrix for SCR Performance Assessment . . . . . 70
B.3 100-Year Hurricane Environmental Data . . . . . 70
B.4 Pipe Properties . . . . . 70
B.5 Capacity Utilization for ALS and ULS Load Cases . . . . . 71
B.6 Summary of Pipe Capacity . . . . . 72
B.7 Riser loads at TDZ for ULS . . . . . 72

## Introduction

Since the first edition of API RP 2RD, *Recommended Practice for Design of Risers for Floating Production Systems (FPSs) and Tensioned-Leg Platforms (TLPs)*, was issued in June 1998, hydrocarbon exploration and production in deep water environments have increased significantly. As a consequence, the need was identified to update that code of practice to address the issues and lessons learned from that experience. The title of the document has been changed to eliminate reference to any one type of floating hull. A broad scope of marine dynamic risers is covered, including various steel catenary risers and top tensioned risers.

# Dynamic Risers for Floating Production Systems

## 1 Scope

This standard addresses riser systems that are part of a floating production system (FPS). Guidelines for design, construction, installation, operation and maintenance of floating production systems (FPSs) are in API 2FPS. A riser is a subsystem in a floating production system.

The provisions of this standard do not apply to the riser systems of mobile offshore drilling units (MODUs).

There is significant interaction among the subsystems in a floating production system. Hull motions affect risers and mooring, and conversely, risers and mooring affect hull motions. Global behavior of the system provides input to assessment of subsystems. Assessment of a subsystem provides feedback (loads) for assessment of the hull and other subsystems.

Determination of the boundaries of a riser system and management of the interactions with other subsystems is the responsibility of the operator.

A riser system is an assembly of components, including pipe and connectors. A riser system can include a riser tensioning system, buoyancy modules, etc. Pipe components can be steel, titanium, or unbonded flexible pipe. Design considerations for unbonded flexible pipe are included primarily by reference to API 17B and API 17J. Design considerations for titanium alloy pipe are included primarily by reference to DNV-RP-F201. Steel and titanium pipe are referred to as rigid pipe and unbonded flexible pipe is referred to as flexible pipe.

All or part of several existing codes, standards, specifications, and recommended practices are included by reference.

Design loads and conditions are described in Section 4. Structural design criteria for rigid pipe are in Section 5. Structural capacity formulae for steel pipe are also in Section 5. Additional requirements for components, including pipe, are in Section 6. Material requirements are in Section 7. Fabrication and installation requirements are in Section 8. Integrity Management is addressed in Section 9.

## 2 Normative References

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

API RP 5C5, *Recommended Practice on Procedures for Testing Casing and Tubing Connections*

API Spec 5L, *Specification for Line Pipe*

API RP 5L1, *Recommended Practice for Railroad Transportation of Line Pipe*

API RP 5LW, *Recommended Practice for Transportation of Line Pipe on Barges and Marine Vessels*

API RP 17B, *Recommended Practice for Flexible Pipe*

API Spec 17J, *Specification for Unbonded Flexible Pipe*

API Spec 17K, *Specification for Bonded Flexible Pipe*

API RP 75, *Development of a Safety and Environmental Management Program for Offshore Operations and Facilities*

API Std 1104, *Welding of Pipelines and Related Facilities*

API RP 1111, 4th Edition, *Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines (Limit State Design)*

API Q1, 8th Edition, *Specification for Quality Programs for the Petroleum and Natural Gas Industry*

ASTM A193, *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High Temperature or High Pressure Service and Other Special Purpose Applications*

ASTM A194, *Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both*

ASTM A320, *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service*

DNV-OS-F101, 2012 Edition, *Submarine Pipeline Systems*

DNV-OS-F201, 2012 Edition, *Dynamic Risers*

ISO 6507-1, *Metallic materials—Vickers hardness test—Part 1: Test method*

NACE MR0175/ISO 15156 (all parts), *Petroleum and natural gas industries—Materials for use in $H_2S$-containing environments in oil and gas production*

# 3 Terms, Definitions, Symbols and Abbreviated Terms

## 3.1 Terms and Definitions

For the purposes of this document, the following terms, definitions, symbols, and abbreviations apply.

**3.1.1**
**accidental loads**
Loads imposed on the riser system from unplanned conditions/occurrences during a reduced extreme environmental event or by survival environmental events.

EXAMPLE Loads resulting from loss of vessel station-keeping and tensioner lock-up are examples of accidental loads.

**3.1.2**
**accidental limit state**
Events with an annual probability of exceedance less than $10^{-2}$ and larger than $10^{-4}$.

NOTE 1 The accidental limit state (ALS) corresponds to conditions with a longer return period than ULS. ALS requires that the system survive, but has a higher risk of damage than ULS conditions.

NOTE 2 When considering potential damaged conditions, the damage should not lead to an escalation of undesirable events.

EXAMPLE A failed mooring line, a flooded compartment, a tensioner failure, a tubing leak or unintended shut in conditions are some ALS cases.

**3.1.3**
**agreement**
Unless otherwise indicated, by agreement means by agreement between manufacturer and purchaser at the time of enquiry and order.

**3.1.4**
**attachment weld**
Fillet or full penetration weld used for attachment of components to pipe or coupling.

**3.1.5**
**blow-out preventer**
**BOP**
Large, specialized valve used to seal, control, and monitor an oil and gas well.

**3.1.6**
**BOP stack**
Assembly of well control equipment including BOPs, spools, valves, hydraulic connectors and nipples that connects to the subsea wellhead or to the surface wellhead on top of a high pressure drilling riser.

**3.1.7**
**buoyancy modules**
Structures of low weight materials, usually foamed polymers strapped or clamped to the exterior of riser joints, to reduce the submerged weight of the riser.

**3.1.8**
**connector**
Mechanical device used to connect adjacent components in the riser system to create a structural joint resisting applied loads and preventing leakage.

EXAMPLE (a) threaded types including (i) one male fitting (pin) and one female fitting (box), or (ii) two pins, a coupling and seal ring(s), (b) flanged types including two flanges, bolts and a gasket/seal ring, (c) clamped hub types including hubs, clamps, bolts and seal ring(s), (d) dog type connectors.

**3.1.9**
**component**
Part of the riser system.

NOTE Includes structural components like pipes, connectors, stress joints, tension joints, landing blocks, slick joints, tubing hanger orientation joints, adapter joints, etc.

**3.1.10**
**corrosion allowance**
**erosion allowance**
**wear allowance**
Amount of wall thickness added to the pipe or component to allow for corrosion/erosion/wear.

**3.1.11**
**crack tip opening displacement**
**CTOD**
Measure of crack severity which can be compared against a critical value at the onset of failure.

**3.1.12**
**design basis**
Set of project specific design data and functional requirements which are not specified or are left open in the general standard.

**3.1.13**
**design criteria**
Quantitative formulations that describe the conditions that shall be fulfilled for each failure mode.

**3.1.14**
**design factor**
Factor (utilization factor equal to one or less) used to set load limit.

NOTE See 5.2.

**3.1.15**
**design life**
Time period for which a riser is to be used for its intended purpose, including storage and working periods with anticipated maintenance, but without substantial repair or replacement being necessary.

NOTE The design life includes the entire period from start of manufacturer to condemnation of the riser system or part of the system.

**3.1.16**
**design load**
Combination of load effects.

**3.1.17**
**design material strength**
Stress used for structural strength calculation.

**3.1.18**
**design pressure**
Maximum sustained difference between internal pressure and external pressure during normal operations, referred to a specified elevation.

**3.1.19**
**drift**
Cylindrical mandrel for verifying drift diameter of individual and assembled equipment.

**3.1.20**
**drift diameter**
Minimum diameter that allows for the passage of the drift.

**3.1.21**
**drilling riser**
System used with floating drilling vessel for guiding the drill string and circulating fluids between the drilling vessel and the seafloor.

**3.1.22**
**dynamic positioning**
Computerized means of maintaining a vessel on location by selectively activating thrusters.

**3.1.23**
**effective tension**
Axial tension in the pipe less the internal pressure times the internal area of the pipe plus the external pressure times the outside area of the pipe.

NOTE Effective tension accounts for the effects of hydrostatic pressure in structural analysis of pipe.

**3.1.24**
**emergency shut down**
**ESD**
Shut down of the facility under emergency conditions during which the internal pressure in a production riser can increase above the normal operating pressure.

**3.1.25**
**environmental load**
Load imposed directly or indirectly by the environment.

EXAMPLE Wind, wave, and current load.

**3.1.26**
**environmental seal**
Outermost pressure-containing seal at a connector interface.

NOTE This seal normally separates a pressurized medium from the surrounding environment.

**3.1.27**
**extended shut-in**
Closure of valve(s) at top of riser for a period that can last for days.

EXAMPLE For production flowlines, the riser may be displaced to dead oil to limit the risk of formation of hydrates. Shut in conditions for each riser should be defined in the operating plan.

**3.1.28**
**extreme event**
An event having a 100-year return period, or an annual exceedence probability of 1 %.

**3.1.29**
**factory acceptance test**
**FAT**
Test conducted by the manufacturer to verify that the manufacture of a specific assembly meets all intended functional and operational requirements.

**3.1.30**
**failure**
Event causing an undesirable condition, e.g. loss of component or system function, or deterioration of functional capability to such an extent that the safety of the unit, personnel or environment is significantly reduced.

NOTE Examples are structural failure (excessive yielding, buckling, rupture, leakage) or operational limitations (excessive riser tensioner stroke).

**3.1.31**
**fatigue analysis**
Conventional stress-life fatigue analysis using material S-N curves and specified fatigue design factors.

**3.1.32**
**fatigue limit state**
The fatigue limit state (FLS) addresses the cumulative effects of cyclic loading.

**3.1.33**
**finite element analysis**
Numerical method for analyzing dynamic and static response by dividing the structure into small continuous elements with the given material properties.

NOTE The analysis can be local or global.

**3.1.34**
**flexible joint**
Laminated metal and elastomer assembly, having a central through-passage equal to or greater in diameter than the interfacing pipe or tubing bore, that is positioned in the riser string to reduce the local bending stresses.

**3.1.35**
**floating vessel**
Installation which is floating and positioned relative to the sea bottom by station-keeping systems such as catenary mooring systems, vertical tendons, and dynamic positioning systems based on thrusters.

**3.1.36**
**fracture mechanics assessment**
Assessment and analysis where critical defect sizes under design loads are identified to determine the crack growth life, i.e. leak or fracture.

**3.1.37**
**functional loads**
Loads that are a consequence of the system's existence and use without consideration of environmental or accidental effects.

**3.1.38**
**galling**
Cold welding of contacting material surfaces followed by tearing of the materials during further sliding/rotation.

NOTE Galling results from the sliding of metallic surfaces that are under high bearing forces. Galling can generally be attributed to inadequate lubrication between the surfaces. The purpose of the lubrication medium is to minimize the metal-to-metal contact and allow efficient sliding of the surfaces. Other ways to prevent galling are to reduce the bearing forces or reduce the sliding distance.

**3.1.39**
**gasket**
Deformable material (or combination of materials) used to prevent leakage of fluid between two surfaces.

**3.1.40**
**global analysis**
Analysis of the complete riser string from the sea floor (wellhead) to top including tensioner joint.

NOTE Bending moments and effective tension distributions along the riser string due to functional loads, vessel motions and environmental loads are determined by global analysis.

**3.1.41**
**heat-affected zone**
Region around a weld that has been affected by welding.

**3.1.42**
**heave**
Floating vessel motion in the vertical direction.

**3.1.43**
**hybrid riser**
Riser with a free-standing vertical section connected to the seabed, supported by a subsurface buoyancy tank at the top and connected to the floating facility by flexible jumpers.

**3.1.44**
**hydraulic connector**
Mechanical connector that is activated hydraulically.

**3.1.45**
**incidental pressure**
Temporary pressure increase due to incidental (i.e. transient) conditions.

EXAMPLE Incidental pressure occurs in situations where the pressure increases temporarily due to surge, unintended shut in, well kill (bull heading), failure of a pressure protection system, or other incidental conditions. Incidental pressure can exceed design pressure temporarily.

**3.1.46**
**jumper**
Short piece of flexible pipe.

**3.1.47**
**kick**
Influx of reservoir fluid into the wellbore during drilling or workover that results in shutting in the well and increased pressure below the shut-in device (usually a BOP).

**3.1.48**
**leak-tight**
Leakage that is acceptable for a particular component.

**3.1.49**
**lifting device**
Tool dedicated for lifting.

**3.1.50**
**load**
Physical influence which causes stress and/or strains in the riser system.

**3.1.51**
**load case**
Combination of simultaneous acting loads.

**3.1.52**
**local buckling**
Buckling mode implying deformations of the cross-section.

NOTE This can, e.g., be due to external pressure (hoop buckling) and moment (wrinkling) or a combination of thereof.

**3.1.53**
**load effect**
Effect of a single load or combination of loads on the structure, such as stress, strain, deformation, displacement, motion, etc.

**3.1.54**
**low-frequency vessel motion**
Motion response at frequencies below wave frequencies typically with periods ranging from 30 s to 300 s.

**3.1.55**
**maintenance**
Total set of activities performed during the service life of the riser to preserve its function.

**3.1.56**
**make-up tools**
Tools to facilitate the make-up of the riser joint connectors.

**3.1.57**
**manufacturer**
Individual or organization that takes the responsibility for the manufacture of a riser component.

NOTE The manufacturer may subcontract one or more of the above mentioned tasks under its responsibility.

**3.1.58**
**maximum operating condition**
Operating condition defined by the operator as the maximum permissible for the system.

NOTE The maximum operating condition can be different for each riser and can be different for different phases of the operation. For example, the maximum operating condition for hydrostatic test might be a one year winter storm, while the maximum operating condition during production might be a 100-year winter storm.

**3.1.59**
**most probable maximum**
Response where the probability density function constructed for the extreme response is at a maximum.

**3.1.60**
**mill/FAT test pressure**
Hydrostatic test pressure applied to riser components upon completion of manufacture and fabrication to test the riser components for strength and/or leak tightness.

**3.1.61**
**nominal value**
Dimensional value specified as nominal on the drawings and specifications.

**3.1.62**
**normal operating pressure**
Maximum internal pressure that is sustained during normal operations referenced to a specific elevation.

EXAMPLE For a production riser, normal operating pressure corresponds to steady state production. For an export riser, normal operating pressure usually corresponds to design pressure.

**3.1.63**
**operating modes**
Conditions that arise from the use and application of the equipment or riser system.

**3.1.64**
**out-of-roundness**
Deviation of the circumference from a circle.

NOTE This can be an ovalization, i.e. an elliptic cross-section, or a local out-of-roundness, e.g. flattening. The numerical definition of out-of-roundness and ovalization is the same.

**3.1.65**
**ovalization**
Deviation of the circumference from a circle which has the form of an elliptic cross-section.

**3.1.66**
**ovality**
Ratio of the difference between the maximum and minimum diameter to the sum of the maximum and minimum diameter of the pipe.

**3.1.67**
**pup joint**
Joint of pipe or tubing shorter than standard length.

**3.1.68**
**purchaser**
Organization that buys the riser system on behalf of the user and/or operator or for its own use.

**3.1.69**
**reduced extreme event**
An environmental event with a return period less than 100 years that can be used in combination with other rare events for accidental load cases.

NOTE 1 There can be several reduced extreme environmental events.

NOTE 2 The appropriate reduced extreme environmental event depends on the nature of the failure and the time to repair.

NOTE 3 A 10 year return period is typical.

**3.1.70**
**resistance**
Mechanical property of a component, a cross-section, or a member of the structure, e.g. bending resistance, local buckling resistance.

**3.1.71**
**response amplitude operator**
**RAO**
Relationship between wave surface elevation amplitude at a reference location and the vessel response amplitude, and the phase lag between the two.

**3.1.72**
**return period**
Average period of time between occurrences of a given event.

NOTE The inverse of return period expressed in years is the statistical probability of such an event occurring in any given year.

**3.1.73**
**riser joint**
Joint consisting of a tubular member(s) with riser connectors at the ends.

**3.1.74**
**riser model**
Structural model which is established from the tabulated data of the riser, to describe the actual riser, and used in global analysis of the riser system.

**3.1.75**
**riser system**
The riser and all integrated components, including subsea and surface equipment.

**3.1.76**
**seal**
Component designed to prevent the passage of fluids.

**3.1.77**
**seamless pipe**
Tubular product fabricated without a welded seam.

NOTE Typically manufactured in a hot forming process by extrusion or drawing which can be followed by cold sizing or finishing to the desired shape, dimensions and properties.

**3.1.78**
**service life**
Duration of time in which the equipment performs under the specified design conditions, i.e. time in active operation, excluding storage periods.

**3.1.79**
**serviceability limit state**
Category describing events with an annual probability of exceedance larger than $10^{-2}$.

NOTE 1 The serviceability limit state (SLS) requires that the system survive with no damage and operate as intended.

NOTE 2 The limiting conditions for normal operation, installation and testing depend on the particular situation. SLS conditions are defined by the operator and reflect the operating plan. These very important cases define the intended operation.

**3.1.80**
**S-N curve**
A plot of stress range (S) against the number of cycles (N) to failure obtained by cycling specimens to failure.

**3.1.81**
**sour service**
Service conditions with $H_2S$ content exceeding the minimum specified by NACE MR0175/ISO 15156 at the design pressure.

**3.1.82**
**specified minimum yield strength**
Minimum yield strength at room temperature prescribed by the specification or standard under which the material is purchased.

**3.1.83**
**strain-based design**
Design where total nominal strain in any direction (excluding strain concentration) due to installation and operations exceeds 0.5 % at the OD surface.

**3.1.84**
**strength**
Mechanical property of a material, usually given in units of stress.

**3.1.85**
**stress concentration factor**
**SCF**
Local peak alternating stress in a component (including welds) divided by the nominal alternating stress in the pipe wall at the location of the component.

NOTE This factor is used to account for the increase in the stresses caused by geometric stress amplifiers that occur in the riser component.

**3.1.86**
**stress intensity factor**
Term used in fracture mechanics to define the local conditions of stress and strain around a crack tip, in terms of global parameters such as of loads, geometry and crack size.

**3.1.87**
**stress joint**
Specialized riser joint designed with a tapered cross-section to control curvature and reduce local bending stresses.

**3.1.88**
**stress range**
The difference between stress maximum and stress minimum in a stress cycle.

**3.1.89**
**stroke**
Total vertical movements (upward and downward) of the riser relative to the vessel which is also the travel of the riser tensioner.

NOTE Stroke is affected by environmental loads, functional loads (i.e. top tension, temperature and mean static vessel offset) and pressure.

**3.1.90**
**subsea tree**
Assembly of valves attached to the uppermost connection of the subsea wellhead and used to control well production.

**3.1.91**
**subsea wellhead**
Assembly used during drilling, completion and production operations that has provisions to lock and seal to a subsea BOP stack, to a subsea tree, to a high pressure drilling riser or to a top-tensioned production riser.

**3.1.92**
**surface tree**
Device placed at top of the riser string that provides flow control of the production and/or annulus bores during production.

**3.1.93**
**surge pressure**
Pressure produced by sudden changes in the velocity of the moving stream of fluids inside the riser.

**3.1.94**
**survival event**
A survival environmental condition with a return period between 100 years and 10,000 years.

NOTE There can be several survival events.

**3.1.95**
**system pressure test**
Field hydrostatic leak-tightness pressure test of the complete riser system performed after installation and before start of operation.

**3.1.96**
**tension joint**
Special riser joint which provides a means for attaching a vertical riser to the floating vessel's tensioning system.

**3.1.97**
**tension ring**
Attachment point on the tension joint for the floating vessel tensioners.

**3.1.98**
**tensioner system**
Device that applies a tension to the riser string while compensating for the relative vertical motion (stroke) between the floating vessel and the top of the deployed riser string.

**3.1.99**
**test pressure**
Internal pressure during field hydrostatic test of risers and/or riser components.

NOTE Risers that are part of a pipeline may require field hydrostatic testing to a pressure greater than design pressure. Field hydrostatic testing of fabricated components may be to a lower pressure. Hydrostatic testing need not be required if other measures with an equivalent level of safety are employed and documented.

**3.1.100**
**top tensioned riser**
Vertical or nearly vertical riser supported by top tension in combination with boundary conditions that allows for relative riser/vessel motions in vertical direction and constrained to follow the horizontal vessel motion at one or several locations.

**3.1.101**
**tubing**
Pipe used in wells to conduct fluid from the well's producing formation into the subsea or surface tree.

**3.1.102**
**tubing riser**
Riser which consists of one or more individual strings of production tubing and a hydraulic control umbilical.

NOTE If multiple tubing strings are used, they can be left either independent of each other, or secured together using some type of clamping device. The hydraulic control umbilical is normally clamped or strapped to one of the tubing strings as it is run.

**3.1.103**
**ultimate limit state**
Events with $10^{-2}$ annual exceedance probability (100-year return period events or events with a 1 % annual probability of occurrence).

NOTE ULS requires that the system survive with no damage, although operations can be suspended. For some cases, ULS and SLS cases can be the same.

**3.1.104**
**verification**
Examination to confirm that an activity, a product or a service is in accordance with specified requirements.

**3.1.105**
**vessel mean offset**
Offset created by steady forces from current, wind and waves.

**3.1.106**
**vessel offset**
Total offset of the vessel, taking into account the vessel mean offset, wave frequency motions and low-frequency wind and wave motions.

**3.1.107**
**vortex-induced vibrations**
**VIV**
In-line and transverse oscillation of a riser in a current induced by the periodic shedding of vortices.

**3.1.108**
**wave frequency motion**
Motion of the vessel at the frequencies of incident waves.

**3.1.109**
**wave scatter diagram**
Table listing occurrence of sea states in terms of significant wave height and wave peak period or mean upcrossing period.

**3.1.110**
**well completion**
Well operations including tubing installation, well perforation and test production.

**3.1.111**
**workover riser**
Jointed riser that provides a conduit from the subsea tree upper connection to the surface and allows for the passage of tools during workover operations of limited duration, and that can be retrieved in severe environmental conditions.

NOTE Historically workover operations have normally been performed in open sea (i.e. for conventional tree systems), but can be performed inside a drilling riser providing sufficient barrier elements are available.

**3.1.112**
**yield strength**
Material specification corresponding to measured tensile stress required to produce a total elongation of 0.5 % of test specimen gauge length.

## 3.2 Symbols

$A$ pipe cross-section area

$A_{\mathrm{i}}$ internal cross section of the pipe

$A_{\mathrm{o}}$ external cross section of the pipe

$\alpha_{\mathrm{fab}}$ fabrication factor

$CE_{\mathrm{IIW}}$ carbon equivalent based upon the International Institute of Welding carbon equivalent equation (i.e. carbon equivalent for weldable steel with a carbon mass fraction > 0.12 %)

$CE_{\mathrm{Pcm}}$ carbon equivalent based upon the chemical portion of the Ito-Bessyo carbon equivalent equation (i.e. carbon equivalent for weldable steel with a carbon mass fraction ≤ 0.12 %)

| | |
|---|---|
| $D$ | nominal outside diameter of pipe |
| $D_{max}$ | greatest measured inside or outside diameter |
| $D_{min}$ | smallest measured inside or outside diameter |
| $\delta_0$ | ovality |
| $E$ | Young's modulus |
| $\varepsilon$ | bending-induced strain in pipe |
| $\varepsilon_b$ | bending strain at which buckling occurs |
| $F_D$ | design factor |
| $\sigma_a$ | axial stress in the pipe wall; |
| $H_s$ | significant wave height |
| $I$ | moment of inertia of section |
| $k$ | parameter to account for variability in pipe mechanical properties and wall thickness |
| $M$ | moment in pipe |
| $M_A$ | bending moment from accidental loads |
| $M_E$ | bending moment from environmental loads |
| $M_F$ | bending moment from functional loads |
| $M_k$ | plastic moment capacity including strain hardening |
| $M_p$ | plastic bending moment capacity of the pipe |
| $M_y$ | yield moment in pipe |
| $N_i$ | number of cycles to failure at constant stress range Si in each stress block |
| $P_y$ | yield pressure at collapse |
| $p_b$ | burst pressure of the pipe |
| $p_c$ | collapse pressure |
| $p_e$ | external pressure |
| $p_{el}$ | elastic hoop buckling (collapse) pressure (instability) of pipe cross-section |
| $p_i$ | internal pressure |
| $p_k$ | characteristic burst pressure capacity |
| $p_p$ | plastic pressure at hoop buckling (collapse) of the pipe cross-section |
| $S$ | specified minimum yield strength of the pipe |
| $S_i$ | constant stress range in each fatigue stress block |
| $T$ | effective tension in pipe |
| $T_a$ | axial (material) tension in pipe |
| $T_E$ | effective tension from environmental loads |

$T_F$ effective tension from functional loads

$T_k$ axial capacity including strain hardening effects

$T_y$ yield tension in pipe

$t$ pipe wall thickness used in design equations (nominal pipe wall thickness reduced for corrosion, wear and/or erosion as appropriate, see 7.3)

$t_{ca}$ corrosion/wear/erosion allowance

$t_{fab}$ nominal pipe wall thickness (includes corrosion/wear/erosion allowance)

$U$ specified minimum ultimate strength of pipe

$\nu$ Poisson's ratio

## 3.3 Abbreviated Terms

| | |
|---|---|
| API | American Petroleum Institute |
| ASTM | American Society for Testing and Materials |
| ALS | accidental limit state |
| ALARP | as low as reasonably practical |
| AUT | automated ultrasonic testing |
| BOP | blow-out preventer |
| BS | British Standard |
| CP | cathodic protection |
| CRA | corrosion resistant alloy |
| CTOD | crack tip opening displacement |
| C/WO | completion/workover |
| ECA | engineering criticality assessment |
| ESD | emergency shut-down |
| FAT | factory acceptance test |
| FLS | fatigue limit state |
| FM | fracture mechanics |
| FMEA | failure mode and effects analysis |
| FMECA | failure mode, effects and criticality analysis |
| FPS | floating production system |
| HAZ | heat-affected zone |
| HAZID | hazard identification |
| HAZOP | hazard and operability |
| HISC | hydrogen-induced stress cracking |
| HV | Vickers hardness |
| IEC | International Electrotechnical Commission |
| IM | integrity management |

| | |
|---|---|
| ISO | International Organization for Standardization |
| ITP | inspection and test plan |
| MAOP | maximum allowable operating pressure |
| MPS | material product specification |
| MPI | magnetic particle inspection |
| MWL | mean water level |
| NA | not applicable |
| NACE | National Association of Corrosion Engineers |
| NDE | nondestructive examination |
| NDT | nondestructive testing |
| OOR | out of roundness |
| PTFE | polytetrafluoroethylene |
| PWHT | post-weld heat treatment |
| QA/QC | quality assurance/quality control |
| QRA | quantitative risk analysis |
| RAO | response amplitude operator |
| ROV | remotely operated vehicle |
| SCF | stress concentration factor |
| SCR | steel catenary riser |
| SITP | shut-in tubing pressure |
| SLS | serviceability limit state |
| SMYS | specified minimum yield strength |
| TDP | touchdown point |
| TDZ | touchdown zone |
| TTF | top tension factor |
| TTR | top tensioned riser |
| ULS | ultimate limit state |
| UOE | pipe fabrication process for welded pipes, expanded |
| VIM | vortex induced platform motions |
| VIV | vortex induced vibration |
| UT | ultrasonic testing |

# 4 Design Loads and Conditions

## 4.1 General

The design of floating production systems (FPSs) is intended to provide for safe, reliable and economic production of oil and gas. The load requirements discussed in this section are primarily intended to address design practice that ensures reliability. The designer should design for loads that can occur and that are reasonably foreseeable. While this may sound simple, getting the proper load cases is not.

HAZOP and FMEA are useful tools to ensure that important cases are not missed and they also provide guidance for mitigation of risk.

Design is for load effects, such as stress, strain, pressure, bending moment, tension, fatigue damage, crack growth, etc. Load effects come from combinations of loads.

Load cases should take account of the operating plan. Determination of appropriate load cases requires a good understanding of the entire system and operating requirements for the various components and phases of operation. These loads and other parameters such as the design pressure are needed for design and the determination of these loads is the responsibility of the operator.

## 4.2 Loads

Loads are classified as functional, environmental (external), accidental, fatigue or construction defined as follows.

a) Functional loads are all loads on the pipe in operation, including all loads that act on the pipe in still water. Examples include weight, external hydrostatic pressure and internal pressure, thermal loads caused by content temperature, and seabed reactions.

b) Environmental loads are loads induced by external environmental parameters. Examples include wind, wave and current loads.

c) Accidental loads are loads caused by accidental occurrences. Examples include 1000-yr wave and current loads, operational malfunction, and loads from impacts/collisions.

d) Fatigue loads are cyclic loads resulting in accumulated damage. Examples include loads due to FPS wave motion, direct wave loading on the riser, vortex-induced vibration and vortex-induced FPS motion.

e) Construction loads are loads which arise as a result of the construction of the riser system including installation, pressure testing, commissioning, maintenance and repair. Examples include transportation, fabrication, installation and retrieval loads.

The design load cases shall be defined to analyze, as applicable, the effect on the FPS risers of combinations of functional, environment, accidental, and fatigue loads.

## 4.3 Design Load Cases

Design load cases are defined by combinations of functional loads (pressure, temperature, contents, and nominal tension), environmental loads, flow-induced loads and accidental loads. The design strength load cases fall within one of the following categories: serviceability limit state (SLS), ultimate limit state (ULS), and accidental limit state (ALS). SLS corresponds to criteria governing normal operational conditions and normal temporary events; ULS corresponds to extreme operational conditions and abnormal temporary events; ALS corresponds to survival conditions or rare accidental loads. Load combinations with a yearly probability of occurrence less than $10^{-4}$ can be ignored.

The fatigue limit state (FLS) represents a potential failure mode. All cyclic loading should be considered for accumulation of fatigue damage. Contributions to fatigue loading include environmental loading due to wind and wave (usually described in a scatter diagram), vortex induced vibrations (VIV), vortex induced platform motions (VIM), thermal cycling, and pressure cycling.

Representative design strength load combinations that can be analyzed are as defined in Table 1.

**Table 1—Representative Intact Strength Load Cases**

| Design Case | Environment | Functional Load | Category |
|---|---|---|---|
| Construction | Associated | Associated | SLS |
| Operation | Maximum operating | Normal operating | SLS |
| Extreme | Extreme | Extended shut in | ULS |
| Survival | Survival | Extended shut in | ALS |
| Test | Associated | Hydrostatic test pressure | ALS |
| Temporary | Associated | Associated | ULS |
| ESD | Maximum operating | ESD | SLS |
| SITP (production riser) | Reduced extreme | SITP | ALS |
| Kick | Reduced extreme | Kick | ALS |
| Incidental pressure | Associated | Associated | ALS |

Representative damaged load cases are described in Table 2. The environmental load condition for one mooring line failed is extreme to be consistent with mooring design.

**Table 2—Representative Damaged Strength Load Cases**

| Design Case | Environment | Functional Load | Category |
|---|---|---|---|
| Failed mooring line | Maximum operating | ESD | ALS |
| Failed mooring line | Extreme | Extended shut in | ALS |
| Flooded compartment | Maximum operating | ESD | ALS |
| Flooded compartment | Reduced extreme | Extended shut in | ALS |
| Damaged tensioner | Maximum operating | ESD | ALS |
| Damaged tensioner | Reduced extreme | Extended shut in | ALS |

Representative fatigue load cases are in Table 3. Construction cases cover the range of construction activities. Operational cases include the sea states in the wave scatter diagram, current loading (VIV and VIM) and should represent all planned configurations and events. Single event cases include extreme storm and current events.

**Table 3—Representative Fatigue Load Cases**

| Case | Environment | Functional Loads |
|---|---|---|
| Construction | Associated | Associated |
| Operating | Wave scatter diagram | Associated |
| Vortex induced vibration (VIV) | Current scatter diagram | Normal operating |
| Vortex induced motion (VIM) | Current scatter diagram | Normal operating |
| Single storm event | Extreme storm | Associated |
| Single current event | Extreme current | Associated |

The riser system design should include analysis of potential riser interference with other risers, mooring lines, tendons, hull, the seabed, and with any other obstruction. If contact is predicted, resulting collision loads should be determined to demonstrate that riser integrity is maintained. See DNV-RP-F203 for a criterion for minimum clearance to avoid collision.

# 5 Design Criteria for Rigid Pipe

## 5.1 Objective

This standard sets out criteria and recommendations for the design, construction, testing, operation and maintenance of risers that are part of a floating production system. The criteria and recommendations are intended to provide for safe and reliable operation of the risers as part of the floating production system. Design and construction practices other than those set forth in this standard may be employed when supported by adequate technical justification. Nothing in this standard should be considered as a fixed rule for application without regard to sound engineering judgment.

This standard provides the general framework for design of riser systems including provisions for checking of limit states for rigid pipes in riser systems. It provides design checks with emphasis on ULS, FLS, SLS and ALS conditions.

A fundamental requirement is that loads and load effects that can cause or contribute to failure of the riser system during its intended use and other reasonably foreseeable operational conditions be identified and accounted for in the design.

The aim of the design is to ensure that the riser pipe and structural ancillary equipment have adequate structural resistance, leak-tightness, fatigue resistance and functionality for all relevant load cases. Resistance against accidental loads shall be considered when applicable.

Structural ancillary equipment should be designed to the same allowable utilization level and load cases as the riser pipe if the failure of the ancillary equipment would impact the integrity of the riser pipe.

Examples of verifications of strength requirements of this chapter are given in Annex A and Annex B for two riser systems.

## 5.2 Design Format

The design format sets limits on loads or load effects to a fraction of the capacity of the component to resist the load or load effect. The limit is set in the form

$$\text{Load or Load Effect} \leq F_D \times \text{Capacity},$$

where

$F_D$ is a design factor which is not to exceed 1.

The design factor depends on the type of load and can be different for SLS, ULS, and ALS categories.

The values of axial load, pressure, bending moment and bending strain to be used in the design check formulae are the most probable maximum values corresponding to the load case.

## 5.3 Capacities of Pipe

### 5.3.1 General

The capacity formulae presented are intended to represent the minimum capacity. Capacity is determined from the product specification. The product specification should define properties (strength, fracture toughness, etc) over the range of temperatures anticipated in service. The properties used in the load checks should correspond to the properties at the temperature corresponding to the load case (see 7.5).

When a corrosion, wear and/or erosion allowance is required, the design process should consider a reduction in wall thickness for certain load cases as appropriate. Determination of the appropriate thickness is part of development of load cases.

### 5.3.2 Burst Pressure

The minimum burst pressure of pipe is determined by Equation 1:

$$p_b = k(S+U)\ln\left(D/(D-2t)\right) \tag{1}$$

where

- $k$ is a parameter to account for variability in mechanical properties and wall thickness, and is equal to 0.45 for API 5L or API 5CT pipe;
- $D$ is the outside diameter of the pipe;
- $t$ is the nominal thickness of the pipe reduced for corrosion, wear and/or erosion as appropriate;
- $S$ is the specified minimum yield strength of the pipe;
- $U$ is the specified minimum ultimate strength of the pipe.

Burst pressure is a characteristic of a product and depends on the product specification. Determination of the minimum burst pressure can also be assessed experimentally using the procedure in API 1111, Appendix A. Improved control of mechanical properties and dimensions can produce pipe with improved burst performance. An example supplementary specification is in API 1111, Appendix B.

### 5.3.3 Collapse

#### 5.3.3.1 Collapse Due to External Pressure

The collapse pressure for pipes can be calculated as a function of nominal wall thickness as per Equation 2.

$$p_c = \frac{P_y\, p_{el}}{\sqrt{P_y^2 + p_{el}^2}} \tag{2}$$

where

- $P_y$ is the yield collapse pressure, given by Equation 3;
- $p_{el}$ is the elastic collapse pressure, given by Equation 4.

$$P_y = 2S\left(\frac{t}{D}\right) \tag{3}$$

$$p_{el}(t) = \frac{2E\left(t/D\right)^3}{1-\nu^2} \tag{4}$$

where

$E$ is Young's modulus;

$\nu$ is Poisson's ratio.

The collapse pressure may alternatively be calculated as a function of the elastic capacity, plastic capacity and the ovality of the pipe as per Equation 5.

$$\left(p_c - p_{el}\right)\left(p_c^2 - p_p^2\right) = p_c\ p_{el}\ p_p\ 2\,\delta_0\ \frac{D}{t} \tag{5}$$

where

$\delta_0$ is pipe ovality, given by Equation 8;

$p_p$ is the plastic collapse pressure of a pipe, given by Equation 6.

$$p_p = 2\frac{t}{D} S\,\alpha_{fab} \tag{6}$$

where

$\alpha_{fab}$ is the fabrication factor, given by Equation 7.

$$\alpha_{fab} = \begin{cases} 1.0 & \text{seamless pipe} \\ 0.85 & \text{UOE pipe} \\ 0.925 & \text{UO/TRB pipe} \end{cases} \tag{7}$$

The initial departure from circularity of pipe and pipe ends (i.e. the initial ovality) is given by Equation 8.

$$\delta 0 = \frac{D_{max} - D_{min}}{D_{max} + D_{min}} \tag{8}$$

The initial ovality shall not be taken less than 0.0025 (0.25 %). Ovalization caused during the construction and installation phase shall be included in the ovality. The ovalization due to external pressure or moment in the as-installed position shall not be included.

An analytical solution to Equation 5 can be found in DNV-OS-F101.

#### 5.3.3.2 Collapse Due to Pure Bending

Pure bending can result in wrinkling of the pipe wall or flattening of the cross section. Both conditions are known as buckling due to bending. The bending strain that can result in such deformation can be calculated using Equation 9.

$$\varepsilon_b = \frac{t}{2D} \tag{9}$$

Deformation of the cross section does not reduce the internal pressure capacity or the tensile capacity unless strains are such that material rupture occurs.

#### 5.3.3.3 Collapse Propagation

For collapse propagation design evaluation, refer to API 1111.

### 5.3.4 Tension

The tension capacity may be calculated by Equation 10.

$$T_{\mathrm{y}} = S A \tag{10}$$

where

$A$ is the pipe cross-section area, given by Equation 11.

$$A = \pi (D - t)\, t \tag{11}$$

### 5.3.5 Yield Moment

The moment that corresponds to a membrane stress equal to yield can be calculated as in Equation 12.

$$M_{\mathrm{y}} = \frac{2SI}{D - t} \approx \frac{\pi}{4} S (D - t)^2\, t \tag{12}$$

where

$I$ is the moment of inertia of the pipe.

The yield moment is used in the Method 1 combined load formulae in 5.4.3.2.

### 5.3.6 Plastic Moment

The bending moment capacity corresponds to yielding of the cross section. The plastic moment can be calculated as in Equation 13.

$$M_{\mathrm{p}} = \frac{S}{6}\left(D^3 - (D - 2t)^3\right) \approx S (D - t)^2\, t = \frac{4}{\pi} M_{\mathrm{y}} \tag{13}$$

Plastic moment is used in the combined load formulae of Methods 2 and 3 in 5.4.3.3 and 5.4.3.4.

## 5.4 Design Criteria

### 5.4.1 Internal Pressure

The casing pressure equal to the pressure caused by a tubing leak, extreme pressure in a drilling riser, hydrostatic test pressure, incidental pressure, and/or design pressure shall not exceed the pressure determined by Equation 14.

$$p_{\mathrm{i}} - p_{\mathrm{e}} \le F_{\mathrm{D}}\, p_{\mathrm{b}} \tag{14}$$

where

$p_e$ is the external pressure;

$p_i$ is the internal pressure;

$F_D$ is a design factor and is given by Equation 15.

$$F_D = \begin{cases} 0.81 & \text{Production casing with tubing leak} \\ 0.81 & \text{Drilling riser with extreme pressure} \\ 0.90 & \text{Hydrostatic test} \\ 0.67 & \text{Incidental pressure} \\ 0.60 & \text{Design pressure} \end{cases} \tag{15}$$

For risers that are part of a pipeline system, refer also to API 1111 or DNV-OS-F101, as appropriate.

Refer to 5.3.1 for guidance on use of wall thickness allowance.

### 5.4.2 External Pressure

Risers can be subject to conditions where the external pressure exceeds the internal pressure. Examples include installation of catenary risers with the pipe empty and annulus evacuation due to loss of circulation during drilling operations.

The net external overpressure (external pressure minus minimum internal pressure) shall not exceed that given by Equation 16.

$$p_e - p_i \le F_D \, p_c \tag{16}$$

where

$F_D$ is a design factor, given by Equation 17.

$$F_D = \begin{cases} 0.6 & \text{SLS, ULS cold expanded pipe (e.g. DSAW)} \\ 0.7 & \text{SLS, ULS seamless or ERW pipe} \\ 1.0 & \text{ALS} \end{cases} \tag{17}$$

Under some circumstances in cold expanded pipe, credit can be taken for partial recovery of compressive yield strength by heat treatment to at least 233 ºC (450 ºF) for several minutes. Such heat treatment may be provided during the fusion bond epoxy coating process of the pipe, provided temperature and duration of heating is carefully controlled. In such cases, the collapse factor of 0.6 may be raised to no more than 0.7. The proposed increase in design factor should be validated through a testing program.

### 5.4.3 Combined Loads

#### 5.4.3.1 Fundamentals

Riser loads during installation and operation include environmental, accidental and temporary load conditions. In the following sections, limits are set on combined axial, pressure and bending loads for SLS, ULS and ALS categories. Since pressure and temperature are specified for each load case, the combined loading criteria set limits on longitudinal load due to axial and bending loads.

Four Methods of combined load criteria are set out. Method 1 sets a limit on combined membrane load. Methods 2 and 4 allow higher bending moments and account for the presence of plasticity. Method 3 also accounts for plasticity, but whether higher bending loads are allowed is dependent on the relative importance of functional and variable bending loads. If the total nominal strain in any direction (excluding strain concentration) due to installation and operations exceeds 0.5 % at the OD surface, the design shall be considered a strain-based design. For all methods, strain limits should be consistent with the qualification of parent materials and welds. Additional material requirements for strain-based design are in 7.7.

Any of the methods can be used for design. The appropriate method for implementation can be selected based on the load case, the materials, and fabrication and installation considerations.

The operator may choose to set more restrictive limits in some cases.

### 5.4.3.2 Method 1

The load combinations and associated design factors for Method 1 are given in Equations 18 and 19.

$$\left|\frac{T}{T_\mathrm{y}}\right| + \left|\frac{M}{M_\mathrm{y}}\right| \le \sqrt{F_\mathrm{D}^2 - \left(\frac{p_\mathrm{i} - p_\mathrm{e}}{p_\mathrm{b}}\right)^2} \quad (\text{internal overpressure}) \tag{18}$$

$$\left|\frac{T}{T_\mathrm{y}}\right| + \left|\frac{M}{M_\mathrm{y}}\right| \le \sqrt{F_\mathrm{D}^2 - \left(\frac{p_\mathrm{e} - p_\mathrm{i}}{p_\mathrm{c}}\right)^2} \quad (\text{external overpressure}) \tag{19}$$

where

$T = T_\mathrm{a} - p_\mathrm{i}A_\mathrm{i} + p_\mathrm{e}A_\mathrm{o}$ is the effective tension in the pipe;

$T_\mathrm{a} = \sigma_\mathrm{a}A$

$\sigma_\mathrm{a}$ is the axial stress in the pipe wall;

$A_\mathrm{o}$ is the external cross section of the pipe

$A_\mathrm{i}$ is the internal cross section of the pipe

$M$ is the moment in the pipe;

$F_\mathrm{D}$ is a design factor, given by Equation 20.

$$F_\mathrm{D} = \begin{cases} 0.80 & \text{SLS, ULS internal and external overpressure} \\ 0.90 & \text{ALS external overpressure for } p_\mathrm{e} - p_\mathrm{i} > 0.5 p_\mathrm{c} \\ 1.00 & \text{ALS otherwise} \end{cases} \tag{20}$$

### 5.4.3.3 Method 2

Method 2 limits axial load based on yield tension including the effect of internal pressure. The load combinations and associated design factors are given in Equations 21 and 22.

$$\left|\frac{M}{M_{\mathrm{p}}}\right| \le \sqrt{F_{\mathrm{D}}^2 - \left(\frac{p_{\mathrm{i}} - p_{\mathrm{e}}}{p_{\mathrm{b}}}\right)^2} \cos\left(\frac{\pi}{2} \frac{T / T_{\mathrm{y}}}{\sqrt{F_{\mathrm{D}}^2 - \left((p_{\mathrm{i}} - p_{\mathrm{e}}) / p_{\mathrm{b}}\right)^2}}\right) \quad \text{(internal overpressure)} \tag{21}$$

$$\left|\frac{M}{M_{\mathrm{p}}}\right| \le \sqrt{F_{\mathrm{D}}^2 - \left(\frac{p_{\mathrm{e}} - p_{\mathrm{i}}}{p_{\mathrm{c}}}\right)^2} \cos\left(\frac{\pi}{2} \frac{T / T_{\mathrm{y}}}{\sqrt{F_{\mathrm{D}}^2 - \left((p_{\mathrm{e}} - p_{\mathrm{i}}) / p_{\mathrm{c}}\right)^2}}\right) \quad \text{(external overpressure)} \tag{22}$$

where

$F_{\mathrm{D}}$ is a design factor, given by Equation 23.

$$F_{\mathrm{D}} = \begin{cases} 0.80 & \text{SLS, ULS} \\ 1.00 & \text{ALS} \end{cases} \tag{23}$$

#### 5.4.3.4 Method 3

Method 3 is based on DNV-OS-F201, which uses a load and resistance factor design (LRFD) format. For load controlled conditions, refer to the section in F201 on Combined Load Criteria for Riser Pipes. For displacement controlled conditions, refer to the F201 section labeled Displacement Controlled Conditions.

When the calculated moment exceeds 90 % of the plastic moment, refer to the requirements of 5.4.3.6.

#### 5.4.3.5 Method 4

Method 4 sets limits on combined axial load and pressure, without considering bending. Refer to API 1111 for further explanation. Bending limits are set based on bending strain.

NOTE There are cases such that the plastic moment limit set by Method 2 does not result in excessive bending strain (i.e. the loading condition is displacement controlled).

The load combinations and associated criteria are given by Equation 24.

$$\sqrt{\left(\frac{p_{\mathrm{i}} - p_{\mathrm{e}}}{p_{\mathrm{b}}}\right)^2 + \left(\frac{T}{T_{\mathrm{y}}}\right)^2} \le F_{\mathrm{D}} \tag{24}$$

where

$F_{\mathrm{D}}$ is a design factor, given by Equation 25.

$$F_{\mathrm{D}} = \begin{cases} 0.9 & \text{SLS, ULS} \\ 1.0 & \text{ALS} \end{cases} \tag{25}$$

For sizing, limiting the load combination in Equation 24 to 0.67 ($F_{\mathrm{D}}$ = 0.67) using static effective tension and normal operating pressure will usually provide a design that meets SLS, ULS and ALS conditions.

Method 4 sets limits for bending strain for cases of internal or external overpressure. The criteria are given by Equations 26 and 27.

$$\varepsilon \le F_D \varepsilon_b \quad \text{(internal overpressure)} \tag{26}$$

$$\varepsilon \le \frac{F_D \varepsilon_b}{1+20\delta_0}\left(1-\frac{p_e - p_i}{f_c\ p_c}\right) \quad \text{(external overpressure)} \tag{27}$$

where

$\varepsilon$ is the bending-induced strain in the pipe;

$F_D$ is a design factor; see Equation 28;

$f_c$ is the collapse factor for use with combined pressure and bending loads; see Equation 29.

$$F_D = \begin{cases} 0.5 & \text{SLS, ULS} \\ 1.0 & \text{ALS} \end{cases} \tag{28}$$

$$f_c = \begin{cases} 0.6 & \text{cold expanded pipe (e.g. DSAW)} \\ 0.7 & \text{seamless pipe} \end{cases} \tag{29}$$

For installation conditions, collapse factors up to 1.0 can be considered.

NOTE The bending strain in Equations 26 and 27 includes strain amplification where appropriate, such as at discontinuities.

For further guidance on the use of these formulae, refer to API 1111. For risers that are part of a pipeline system, refer also to API 1111 or DNV-OS-F101, as appropriate.

#### 5.4.3.6 Bending Check (for Moment Exceeding 90 % of Plastic Moment)

For bending moments that approach plastic moment, load controlled conditions can lead to excessive bending strain. The plastic moment de-rated for tension, pressure and temperature is given by Equation 30.

$$M_{max} = M_p \sqrt{1-\left(\frac{p_i - p_e}{p_b}\right)^2}\cos\left(\frac{\pi}{2}\frac{T/T_y}{\sqrt{1-\left((p_i - p_e)/p_b\right)^2}}\right) \tag{30}$$

If the calculated moment is less than 90 % of the de-rated plastic moment, then strains are small and no further check is needed. For calculated moment greater than 90 % of the de-rated plastic moment, it is appropriate to examine the load condition to assess the risk of excessive bending strain. The recommendation can be written as:

$M \le 0.9 M_{max}$ no further check required

$M > 0.9 M_{max}$ check bending strain according to Method 4

The bending check is appropriate for Methods 2 and 3 where the calculated moment exceeds 90 % of the plastic moment. The Method 1 limits satisfy the check since plastic moment is significantly greater than that allowed by Method 1 criteria.

NOTE Bending strain for the further check should be calculated using the nonlinear moment curvature relationship. The nonlinear moment curvature relationship accounts for the stress strain relation for the material.

### 5.4.4 Fatigue

#### 5.4.4.1 General

Fatigue assessment shall include all cyclic loading, including cycles with inelastic deformation.

#### 5.4.4.2 Fatigue Analysis

Fatigue damage may be calculated using an S-N approach or using a fracture mechanics (dA/dN) approach (e.g. BS 7910). The S-N curve used for fatigue design should be qualified for the intended service conditions including fluids, post-yield conditions, etc. If the S-N approach is used, damage should be accumulated using Miner's rule for summation of damage as stated by Equation 31 (see DNV-RP-C203 and DNV-RP-F204 for guidance).

$$\text{Damage} = \sum_{\text{i}=1}^{k} \frac{n_\text{i}}{N_\text{i}} \tag{31}$$

where

$n_\text{i}$ is the constant stress range in each fatigue stress block;

$N_\text{i}$ is the number of cycles to failure at constant stress range $S_\text{i}$ in each fatigue stress block.

Hot spot strains in service can be considered using notionally elastic stresses if the total range is less than twice yield and shakedown occurs. Plasticity during reeling and unreeling is displacement controlled and is subject to separate considerations.

A significant amount of fatigue damage can result from a single extreme event or from a single survival event. The calculated damage using the scatter diagram approach can underestimate potential damage from a single, low probability event, such as a hurricane or a loop current in the Gulf of Mexico. Extreme events should be included in the fatigue analysis to account for both the long term persistence scatter diagram and the extreme events that can significantly affect the fatigue life of the riser system. The duration of such an extreme event should be chosen to account for the event duration in the given geographical area. Limits are set for expected damage during operation, damage due to a single extreme event, and damage due to a single survival event. The accumulated damage limits are given by Equation 32.

$$\text{Damage} \le \begin{cases} 0.1 & \text{during service life} \\ 0.1 & \text{during a single ULS event} \\ 1.0 & \text{during a single ALS event} \end{cases} \quad \text{for S-N approach} \tag{32}$$

where accumulated damage equalling 1.0 represents the limit defined by the design fatigue curve.

#### 5.4.4.3 Engineering Criticality Assessment

Fracture mechanics-based assessments should be performed for the establishment of inspection intervals. This analysis is commonly referred to as an engineering criticality assessment (ECA). The maximum inspection interval should be based on one-fifth of the time required for a reliably-detectable crack to grow to failure. The methodology of BS 7910 or a similar industry-recognized guideline should be used to evaluate the crack's failure criteria and growth.

Accurate understanding of the fracture toughness and crack growth rate under cyclic loading is necessary for the ECA. The designer should obtain these values with an understanding of the implications of the environment and load conditions under which the component is operating.

# 6 Components

## 6.1 General

A riser is an assembly of components. Pipe is a component that can be rigid pipe or unbounded flexible pipe. Pipe components can be joined in series by welds or by mechanical connectors. Components in series with pipe components that experience the same internal and external pressure loads as the pipe component are designated pressure-containing components. Examples include stress joints, flexible joints, wellhead connectors, surface wellheads, etc. Other components that can be included in the riser system include riser tensioning systems, buoyancy modules, and VIV suppression devices.

A riser component or an assembly of riser components is considered a product. A complete riser system, a riser tensioning system, threaded and coupled casing, and a riser flange are all examples of riser products.

Requirements for product realization, including verification and validation, are in API Q1, Section 7. Requirements related to the product (Subsecton 7.2 of API Q1) shall include the following:

a) component loads from the riser analyses (see Section 4);

b) rigid pipe verification (see Section 5);

c) material requirements (see Section 7).

Documentation required by Subsections 7.1 through 7.3 of API Q1 shall be made available to the operator.

Existing products may be considered for use. Supplementary material specifications, verification and validation can be required to meet the requirements for this application.

Validation can include testing in accordance with existing standards, such as API 5C5. Supplemental testing, e.g. fatigue testing, can be required to meet the requirements for this application.

NOTE HAZOP and FMEA are useful tools to ensure that important requirements are not missed. They also provide guidance for mitigation of risk.

## 6.2 Fatigue

The requirements of 5.4 apply to all components.

## 6.3 Pressure-containing Components

### 6.3.1 Component Capacities

The minimum capacities of a component shall be determined for loading by (1) internal pressure and (2) external pressure. The minimum capacity under combined loads, including load combinations arising from Section 4, shall also be determined. Capacity can be governed by structural response or by leakage. Since capacity can be affected by temperature, temperature effects shall be included in determination of capacities.

#### 6.3.2 Internal Pressure and External Pressure

Limits for internal overpressure and for external overpressure shall not exceed the same fraction of component capacity as used to determine the associated pipe component limit (see 5.4.1 and 5.4.2).

#### 6.3.3 Combined Loads for Components Other Than Rigid Pipe

Combined loads from analyses of Section 5 shall not exceed 80 % of the component combined load capacity for SLS and ULS cases and shall not exceed 100 % of the component combined load capacity for ALS cases.

NOTE See API 17G for additional information on riser connectors.

# 7 Materials

## 7.1 Scope

This section provides requirements and guidelines for material selection, manufacture, testing, corrosion protection, fabrication, inspection and documentation. For information on titanium alloys refer to DNV-RP-F201.

## 7.2 General Requirements

#### 7.2.1 Selection

Materials shall be selected to the following:

a) have properties necessary to comply with the functional requirements and be compatible with all anticipated internal and external fluids, temperatures and environments during all operations, consistent with design;

b) be suitable for all anticipated operations associated with dynamic risers for floating production systems, including loads associated with the motions of floating facilities, current and vortex-induced vibrations (VIV), seafloor interaction, production (inertial, thermal, etc.), well stimulation and other operations, transportation, handling and storage;

c) have the mechanical properties, including strength, toughness and fatigue performance, necessary to comply with design requirements;

d) be suitable for the intended fabrication and installation methods, such as welding, induction bending, cladding, reeling, corrosion protection, etc., as necessary;

e) avoid a risk of galvanic corrosion and dissimilar material interaction issues;

f) retain adequate material performance during the entire anticipated life of the project;

g) have sufficient resistance to abrasion/wear or mechanical damage likely to occur during all anticipated operations.

Manufacturing processes should be selected such that critical areas of risers and riser components can be appropriately inspected and non-destructively tested (NDT) during fabrication.

Pressure-containing components and components directly welded to pressure-containing components shall not be metal castings.

Galling should be considered as part of material selection for components with high sliding contact stresses, such as threaded connections.

Non-metallic (i.e. polymers, elastomers, composites, etc.) material selection shall be based on an evaluation of the compatibility of the non-metallic with service environment, including temperature, cyclic loading and composition of anticipated fluids and substances to which the material can be exposed.

Each of the following should be considered as appropriate to non-metallic seal requirements and evaluated (see ISO 23936) when selecting the material:

— adequate physical and mechanical properties, such as hardness, strength, elongation, elasticity, flexibility, compression set, tear resistance, etc., during all anticipated operations;

— resistance to high-pressure extrusion or creep;

— resistance to thermal cycling and dynamic loadings;

— resistance to issues associated with rapid gas decompression;

— degradation of properties during design life.

### 7.2.2 Specifications

Material shall comply with the requirements of recognized industry standards such as those listed in Table 4.

**Table 4—Applicable Material Specifications**

| Item | Standards |
|---|---|
| Line pipe | DNV-OS-F101 or API 5L |
| Welding | DNV-OS-F101 or API 1104 |
| Components | DNV-OS-F101 or applicable ASME standards |
| Flexible pipe | API 17J or API 17K or API 17B |
| Tubular | API 5CT |

Component specifications shall be prepared for all riser components. These component specifications should establish requirements for method and process of manufacture, chemical composition, heat treatment, physical and mechanical properties, weldability, dimensions and tolerances, surface conditions, testing, examination and NDT, marking, temporary coating and protection, certification and documentation.

Manufacturing procedure specifications (MPS) shall be prepared by the manufacturer for manufacture and fabrication of all riser components. The MPS should describe how the specified properties are to be achieved and verified as part of manufacturing/fabrication. The MPS should address all factors that affect the quality and reliability of the manufacture or fabrication. Every principal manufacturing or fabrication step from receiving material to shipment of finished product(s) should be addressed, including heat treatments, forming and machining operations, examinations, NDT and checkpoints. References to the detailed procedures used for the execution of all steps should be included.

Welding specifications shall be prepared for all welded components ensuring that the properties required by the design are satisfied. The specifications should be based on industry standard codes such as ASME BPVC, Section IX, API 1104 and DNV-OS-F101.

### 7.2.3 Qualification of Materials and Manufacturers

All materials used for risers and riser components shall be qualified as per specification. The qualification should address potential failure modes, including factors associated with all anticipated internal and external fluids, temperatures, loads and cyclic loads, installation methods, adjacent materials and design lifetime. If qualification of materials by testing is required, the extent of testing and associated analyses and acceptance criteria should be documented.

Requirements for the qualification of manufacturing processes, fabrication processes, manufacturers and fabricators should be considered for every product. The complexity and criticality of the product to be manufactured or fabricated and the experience of the manufacturer and fabricator should be taken into account.

For strain-based design both material and welding procedures shall be selected and qualified for required strain capacity; refer to 7.7 and 7.11.5.

For fatigue design both material and welding procedures shall be selected and qualified for required fatigue capacity.

### 7.2.4 Traceability

All pressure-containing and load bearing components and materials, including fasteners, shall be traceable, including stages of manufacture, fabrication, transportation, and handling, if possible. Less critical components should also be traceable.

### 7.2.5 Marking

Materials and components should be marked in accordance with the requirements of the applicable product standard or owner's requirement. All marking should be such that it is easily identifiable and retained during subsequent activities. Marking should not compromise product performance. For example, marking by die stamping should not be allowed in fatigue sensitive areas.

### 7.2.6 Inspection Documents

Components should be supplied with an inspection document in accordance with applicable product standard or owner's requirements.

### 7.2.7 Records

Complete records according to owner's specifications should be provided. These records can include chemical composition, material properties, fabrication procedures, dimensions, inspection, welding procedures, handling, transportation, storage, and installation.

### 7.2.8 Protection and Handling

Pipe and other components should be protected and handled in accordance with the requirements of the applicable product standard or owner's requirement. For example, pipe/connector ends and other component openings can be fitted with suitable end caps/covers.

Surface condition for pipe and other components should be controlled during all phases of manufacturing, storage, transportation and installation to minimize initial defects that might impair fatigue performance. These include, handling damage, corrosion, surface roughness and grinding.

## 7.3 Steel

### 7.3.1 General

Steel should be manufactured in a manner ensuring uniform chemical composition, uniform material properties and fine grain structure.

Steel should be manufactured by a process that includes vacuum degassing or AOD.

### 7.3.2 Chemical Composition and Analysis

For weldable steel riser pipe and steels for other riser components with a product analysis carbon mass fraction equal to or less than 0.12 %, the carbon equivalent should be determined using the chemical portion of the Ito-Bessyo carbon equivalent equation, as given by Equation 33.

$$CE_{\mathrm{Pcm}} = \mathrm{C} + \frac{\mathrm{Si}}{30} + \frac{\mathrm{Mn}}{20} + \frac{\mathrm{Cu}}{20} + \frac{\mathrm{Ni}}{60} + \frac{\mathrm{Cr}}{20} + \frac{\mathrm{Mo}}{15} + \frac{\mathrm{V}}{10} + 5\mathrm{B} \tag{33}$$

where

$CE_{\mathrm{Pcm}}$ is the carbon equivalent, based upon the chemical portion of the Ito-Bessyo carbon equivalent equation (i.e. carbon equivalent for weldable steel with a carbon mass fraction ≤ 0.12 %);

C, Si..., are the mass fraction in percent of the associated chemical elements.

For weldable steel riser pipe and steels for other riser components with a product analysis carbon mass fraction greater than 0.12 %, the carbon equivalent should be determined using the International Institute of Welding carbon equivalent equation, as given by Equation 34.

$$CE_{\mathrm{IIW}} = \mathrm{C} + \frac{\mathrm{Mn}}{6} + \frac{(\mathrm{Cr} + \mathrm{Mo} + \mathrm{V})}{5} + \frac{(\mathrm{Ni} + \mathrm{Cu})}{15} \tag{34}$$

where

$CE_{\mathrm{IIW}}$ is the carbon equivalent, based upon the International Institute of Welding carbon equivalent equation (i.e. carbon equivalent for weldable steel with a carbon mass fraction > 0.12 %);

C, Mn..., are the mass fraction in percent of the associated chemical elements.

The amount of all elements used in the $CE_{\mathrm{Pcm}}$ and $CE_{\mathrm{IIW}}$ equations shall be reported for steels. Additionally, S, P, Al and N shall be reported for steels. Chemical composition shall be determined by analysis in accordance with recognized standards. Amount of all elements listed in the material specification shall be determined and reported.

If the steel is to be welded, the manufacturer shall supply weldability data for the type of steel concerned or perform weldability tests. Details for carrying out the weldability tests and the acceptance criteria should be as specified in the purchase order or materials specification. The requirements for the chemical composition of the steels and the limiting values of $CE_{\mathrm{Pcm}}$ and $CE_{\mathrm{IIW}}$ shall be stated in the component specifications.

NOTE The behavior of the steel during and after welding depends not only upon the steel composition but also upon welding consumables used and the conditions of preparing for, and carrying out, welding.

The chemical composition limits of low-alloy steels, such as AISI 4130 and AISI 4140, should be modified as follows:

— P: 0.025 % maximum;

— S: 0.025 % maximum.

## 7.4 Other Materials

### 7.4.1 General

Other materials, such as titanium or composites, may be used.

### 7.4.2 Titanium

For additional guidance on use of titanium, see DNV-RP-F201.

### 7.4.3 Composites

Composite materials have failure modes significantly different from metals, and appropriate testing and qualification methods should be chosen.

NOTE For additional guidance on composite materials, refer to DNV-OS-C501 and DNV-RP-F202.

## 7.5 Requirements for Elevated Temperature

A material should only be used within the range of temperatures for which the strength properties are defined in the product standard. If the product standard does not contain the specific strength values for the maximum design temperature, strength properties should be determined by tensile testing at the maximum design temperature.

## 7.6 Requirements for Sour Service

Metallic materials in sour production environments shall comply with NACE MR0175/ISO 15156 (all parts)

Qualification testing of all riser pipe, other riser components, welding consumables and coatings, as applicable, shall be carried out in accordance with NACE MR0175/ISO 15156 (all parts).

Potential degradation of fatigue performance in sour production environments shall be considered.

Drying or use of scavengers or corrosion inhibitors shall not relax the requirement for sour production equipment to meet NACE MR0175/ISO 15156 (all parts). Risk for sour conditions during the lifetime should be evaluated, especially if water injection is foreseen.

## 7.7 Requirements for Strain-based Design

If the total nominal strain in any direction (excluding strain concentration) due to installation and operations exceeds 0.5 % at the OD surface, the design shall be considered strain-based design. For strain-based design, the following additional requirements should apply.

a) Material selection—Tensile property specifications for base materials used in strain-based design should include upper and lower limits for longitudinal yield strength, uniform elongation and yield-to-tensile strength ratio. Tensile and Charpy impact testing should include the direction associated with the largest strain, e.g. the longitudinal direction for pipe. Tensile testing results should be documented and include a significant portion of the stress-strain curve. Charpy testing should be done on material in the appropriately strain-aged condition. For applications in which the material is subjected to coating (e.g. application of fusion bonded epoxy), mechanical properties in the as-coated condition should also be given (see 7.10.5.1 and 7.10.5.2). DNV-OS-F101, Section 5, D1100, may be used (Supplementary Requirement P).

b) Tests should be performed to demonstrate that the riser welds have the necessary resistance against both crack extension by tearing and unstable fracture due to both installation and in-service conditions. DNV-RP-F108 may be used.

NOTE Internal pressure can reduce the longitudinal strain capacity by more than 50 % and should be considered in the design and qualification.

## 7.8 Prevention of Brittle Fracture

### 7.8.1 General

Materials shall be selected to prevent brittle fracture. Charpy impact testing shall be performed in accordance with component specifications to verify material and weld toughness in the final delivery condition. The test temperature for Charpy impact testing of steel pipes should be in accordance with Table 5.

**Table 5—Test Temperature for Charpy Impact Testing of Steel and Steel Welds**

| **Nominal Wall Thickness** mm | **Test Temperature Relative to $T_{min}$** °C |
|---|---|
| ≤ 20 | $T_{min}$ |
| 20 < $t$ ≤ 40 | $T_{min}$ – 10 |
| >40 | $T_{min}$ – 20 |
| NOTE $T_{min}$ refers to the lowest anticipated service temperature. | |

### 7.8.2 Fracture Mechanics Toughness Testing

For all components thicker than 13 mm or when specified, fracture mechanics toughness testing of the base metal and welds should be performed in accordance with industry standards such as BS 7448.

For steels, base metal, heat-affected zone and weld-metal, the minimum toughness should be specified in project requirements.

NOTE Environmental conditions should be considered when specifying fracture mechanics toughness testing.

### 7.8.3 Hardness

Hardness of base material and weld cross-section samples shall be tested using the Vickers HV10 method according to ISO 6507-1. Hardness readings shall satisfy the requirements of the welding specifications.

For pipe base material tests, individual hardness readings exceeding the applicable acceptance limit can be considered acceptable if the average of a minimum of three and maximum of six additional readings taken within close proximity does not exceed the applicable acceptance limit and if no such individual reading exceeds the acceptance limit by more than 10 HV10 units.

Hardness test locations for seamless and seam-welded pipe shall be as shown in Figure 1, except that

— when $t$ < 4.0 mm, it is only necessary to carry out the mid-thickness traverse,

— for pipe with 4.0 mm ≤ $t$ < 6.0 mm, it is only necessary to carry out the inside and outside surface traverses.

Hardness testing of welds shall be performed on the specimens used for macro examination, and as shown in Figure 1 and Figure 2.

For seam welded pipe the following applies:

— for pipe with $t$ < 4.0 mm, it is only necessary to carry out the mid-thickness traverse;

— for pipe with 4.0 mm ≤ $t$ < 6.0 mm, it is only necessary to carry out the inside and outside surface traverses.

In the weld metal of seam welds, a minimum of three indentations equally spaced along each traverse shall be made. For girth welds and seam welds, indentations in the HAZ shall be made along the traverses for each 0.5 mm to 1.0 mm (as close as possible but provided indentation is made into unaffected material, and starting as close to the fusion line as possible according to Figure 1).

Hardness testing of clad/lined pipes shall have an additional hardness traverse located in the middle of the CRA material (see Figure 2).

For hardness testing of weld overlay, testing shall be performed at a minimum of three test locations: in the base material, in the HAZ and in each layer of overlay up to a maximum of two layers.

## 7.9 Corrosion Protection

All riser system components should be made of materials appropriate for the anticipated corrosive service or have appropriate corrosion protection to avoid damage involving external and internal corrosion. Corrosion protection can be provided by a combination of the following: material selection, coatings, corrosion inhibition, CP, and routine preservation. As a minimum, the following should be considered: marine environment, all anticipated internal environments (including production, hydrotest fluids, well stimulation, etc., as applicable), potential galvanic properties of welds and attached components, crevice corrosion, CP and splash zone requirements.

For risers manufactured from carbon or low alloy steel, corrosion allowance requirements should be assessed and incorporated into design calculations.

Selection of external coating systems can include consideration of the following:

a) mechanical loading, including hydrostatic pressure, thermal expansion (or contraction), handling/installation loads, fatigue loads, damage due to make-up and break-out of threaded connectors, and wear against other components;

b) resistance to damage from temporary exposure to internal fluids during make-up or break-out of threaded connectors;

c) resistance to under-film corrosion, disbonding, cold flow, embrittlement, chalking and cracking;

d) resistance to galvanic corrosion where dissimilar materials are joined;

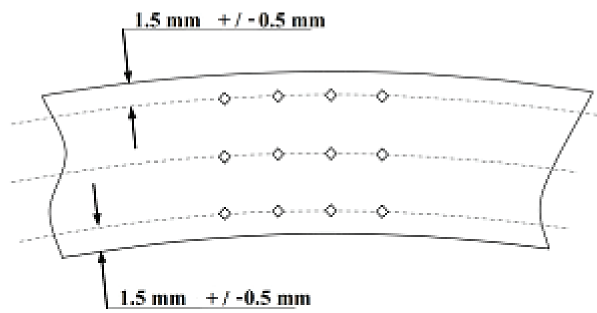
e) enhanced protection under strakes and fairings where CP might not be as effective;

f) enhanced protection in the splash zone where CP is not as effective;

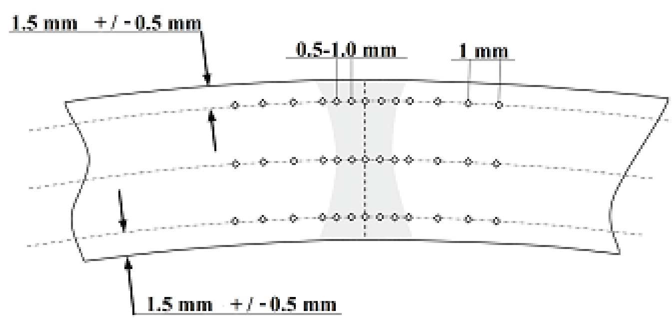
g) maintenance, repair and/or reapplication;

h) routine preservation;

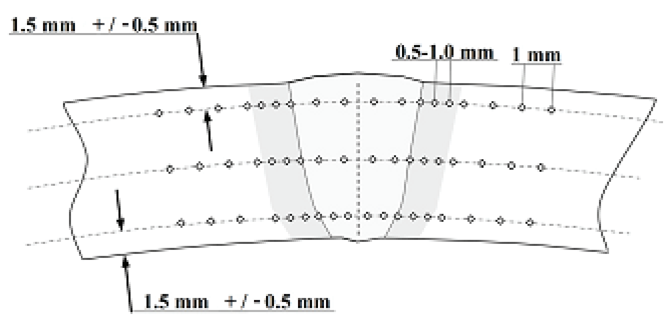
i) passive fire protection.




**a) Seamless Pipe**




**b) Seam-welded Pipe Without Consumables**




**c) Seam-welded Pipe with Consumables**

**Figure 1—Hardness Locations in Seamless and Seam Welded Pipe**

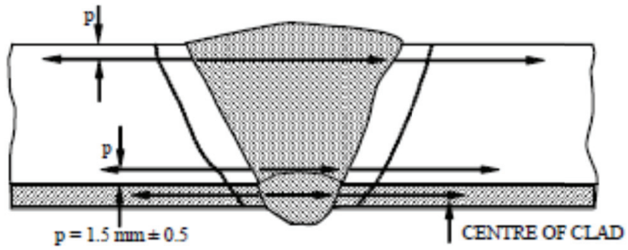



**Figure 2—Hardness Locations for Clad Materials**

For CP, the riser design should ensure reliable electrical continuity to each component for the design life. The CP system should be designed and coordinated with that of other adjacent equipment, such as the hull of the floating installation itself, other risers and subsea equipment.

The design of the CP systems should meet the minimum requirements in ISO 15589-2 or equivalent.

If materials susceptible to hydrogen embrittlement are used with CP, qualified mitigations (such as coatings and weld procedures) should be taken to avoid possible failure mechanisms. Materials of concern can include high strength steel, duplex stainless steel, and butter welds.

For CP, electrical continuity and isolation should be verified to be in accordance with the design.

## 7.10 Products

### 7.10.1 Forgings and Extrusions

#### 7.10.1.1 General

The following general requirements for forgings and extrusions apply.

a) Steel forging shall be performed in compliance with the accepted MPS. Each forged product shall be hot worked as far as practicable, to the final size with a minimum reduction ratio of 4:1.

b) The work piece shall be heated in a furnace to the required working temperature.

c) The working temperature shall be monitored during the forging process.

d) If the temperature falls below the working temperature, the work piece shall be returned to the furnace and re-heated before resuming forging.

e) The identity and traceability of each work piece shall be maintained during the forging process.

f) Weld repair of forgings is allowed only if all of the following are met:

- agreement between the manufacture and purchaser;
- a specific and qualified weld procedure is developed for the repair;
- the forging fatigue life is re-evaluated as fit-for-service with the repair weld (i.e. weld versus base metal S/N curves).

#### 7.10.1.2 Testing

Destructive testing shall be performed according to the component specification. A full-thickness prolongation representative of the thickest section of a production forging or extrusion should be used or an extra forging should be sacrificed. The extent of testing to be performed during production should be as per product specification. Testing can include chemical composition, tensile, Charpy impact, fracture toughness, hardness, and metallography.

### 7.10.2 Structural Riser Components

Structural riser components are defined as components that are not pressurized or welded to pressurized riser components. Some examples of structural riser components are buoyancy cans, tensioners, porches, pull tubes, etc.

Structural riser components should satisfy the requirements of specified material standards, such as ASTM A36, ASTM A516 and ASTM A537, and API 2H, API 2W and API 2Y.

Fabrication of structural riser components should be consistent with specified structural design codes, such as API 2A-WSD.

Welding of structural riser components should be consistent with specified structural welding codes, such as AWS D1.1.

### 7.10.3 Bolting

Carbon and low-alloy steel bolts and nuts for pressure-containing and main structural applications shall be selected in accordance with Table 6.

**Table 6—Carbon and Low-alloy Steel Bolts and Nuts for Pressure-bearing or Main Structural Applications**

| Temperature Range °C | Bolt | Nut | Size Range |
|---|---|---|---|
| –100 to +400 | ASTM A320, Grade L7/L7M | ASTM A194, Grade 4/S | <65 mm |
| –46 to +400 | ASTM A193,Grade B7/B7M | ASTM A194, Grade 2H | <65 mm |
| –100 to +400 | ASTM A320, Grade L43 | ASTM A194, Grade 7 | <100 mm |

When bolts and nuts are to be used at elevated temperature, the need for strength de-rating shall be considered.

UNS N06625 (Alloy 625) is applicable as subsea bolting material without cathodic protection but should only be used in the solution annealed or annealed condition (ASTM B446) or cold-worked to SMYS 550 MPa maximum, unless exposure to cathodic protection can be excluded. Restrictions for sour service according to NACE MR0175/ISO 15156 shall apply when applicable.

To restrict damage by HISC for low alloy and carbon steels, the hardness for any bolts and nuts to receive cathodic protection shall not exceed 350 HV, as specified for the standard grades in Table 6. The same restriction shall apply for solution annealed or cold-worked type AISI 316 austenitic stainless steel and any other cold-worked austenitic alloys. Precipitation hardening Fe-base or Ni-base alloys, duplex and martensitic stainless steels should not be specified as bolting material if subject to cathodic protection. The hardness of bolts and nuts shall be verified for each lot (i.e. bolts of the same size and material, from each heat of steel and heat treatment batch).

Mechanical tests shall be taken from the final fastener products in accordance with requirements of specified product standard when:

— the fasteners are produced by forming (e.g. headed fasteners produced by upsetting or forging, hot or cold),

— the fasteners have been subject to heat treatment, or

— nominal thread size falls into a different diameter range than the starting bar.

All fasteners used in the subsea systems shall be certified in accordance with ISO 10474 Type 3.1B or EN 10204 Type 3.1. All individual fasteners shall have marking traceable to the representative material certificate. For fasteners manufactured directly from bars, material certificates shall be attached to intermediate and final manufacturer's certificates.

Traceability of fasteners for each connection and the fasteners material certificates shall be maintained and included in the as-built documentation. The individual identification shall be visible on the fastener after installation as far as practically possible.

Any coating of bolts shall be selected with due considerations of how such coatings affect stud tensioning and as-installed properties.

NOTE There have been concerns that hot-dip zinc coating can cause loss of bolt tensioning and that polymeric coatings can prevent efficient cathodic protection. PTFE coatings have low friction coefficient and the torque has to be applied accordingly.

#### 7.10.4 Syntactic Foam Buoyancy

Buoyancy materials should be selected to provide the required buoyant lift over the intended design life. See API 16F for specifications on marine drilling riser equipment.

Syntactic foam exhibits a progressive buoyancy loss due to water absorption over time. The rate of buoyancy loss is inversely related to the strength and density of the syntactic foam. Typically, heavier or stronger syntactic foam materials are required for service at greater depths and over longer periods in service. Selection of particular syntactic foam should be based on test data.

#### 7.10.5 Coatings

##### 7.10.5.1 Coating Selection

External coating selection shall take into account the following:

— tensile strength, elongation, flexibility, adhesion, resistance to disbanding, abrasion and impact resistance;

— compatibility with temperature and pressure requirements;

— thermal insulation requirements;

— compatibility with environmental and biofouling requirements;

— ease of repair, resistance to mechanical damage and compatibility with the cathodic protection systems.

NOTE For guidance on preparation of manufacturing specifications, testing and acceptance criteria for coating systems refer to DNV-RP-F106.

#### 7.10.5.2 Insulation Coating Systems

Insulation systems can be required to improve flow assurance. Component specifications shall indicate if insulation is required and the necessary thermal and mechanical properties taking into account the following.

a) Whether directly applied to the surface, pipe-in-pipe or active heating;

b) The effect of compression, creep, densification and water adsorption on selected thickness;

c) Qualification testing with emphasis on cathodic disbondment, simulated service tests, bend tests, adhesion tests, shear/compressive strength and the U value determination;

d) Method of installation, i.e. S-lay, J-lay, or reeled. The following should be considered in the selection process:

- lay tension capabilities of each vessel;
- sag and overbend stresses;
- reeling of large diameter pipelines (plasticity and ovalization);
- field joints (complexity of field joints and application times);
- annulus gap between inner and outer pipe (pipe-in-pipe).

## 7.11 Manufacture, Welding and Fabrication

### 7.11.1 General

The manufacturer should implement a system covering all aspects of the welding specification and quality control involving competent personnel with defined responsibilities. See API Q1, Section 6.2.2.

Material traceability should be maintained during all stages of manufacturing and fabrication.

Dimensional tolerances and surface roughness during manufacture and fabrication should comply with those assumed in the design analysis of the riser system.

All defects and deficiencies should be corrected before structural components are painted, coated or otherwise made inaccessible.

The fabricator should establish and use a consistent weld numbering/identification system for systematic weld identification on all relevant drawings and as reference in all documentation.

### 7.11.2 Welding Procedure Specifications

Welding procedure specifications should be established in accordance with EN 288-2, API 1104, ASME BPVC, Section IX, DNV-OS-F101, or equivalent codes.

### 7.11.3 Qualification of Welding Procedures

Welding procedures for steel should be qualified in accordance with EN 288, API 1104, ASME Section IX, DNV-OS-F101 or equivalent codes.

Mechanical testing should be performed as specified in ASME BPVC, Section IX, API 1104, EN 288 (all parts) or equivalent codes and the additional requirements in this part of 7.11.3.

The test weld should be 100 % examined for both surface and volumetric defects with the relevant NDT methods.

NDT of qualification welds should not be performed until at least 24 hours have elapsed since the completion of welding. This time delay may be reduced subject to agreement, provided that welding processes with low content of hydrogen are used, adequate handling of welding consumables is verified and measures such as post-heating of the weldments are taken to control hydrogen content.

#### 7.11.4 Fatigue Performance of Girth Welds

Welding procedure specification and qualification shall produce girth welds whose fatigue performance meets or exceeds the S-N fatigue curve selected for design.

Proposed welding procedure performance shall be demonstrated by either fatigue testing of small-scale strip tests or by full-scale fatigue testing. This requirement may be waived subject to either of the following conditions being satisfied:

— required weld performance is consistent with workmanship quality welding (for example DNV F3 curve).

— the welding procedure has been previously qualified for fatigue performance, is fully documented and is accepted by the operator and an independent, qualified third-party as demonstrating equivalent performance for the intended service.

NOTE 1 Fatigue test data should demonstrate the intended S-N fatigue performance based on a 95 % confidence interval.

NOTE 2 The mean S-N curve should exceed the design curve by at least two (2) standard deviations.

S-N curves with two slopes may be considered, however the verification should provide adequate data to demonstrate the change of the slopes.

If a novel welding procedure is selected, the fatigue performance should be qualified. The number of test specimens should be adequate to derive the mean and design S-N curve with 95 % confidence.

Specimen quality for fatigue testing should be representative of that expected to be attained under actual production. All fatigue test specimens should be inspected by NDT to the same requirements as specified for the production welds and meet the same NDT acceptance criteria established prior to being tested. For girth welds of risers subject to >0.5 % nominal strain in any direction during installation or in-service conditions, fatigue testing should be carried out after application of representative cycles of straining.

For girth welds designed to operate in a $H_2S$ and/or $CO_2$ environment, additional testing to assess the effect of the environment on fatigue performance should be performed.

#### 7.11.5 Strength Requirements for Strain-based Design

For strain-based design, as defined in 7.7, overmatching the strength of welds relative to base material is important. Maximum specified yield strength of the base material should be less than the yield strength of the weld metal. Weld metal should be batch tested to determine all weld metal yield and tensile strengths.

#### 7.11.6 Qualification of Welders and Welding Operators

Welders and welding operators should be approved to ASME BPVC, Section IX, API 1104, EN 287-1/ISO 9606-1, EN 1418 as applicable or equivalent codes.

#### 7.11.7 Welding Consumables

Welding consumables should be suitable for their intended use with the parent metals, the welding processes and the fabrication conditions, giving welds with the required properties and corrosion resistance in the final condition. Welding consumables should comply with a recognized standard. Welding consumable materials should be selected such that the weld metal satisfies the mechanical properties as specified for the welding procedure specification.

Maximum hydrogen content of coated consumables should be stipulated. In the selection of welding consumables, consideration should be given to corrosion properties and properties after post-weld heat treatment.

If sour service is specified, the chemical composition of welding consumables should comply with NACE MR0175/ISO 15156 (all parts).

All welding consumables should be stored and treated in accordance with specified requirements.

#### 7.11.8 Material Receipt, Identification and Tracking

All material should be inspected for damage upon arrival. Quantities and identification of the material should be verified and preserved during handling, storage and all fabrication activities. Damaged items should be clearly marked and disposed of properly.

Items should be inspected for loose material, debris and other contamination and cleaned internally before being added to the assembly. The cleaning method should not cause damage to any internal coating.

A tracking system should be used to maintain records of the various components and welds.

#### 7.11.9 Cutting

Local effects on material properties and carbon contamination by thermal cutting should be controlled. Preheating of the area to be cut can be required. Carbon contamination of the affected area should be removed.

#### 7.11.10 Forming of Materials

Forming of plates, pipes, etc. should be carried out according to a specification outlining the successive and controlling steps. The forming specification should be qualified by destructively testing a qualification sample. Essential variables for the qualification test should be established and should include heating and heat treatment temperatures and total strain. The effects of strain aging should be addressed.

The specified mechanical properties should be attained in the final condition of all components.

#### 7.11.11 Properties After Forming and Heat Treatments

For materials subjected to heat treatment, hot or cold forming, welding, coating involving high temperatures or other processes that can affect the material properties, compliance with the specified requirements in the final condition should be documented. Documentation should be provided for parent material and, in case of welded components, for weld metal and heat-affected zones.

Suitable allowances for possible degradation of the mechanical properties of a material, e.g. as a result of subsequent fabrication activities, should be addressed in the specification.

#### 7.11.12 Welding Preparation and Fit-up

Mill scale, rust, etc. should be cleaned from the weld bevel area prior to welding, and the groove should be dry and clean. The fit-up should be checked before welding. The root gap and root high-low should be measured and recorded to demonstrate conformance with the welding specification.

Pipe and components should be supported in such a way that excessive stressing of the welds due to shrinkage during welding is avoided.

Radial offsets and out-of-squareness of pipe abutting ends should be minimized, for example by rotating the pipe until the best possible fit has been obtained.

Dimensional requirements at pipe ends and fit-up tolerances for fatigue-sensitive locations should be consistent with design requirements.

#### 7.11.13 Cladding

Cladding is a material of dissimilar chemical composition metallurgically bonded to a structural material surface for improved corrosion protection and/or wear resistance. Cladding in this section is in reference to the metallurgical bond of corrosion resistant alloy (CRA) to the substrate for corrosion protection. Clad welds are girth welds of two pipes with internal cladding.

The properties of the clad material and clad-steel interface should be qualified for the intended service.

The additional wall thickness caused by cladding may be used in strength calculations only if it is permitted by industry guidelines, or qualified by appropriate testing and/or conservative finite element analyses.

The effective depth of cladding is the depth to which the specified chemical composition is achieved below the final surface finish (e.g. as welded, after machining, etc). Chemical samples should be removed below the specified minimum effective depth during qualification to verify the chemical composition is adequate for corrosion protection.

Welding consumables should have less than 5 mL/100 g of diffusible hydrogen with proper storage techniques. Welding consumables should conform to AWS A5.14 for CRA consumables and include a materials test report (MTR). The maximum hardness for both the surface of the cladding and the interface with carbon steel pipe should be in accordance with NACE MR0175/ISO 15156 (all parts) for non-sour or sour service. Visual inspection and either magnetic particle or dye penetrant testing should be done after the overlay procedure. All surface breaking flaws should be removed.

During tacking and girth welding of clad pipe, the oxygen content of the backing gas should be measured and controlled to be less than 500 ppm until the weld thickness is a minimum of 10 mm. Welding consumables should conform to AWS A5.14 for CRA consumables and include a MTR. The MTR should provide the actual mechanical testing results for each lot of the consumables. A procedure should be developed for handling, storing, and identifying welding consumables.

The maximum hardness of the clad welds should be in accordance with NACE MR0175/ISO 15156 (all parts) for sour service.

CRA bends should be qualified to ISO 15590-1. Corrosion testing should be performed on bends with the surface in the as finished condition for production (e.g. ASTM G48 for duplex and nickel alloys). If a gauging tool is used to check the ID dimensions of a pipe, the gauge should not be fabricated with carbon steel materials to prevent contamination of the corrosion resistant cladding. Acceptable materials are stainless steel or corrosion resistant material similar to the cladding.

NOTE Other types of CRA linings such as mechanically-lined pipe should only be considered after substantial qualification testing.

#### 7.11.14 Heat Treatment After Forming and Welding

Heat treatment should be performed in accordance with written manufacturing procedure specifications that describe the control of the parameters critical for the heat-treatment process. The heat treatment specification should be qualified by destructively testing qualification samples representative of the final product. The specified mechanical properties should be attained in the final condition of all components. Essential variables for the qualification test should be established and should include heating and heat treatment temperatures and total strain (e.g. for induction bending), as applicable. Essential variables and acceptable ranges for the essential variables should be agreed between manufacturer and purchaser.

## 7.12 Examination and Non-destructive Testing (NDT)

### 7.12.1 General

NDT should be chosen consistent with the method's ability to detect and size applicable imperfections for the material, geometry and welding process used. As the NDT methods differ in their limitations and/or sensitivities, combinations of two or more methods may be required to ensure reliability.

The preferred method for detection of surface imperfections in ferromagnetic materials is magnetic particle inspection (MPI). The preferred method for detection of surface imperfections in non-magnetic materials is dye penetrant examination. MPI should use the wet fluorescent method consistent with existing standards, such as ISO 9934. The surface condition of the component being examined using MPI or dye penetrant should be sufficiently smooth to reliably detect flaws smaller than the associated acceptance criteria, as shown in the applicable component specification.

For detection of internal imperfections, either UT and/or radiographic examination should be used. It may be necessary to supplement radiographic testing with UT or vice versa to enhance the probability of detection or characterization/sizing of flaws.

UT examination should be used when it is necessary to know height and length of planar imperfections, e.g. to be consistent with fracture mechanics assessments.

Alternative methods or combinations of alternative methods for detection and sizing of imperfections may be used if it is demonstrated that they are capable of detecting and sizing imperfections with an acceptable equivalence to the preferred methods.

Detailed procedures for all visual examinations and NDT consistent with existing product standards and codes, as applicable, should be drafted.

Load bearing attachment welds onto the surface of a rolled product should be examined using UT for laminar tearing.

All NDT should be documented in such a way that the tested areas can be easily confirmed later.

### 7.12.2 Personnel Qualifications

All personnel involved in visual examination should be qualified and certified in accordance with recognized standards, consistent with relevant specifications.

Personnel responsible for NDT activities should be qualified according to ISO 9712, ASNT SNT-TC-1A (Level 3), or equivalent.

NDT operators should be qualified according to ISO 9712, ASNT SNT-TC-1A (Level 2), or equivalent. NDT equipment operators holding Level 1 qualifications may participate in NDT examination if under the direct supervision and responsibility of Level 2 operators.

#### 7.12.3 Visual Examination and NDT of Welds

Completed welds should be subjected to visual examination and NDT during manufacture and fabrication. The following should be applicable to all welded joints.

a) Welded joints should be visually examined before other NDT is performed.

b) All girth welds in riser pipe and other tubular riser components should undergo 100 % volumetric (UT and/or radiographic, as applicable) examination.

c) For girth welds in fatigue sensitive service, UT examination should be considered to address potential for planar flaws in the weld root region.

d) NDT should be carried out on the weld in the final heat-treated condition.

e) All NDT and visual examination should be documented such that the examined areas can be easily identified and such that the performed testing can be reliably repeated. The reports should identify all indications present in the weld area and state whether or not the weld satisfies the acceptance criteria.

f) AUT of clad welds should be qualified with the same CRA cladding and thickness as used during production. The AUT system should demonstrate the ability to detect and accurately size length and vertical height of indications with a resolution compatible with the applicable acceptance criteria using a qualified system. The AUT system should be calibrated throughout the production process. Defects in the ends of the CRA pipe should be accounted for to assist in determining if the flaw is located in the weld or in the ends.

#### 7.12.4 Acceptance Criteria

Acceptance criteria for NDT methods should be established either from results of fracture mechanics analyses (fit-for-purpose approach, for AUT only), or from workmanship criteria (see 5.4.4.3), on the basis of recognized industry standards, such as API 1104 or DNV-OS-F101 and DNV-OS-F201. The acceptance criteria should be adapted to the selected inspection systems and take into account their sizing accuracy and reliability.

# 8 Fabrication and Installation

## 8.1 General

### 8.1.1 Purpose

This section provides minimum requirements and general guidance for the fabrication and installation of marine riser systems. Fabrication and installation requirements and guidelines discussed in this section are primarily intended to address quality assurance/quality control (QA/QC) and installation practices that ensure riser systems are fabricated and installed in a safe manner and in compliance with the design and regulatory requirements. Guidelines for verifying that installed riser systems meet design requirements are also presented.

### 8.1.2 Scope

Marine riser systems discussed in this section include top tension risers (TTR), steel catenary risers (SCR) and hybrid risers. As used in this section, fabrication refers to all machining, welding, coating, testing, QA/QC, and other activities required to manufacture a riser system. Installation includes land transportation to an offshore marshalling site, marine shipping to the installation site, and marine installation operations. See API 17B for installation of flexible pipe risers and components of flexible pipe risers.

## 8.2 Fabrication

### 8.2.1 QA/QC

Prior to commencing fabrication, a QA/QC plan shall be developed. The QA/QC plan shall:

- describe the quality system in accordance with a recognized industry standard;
- define procedures for processing non-conformances including root cause evaluation and corrective action. Any occurrence of non-conformities shall be investigated to determine the root cause. Corrective action shall be taken to address the non-conformity and prevent further occurrences;
- set forth the requirements for inspection and test plans (ITP).

Each ITP shall include the following:

- breakdown of tasks;
- specification requirements;
- inspection intervals;
- third party inspection notification points.

The frequency and nature of inspection shall be sufficient to ensure the specified requirements are achieved.

### 8.2.2 Documentation

During fabrication, the following records shall be maintained as applicable:

- material certified mechanical test reports;
- dimensional logs;
- welding records;
- non-destructive examination (NDE) records;
- coating records;
- welder qualification records and inspection personnel qualification records;
- serialization/traceability records;
- hydrostatic test records;
- qualification test records;
- non-conformance reports.

These records shall be submitted to the operator as part of the fabrication documentation package.

### 8.2.3 Acceptance Testing

#### 8.2.3.1 Girth Weld Fatigue

Where girth welds are subjected to fatigue loading, full-scale fatigue testing, as part of the weld procedure qualification shall be performed to demonstrate the welding procedure delivers welds meeting design requirements. See 7.11.4 for information on qualification testing.

#### 8.2.3.2 Riser Component Qualification

Riser components such as riser connectors, tieback connectors, tensioners, VIV suppression devices, buoyancy modules, instrumentation modules, coatings, including field joint coatings, etc. shall be demonstrated as fit-for-purpose and compatible with the installation methods.

#### 8.2.3.3 NDE System Qualification

The NDE system used for weld inspection shall be qualified to demonstrate that the design tolerances for flaw size and probability of detection are met. The qualification shall use production material (pipe and forgings) and weld configuration. The calculated weld flaw acceptance criteria shall be adjusted to accommodate the NDE sizing tolerance determined during this qualification testing. Details for qualification criteria are given in 7.12.

## 8.3 Transportation, Shipping and Marine Operations

### 8.3.1 Installation Analysis

#### 8.3.1.1 Installation Load Cases

Installation and transportation load cases shall be identified for the proposed installation methods. Analysis shall be performed for these load cases as applicable.

#### 8.3.1.2 Installation Limit Conditions

Installation and transportation analysis shall be performed to determine as applicable the maximum seastate or installation vessel motion, current profiles and wind profiles in which the required operations can be conducted while meeting strength and fatigue requirements as outlined in 8.3.1.3. Different limit conditions can be selected for various stages in the operation, depending on the duration of the installation operations and the consequences of exceeding the selected conditions.

#### 8.3.1.3 Strength and Fatigue Evaluation

Strength analysis shall be conducted to verify that stress and strain levels remain within allowable limits throughout all of the transportation and installation operations. This strength analysis shall consider all loading conditions; e.g. lifting, reeling, towing, upending and stalking.

Depending on the type of riser and method of transportation, dynamic analysis shall be conducted to determine that the fatigue damage due to transportation and installation meets specification requirements. The risers shall be analyzed for installation conditions with varying amounts of riser deployed.

### 8.3.2 Risk Assessment

#### 8.3.2.1 Risk Management Plan

A risk management plan shall be prepared to identify, describe, communicate and document the objectives, responsibilities and activities specified for assessing and reducing risk to as low as reasonably practical (ALARP).

The plan shall reflect the criticality of the riser system, the criticality of planned operations, and previous experience with similar systems or operations.

Risks should be assessed against criteria for

— personnel safety,

— environment,

— assets and/or lost production, and

— reputation.

Defined criteria shall comply with project policies, and be specific for each of the areas above. The risk management plan shall ensure that risk assessments are reviewed and updated in accordance with the change management process.

It is the role of the risk assessment process to highlight critical activities and items such as:

— lifting and handling procedures;

— dropped objects/impact loads;

— snagging;

— simultaneous operations.

#### 8.3.2.2 Risk Assessment Methodology

Risk assessment methodology shall follow industry-recognized processes such as quantitative risk analysis (QRA), failure mode and effect analysis (FMEA) or hazard and operability (HAZOP) assessment. These provide an estimation of the overall risk to human health and safety, environment and assets and shall consider:

— hazard identification;

— assessment of probabilities of failure events;

— consequence of failure;

— risk assessment.

NOTE Additional guidance for performing risk assessment for marine and subsea operations can be found in ISO 17776 and DNV-RP-H101.

### 8.3.3 Transportation and Handling Plan

A plan documenting procedures for safe and efficient packaging, transport and handling of the riser components shall be developed based on industry codes and recommended practices. This plan shall include:

— requirements for packaging to prevent handling damage;

— preservation requirements for short and long term corrosion protection;

— requirements for the type of transport vehicle/vessel;

— consideration of transport vessel motions;

— deck loads and deck space requirements;

— lay down areas;

— weight, length and diameter of components to be shipped;

— location of lift points;

— recommended lifting and handling equipment;

— crane capacities and reaches at load, derrick capacities, and clearances;

— layout and method of securing riser components on the trucks, barges, supply boats, etc.

Transportation of line pipes by railroad shall meet the provisions of API 5L1. When line pipes are transported on barges and marine vessels provisions of API 5LW shall apply.

#### 8.3.4 Installation Procedures

##### 8.3.4.1 Installation Manual

Installation shall be according to a documented procedure; any deviation outside the established procedures shall be subject to a management of change process.

Procedures shall be supported by engineering calculations, qualification of personnel and processes, and qualification of equipment and installation vessels.

The installation contractor shall prepare an installation manual documenting all procedures required to meet the design requirements in a safe and efficient manner. The manual shall include the following:

— planned installation procedures;

— procedures and processes covering contingency situations;

— procedures for emergency conditions;

— limiting environmental conditions;

— weather window for completing operations;

— quality assurance activities such as inspection, witness/hold points;

— design and operational limitations;

— health, safety and environmental issues;

— responsibilities and communication procedures.

Contingency procedures shall consider the following, as applicable:

— weather conditions in excess of the operating limit conditions;

— ballast system breakdown or partial failure;

— loss of towing tension;

— excessive towing tension;

— third party marine activities;

— buckling and subsequent flooding of the riser;

— failure of vessel station keeping system;

— failure of tensioner system;

— ROV breakdown;

— other critical or emergency situations identified in FMEA analysis or HAZOP studies.

#### 8.3.4.2 Towing

When towing is employed for riser installation, consideration shall be given to the following:

— interactions with third party marine activities during launch and tow;

— risk of riser damage during launch activities;

— tow distance and operating limit conditions with regard to weather window for the tow;

— towing speed and tension capacity of the tow vessel;

— fatigue damage of the riser due to interaction with the waves and current;

— control of weight and buoyancy distribution;

— ballast control during tow;

— ballast control during installation and upending;

— tow depth and hydrostatic collapse pressure of the riser;

— risk of interaction with the seabed and seabed objects including third party infrastructure;

— risk of buckling the riser pipe during upending.

Towing shall not commence unless an acceptable weather window for the tow is available. Notification of the tow shall be given to the relevant authorities, owners of subsea installations crossed by the towing route and users of the sea.

Tension in the towing line and the towing depth shall be kept within the specified limits during the tow. Where required, ballasting or de-ballasting may be performed to adjust the towing depth to the specified values.

NOTE For additional guidance pertaining to installation by towing, refer to DNV-OS-F101, Section 10 F.

#### 8.3.4.3 Reeling

SCRs installed using the reel-lay method can be welded onshore. The following procedures shall be developed when reeling is used as the installation method:

— load-out/spooling of pipe onto reel;

— pipe straightening;

— installation of ancillary equipment, i.e. anodes, VIV suppression, instrumentation, etc.;

— installation, welding and NDT of sections requiring alternate installation methods, e.g. in-line structures.

A riser that is reeled onto a spool can be subjected to large plastic strains. When two abutting pipe joints have dissimilar tangential stiffness, e.g. due to different wall thicknesses or varying material properties, a discontinuity occurs. The result of this is a concentration of compressive strains in the softer joint in an area close to the weld. For guidance pertaining to installation by reeling, refer to DNV-OS-F101, Section 10 F.

#### 8.3.4.4 S- or J-lay

During S- or J-lay installation the overall riser configuration shall be monitored for all relevant parameters. Typical parameters should include riser tension, departure angle, touchdown point and vessel heading. A risk assessment shall be conducted to evaluate a flooded riser scenario, including an evaluation of whether tensioners (if used) can hold on to flooded riser and whether the A&R system is sized to safely lower a flooded riser.

In case of tensioner failure or failure in the tensioner system, the riser installation shall not re-start before the system has been repaired.

The abandonment and recovery (A&R) system shall be able to recover the riser when water filled, or alternative methods for recovering the riser shall be available.

NOTE For additional guidance pertaining to installation, refer to DNV-OS-F101, Section 10.

#### 8.3.4.5 TTR Installation (Stalking)

TTRs are normally deployed from the floating production facility with a derrick and pipe-handling system. Riser joint dimensions and weight limitations shall be considered in design of the pipe handling.

The following shall be considered in the installation of TTRs:

— special running and handling tools;

— space out requirements, where special segments can be used in the riser string to achieve a specific overall length between desired connection points;

— accessories that must be attached to the riser during running, e.g. buoyancy modules, anodes, or VIV suppression devices;

— the method(s) used to guide the risers to the sea floor;

— interference with other risers, mooring lines and other obstructions during installation;

— motion compensation requirements that might be required during running and landing phases;

— support vessels, including ROVs that might be needed for deployment.

### 8.3.5 Installation Documentation and Verification

#### 8.3.5.1 As-built Documentation

The as-built documentation shall be prepared post installation. The as-built documentation can include, for example:

— summary of installation scope;

— key drawings of the riser system including extent, main interfaces, configuration, boundary conditions, main dimensions and main components;

— welding program details, including a weld map;

— QA/QC program details, specifically including NDE program details;

— incidents that occurred during installation;

— acceptance criteria and evaluation results;

— dimensional control adherence;

— as-installed surveys and drawings;

— confirmation of compliance with the design specifications and the approved fabrication plan including any approved deviation from the design specifications and the approved fabrication plan;

— as-built data book.

#### 8.3.5.2 System Pressure Test

Riser systems that are considered part of the pipeline shall be pressure tested as per the requirements of API 1111 or DNV-OS-F101. Where riser system components are proof tested during fabrication, a leak test to maximum allowable operating pressure (MAOP) shall be sufficient for the system pressure test.

#### 8.3.5.3 TTR and Hybrid Riser Tension Setting

Riser tensions shall be verified upon completion of installation and monitored on a regular basis. Tension can be measured, for example, directly through load cells or strain gages or indirectly by measuring pressure in tensioner cylinders or buoyancy can chambers.

Tension monitoring (or installation) calculations should be submitted to the company for approval before actual installation takes place.

#### 8.3.5.4 SCR Configuration

Post installation survey for SCR's may be required. This can include:

— touchdown point location;

— departure angle of the riser at the floater interface;

— SCR lengths, lay azimuth;

— location of buoyancy modules/weight modules;

— VIV suppression coverage.

Deviations from the design specification shall be noted and as-built re-analysis conducted as deemed necessary.

#### 8.3.5.5 Hybrid Riser Configuration

Post installation survey for hybrid risers shall be performed to verify the following, as applicable:

— tank depth and ballast system configuration;

— tension;

— orientation and inclination;

— jumper configuration;

— riser base configuration.

# 9 Riser Integrity Management

## 9.1 Introduction

A riser integrity management program shall be developed and implemented (see API 75). Riser integrity management is a continuous process of knowledge and experience management applied throughout the lifecycle to assure that the riser system is managed cost effectively and safely and remains reliable and available, with due focus on personnel, asset, operations and environment.

NOTE Risers are critical equipment as defined in API 75.

The integrity management program should require that procedures are in place and implemented so that risers are designed, fabricated, installed, tested, inspected, monitored, and maintained in a manner consistent with appropriate service requirements, manufacturer's recommendations, or industry standards. The scope of the integrity management program should be defined by the operator.

Many national authorities have specific requirements for integrity management (IM) activities. These can be in the form of minimum requirements for documentation of risk and risk reducing measures, such as which documents are to be presented to the authorities and mandatory use of standards. The authorities can also have requirements for integrity management activities, such as roles and responsibility, content and form of verification activities, terminology, minimum inspection scope, periodicity of inspections, and condition monitoring. The particulars of the relevant national requirements shall be observed when planning and performing riser integrity management.

## 9.2 Riser Integrity Management Plan

A systematic, objective and repeatable process is recommended for developing and implementing an integrity management plan for a riser field system. The plan should include the following elements:

— identification of failure modes and failure drivers

— risk assessment

— barrier and mitigation measures

— inspection and monitoring

— maintenance

— riser life extension and accommodation of changes in design conditions

The riser integrity management plan should consider the following documents:

— design basis;

— design reports;

— fabrication records;

— installation records.

As a minimum, TTR and hybrid riser tension shall be monitored at regular intervals during field life.

# Annex A
(informative)

# Example TTR Design

## A.1 Introduction

This annex gives an example of using burst and collapse equations from 5.3 to size the riser pipes for a top-tensioned dual-casing riser. The sized pipes are used to build a finite element model for evaluating riser response loads under several environmental conditions. Combined loads obtained from the finite element analysis are checked using Method 1 through Method 4 in 5.4. The main purpose of this annex is to provide an example application of the equations listed in 5.3 and 5.4. Users are encouraged to follow sound engineering judgment and a consistent methodology in performing riser analysis for obtaining the riser response loads for combined load check of 5.4.

The design of the production tubing for TTRs is the responsibility of completion engineers who often use operator's internal design guidelines. The example given in this annex does not cover checking tubing strength with the design equations given in 5.3 and 5.4. However, the interactions between tubing and inner and outer risers shall be captured by the user of this document. The finite element model built for this example considered the axial stiffness and bending stiffness of the tubing as part of the composite riser model. The composite finite element used to model the TTR implies that there shall be sufficient centralizers placed between tubing and inner riser in high curvature areas to prevent excessive local bending of the tubing. The curvature captured in the high bending areas from the composite model should be provided to the tubing designer for tubing strength check.

## A.2 Load Cases

Table A.1 lists example load cases for a top-tensioned production riser. Each functional mode combines operational environments and mooring conditions to define the cases.

**Table A.1—Production Riser Load Case Matrix**

| Load Case | Description | | | Limit State |
|---|---|---|---|---|
| 1 | Pressure test of outer casing (no environment, mooring Intact) | | | |
| | TTF =1.4 (See A.6.2 for TTF definition) | | | SLS |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m3 / 20.6 MPa (8.56 ppg / 3000 psi) | Not carried | Not carried | |
| 2 | Pressure test of inner casing (no environment, mooring intact) | | | |
| | TTF =1.4 | | | SLS |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0 MPa (8.56 ppg / 0 psi) | 1026 kg/m$^3$ / 37.9 MPa (8.56 ppg / 5500 psi) | Not carried | |
| 3 | Pressure test of tubing (no environment, mooring intact) | | | |
| | TTF =1.4 | | | SLS |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0 MPa (8.56 ppg / 0 psi) | 23.9 kg/m$^3$ / 0 MPa (0.2 ppg / 0 psi) | 1026 kg/m$^3$ / 37.9 MPa (8.56 ppg /5500 psi) | |

| Load Case | Description | | | Limit State |
|---|---|---|---|---|
| 4 | Completion/workover with BOP (10-yr-hurricane, mooring intact) | | | SLS |
| | TTF =1.4 | | | |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0 MPa (8.56 ppg / 0 psi) | 1857 kg/m$^3$ / 0 MPa (15.5 ppg / 0 psi) | Not carried | |
| 5 | Normal producing (100-yr-winterstorm, mooring intact) | | | ULS |
| | TTF =1.4 | | | |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0.69 MPa (8.56 ppg / 100 psi) | 23.9 kg/m$^3$ / 0.69 MPa (0.2 ppg / 100 psi) | 779 kg/m$^3$ / 20.6 MPa (6.5 ppg / 3000 psi) | |
| 6 | Shut-in (100-yr-winterstorm, mooring intact) | | | ULS |
| | TTF =1.4 | | | |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0.69 MPa (8.56 ppg / 100 psi) | 23.9 kg/m$^3$ / 0.69 MPa (0.2 ppg / 100 psi) | 779 kg/m$^3$ / 37.9 MPa (6.5 ppg / 5500 psi) | |
| 7 | Shut-in with inner annulus evacuated (10-yr-hurricane, mooring intact) | | | ULS |
| | TTF =1.4 | | | |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0.69 MPa (8.56 ppg / 100 psi) | 0.0 kg/m$^3$ / 0 MPa (0 ppg / 0 psi) | 779 kg/m$^3$ / 37.9 MPa (6.5 ppg / 5500 psi) | |
| 8 | Shut-in with tubing leak (10-yr-hurricane, mooring intact) | | | ALS |
| | TTF =1.4 | | | |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0.69 MPa (8.56 ppg / 100 psi) | 778.9 kg/m$^3$ / 37.9 MPa (6.5 ppg / 5500 psi) | 779 kg/m$^3$ / 37.9 MPa (6.5 ppg / 5500 psi) | |
| 9 | Completion / workover with BOP (100-yr-hurricane, mooring intact) | | | ULS |
| | TTF =1.4 | | | |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0 MPa (8.56 ppg / 0 psi) | 1857 kg/m$^3$ / 0 MPa (15.5 ppg / 0 psi) | Tubing : Not carried | |
| 10 | Inner casing leak during workover with kick with BOP (no environment, mooring intact) | | | ALS |
| | TTF =1.4 | | | |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1078 kg/m$^3$ / 20.6 MPa (9 ppg / 3000 psi) | 1857 kg/m$^3$ / 20.6 MPa (15.5 ppg / 3000 psi) | Tubing : Not carried | |
| 11 | Normal producing (100-yr-winterstorm, mooring damaged) | | | ALS |
| | TTF =1.4 | | | |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0.69 MPa (8.56 ppg / 100 psi) | 23.9 kg/m$^3$ / 0.69 MPa (0.2 ppg / 100 psi) | 778.9 kg/m$^3$ / 20.6 MPa (6.5 ppg / 3000 psi) | |

| Load Case | Description | | | Limit State |
|---|---|---|---|---|
| 12 | Shut-in (100-yr-winterstorm, mooring damaged) | | | |
| | TTF =1.4 | | | ALS |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0.69 MPa (8.56 ppg / 100 psi) | 23.9 kg/m$^3$ / 0.69 MPa (0.2 ppg / 100 psi) | 778.9 kg/m$^3$ / 37.9 MPa (6.5 ppg / 5500 psi) | |
| 13 | Shut-in with inner annulus evacuated (100-yr-hurricane, mooring intact) | | | |
| | TTF =1.4 | | | ALS |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0.69 MPa (8.56 ppg / 100 psi) | 0.0 kg/m$^3$ / 0 MPa (0 ppg / 0 psi) | 779 kg/m$^3$ / 37.9 MPa (6.5 ppg / 5500 psi) | |
| 14 | Shut-in with both annuluses evacuated (100-yr-hurricane, mooring intact) | | | |
| | TTF =1.4 | | | ALS |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 0.0 kg/m$^3$ / 0 MPa (0 ppg / 0 psi) | 0.0 kg/m$^3$ / 0 MPa (0 ppg / 0 psi) | 779 kg/m$^3$ / 37.9 MPa (6.5 ppg / 5500 psi) | |
| 15 | Shut-in with tubing leak (100-yr-hurricane, mooring intact) | | | |
| | TTF =1.4 | | | ALS |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0.69 MPa (8.56 ppg / 100 psi) | 779 kg/m$^3$ / 37.9 MPa (6.5 ppg / 5500 psi) | 779 kg/m$^3$ / 37.9 MPa (6.5 ppg / 5500 psi) | |
| 16 | Completion/workover with BOP (100-yr-hurricane, mooring damaged) | | | |
| | TTF =1.4 | | | ALS |
| | OUTER CASING (density/net internal pressure) | INNER CASING (density/net internal pressure) | TUBING (density/net internal pressure) | |
| | 1026 kg/m$^3$ / 0 MPa (8.56 ppg / 0 psi) | 1857 kg/m$^3$ / 0 MPa (15.5 ppg / 0 psi) | Tubing : Not carried | |

## A.3 Production Riser Stack-up

Figure A.1 shows a sketch of the production riser stack up and elevations for a riser in 1500 m of water. The production riser is supported by a push-up style hydro-pneumatic tensioner that in turn is supported by the production platform. As shown, during production the top-tensioned riser system consists of a surface production tree, riser tensioner, keel joint, standard joints, stress joint, and a tieback connector for connecting the riser to the subsea wellhead. The riser follows the production platform motion at the support points at the tensioner and the keel joint.

## A.4 Pipe Sizing

Pipe wall sizing is an iterative process mainly involving three steps. First step involves selecting a suitable pipe internal diameter to meet the minimum drift requirements. In the second step, pipe wall is sized to meet burst and collapse checks. Finally, the third step involves checking the market availability of the selected pipe size. If the pipe is not a readily available standard pipe size then it is adjusted to match the closest available standard pipe size that satisfies the burst and collapse checks. If the project constraints do not allow adopting a standard pipe size then a special order for the required pipe size can be made with the pipe mill. The pipe size given in this example is a result of the iterative pipe sizing process, and only the finally derived pipe sizes are discussed in this section.

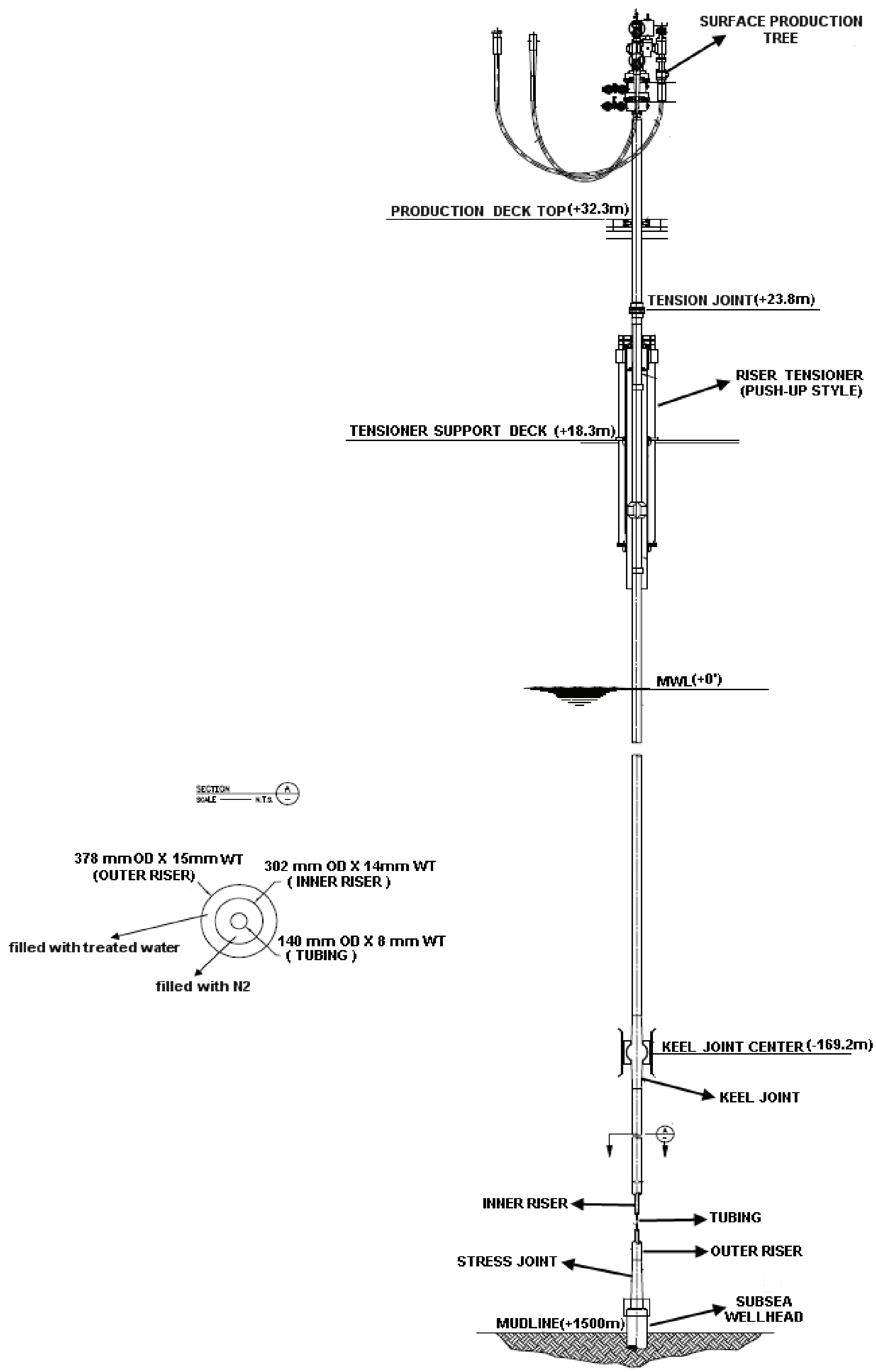



**Figure A.1—Production Riser Stack-up**

In this annex, the drift diameters of the outer and inner risers are specified as 343 mm and 269 mm. The internal diameter of the riser pipe is selected to be greater than or equal to the drift diameter plus 4.8 mm (see API 5CT). The outer and the inner risers were initially sized for 377.8 mm outer diameter × 15.1 mm wall thickness and 301.6 mm outer diameter × 14.0 mm wall thickness. Both these riser sizes meet the drift requirement of API 5CT. The riser pipe sizes and the material properties are given in Table A.2.

**Table A.2—Riser Pipe Sizes and Materials**

| Riser Pipe Type | Material | Nominal Outer Diameter $D$ | | Nominal Wall Thickness $t_{fab}$ | | Specified Minimum Yield Strength $S$ | | Specified Minimum Ultimate Strength $U$ | |
|---|---|---|---|---|---|---|---|---|---|
| | | mm | in. | mm | In. | MPa | psi | MPa | psi |
| Outer Casing | X-80 | 377.8 | 14.875 | 15.1 | 0.594 | 552 | 80,000 | 655 | 95,000 |
| Inner Casing | X-95 | 301.6 | 11.875 | 14.0 | 0.550 | 655 | 95,000 | 724 | 105,000 |
| Tubing | X-95 | 139.7 | 5.500 | 7.7 | 0.304 | 655 | 95,000 | 724 | 105,000 |

[a] Nominal wall thickness includes a 1.5 mm corrosion and wear allowance.

## A.5 Burst and Collapse Check

### A.5.1 Burst Pressure Check

Burst pressure was checked against the minimum burst pressure, as defined in Equation 1 in 5.3.2. To account for localized corrosion/wear, pipe wall thickness without corrosion/wear allowance is used in the burst pressure equation for outer and inner risers. A corrosion/wear allowance of 1.5 mm is used for both the risers. The outer riser can see a maximum internal pressure of 21 MPa at mean water level (MWL) during workover with inner riser leak (Load Case 10). Similarly, the inner riser can see a maximum internal pressure of 38 MPa during shut-in with tubing leak (Load Cases 8 and 15). As shown in Table A.3 and Table A.4, both these pressures are less than the internal overpressure limits for production riser with tubing leak given in 5.4.1. Burst pressure calculations for outer and inner risers are given in A.5.1.1 and A.5.1.2.

#### A.5.1.1 Outer Riser

To account for localized corrosion and wear, the minimum burst pressure capacity is calculated using:

$$\begin{aligned} t &= t_{\text{fab}} - t_{\text{ca}} \\ &= 15.1\text{ mm} - 1.5\text{ mm} \\ &= 13.6\text{ mm} \end{aligned}$$

Accordingly, the minimum burst pressure of outer riser pipe is:

$$\begin{aligned} p_{\text{b}} &= k \times (S+U) \times \ln\left(\frac{D}{D-2\times t}\right) \\ &= 0.45 \times (552\text{ MPa} + 655\text{ MPa}) \times \ln\left(\frac{377.8\text{ mm}}{377.8\text{ mm} - 2\times 13.6\text{ mm}}\right) \\ &= 40.5\text{ MPa} \end{aligned}$$

**Table A.3—Internal Overpressure Limits for Outer Riser**

| Condition | Design Factor $F_D$ | Allowable Internal Pressure $F_D\, p_b$ | |
|---|---|---|---|
| | | MPa | psi |
| Design pressure | 0.60 | 24.3 | 3520 |
| Incidental overpressure | 0.67 | 27.1 | 3930 |
| Production casing with tubing leak | 0.81 | 32.8 | 4760 |
| NOTE Pressure for testing the installed TTR offshore has to be checked against sub-mudline casing program. | | | |

### A.5.1.2 Inner riser

To account for localized corrosion and wear, the minimum burst pressure capacity is calculated as:

$$
\begin{aligned}
t &= t_{\text{fab}} - t_{\text{ca}} \\
&= 14.0 \text{ mm} - 1.5 \text{ mm} \\
&= 12.5 \text{ mm}
\end{aligned}
$$

Accordingly, the minimum burst pressure of inner riser pipe is:

$$
\begin{aligned}
p_{\text{b}} &= k \times (S + U) \times \ln\left(\frac{D}{D - 2 \times t}\right) \\
&= 0.45 \times (655 \text{ MPa} + 724 \text{ MPa}) \times \ln\left(\frac{301.6 \text{ mm}}{301.6 \text{ mm} - 2 \times 12.5 \text{ mm}}\right) \\
&= 53.4 \text{ MPa}
\end{aligned}
$$

**Table A.4—Internal Overpressure Limits for Inner Riser**

| Condition | Design Factor $F_D$ | Allowable Internal Pressure $F_D\, p_b$ | |
|---|---|---|---|
| | | MPa | psi |
| Design pressure | 0.60 | 32.1 | 4650 |
| Incidental overpressure | 0.67 | 35.8 | 5190 |
| Production casing with tubing leak | 0.81 | 43.3 | 6280 |

## A.5.2 Collapse Pressure Check

Collapse pressure was checked against the collapse pressure capacity due to external pressure, as defined in Equation 2 in 5.3.3.1. As for the burst pressure check, pipe wall thickness without corrosion/wear allowances is used in the collapse pressure check of outer and inner risers. Seamless pipe (fabrication factor $\alpha_{fab}$=1) with 1 % ovality and a corrosion/wear allowance ($t_{ca}$) of 1.5 mm are used in both the risers. The outer riser can see a maximum hydrostatic external pressure of about 15 MPa at the mudline during shut-in with both annuli evacuated (Load Case 14). The inner riser can see a maximum external pressure of about 16 MPa at the mudline during shut-in with inner annulus evacuated (Load Case 13). As shown in Table A.5 and Table A.6, both these pressures are less than the external overpressure limits for ALS cases given in 5.4.2. Collapse pressure checks for both outer and inner risers are given as follows.

Both the outer and inner risers have the following properties:

$$E = 207\,000 \text{ MPa}$$
$$\nu = 0.3$$
$$\alpha_{fab} = 1.00$$
$$\delta_o = 0.01$$

#### A.5.2.1 Outer Riser

To account for localized corrosion and wear, the minimum burst pressure capacity is calculated using:

$$\begin{aligned} t &= t_{fab} - t_{ca} \\ &= 15.1 \text{ mm} - 1.5 \text{ mm} \\ &= 13.6 \text{ mm} \end{aligned}$$

Using Equation 4 in 5.3.3.1, the elastic collapse pressure $p_{el}$ is calculated as

$$\begin{aligned} p_{el} &= \frac{2 \times E \times \left( t/D \right)^3}{1 - \nu^2} \\ &= \frac{2 \times 207{,}000 \text{ MPa} \times \left( 13.6 \text{ mm} / 377.8 \text{ mm} \right)^3}{1 - 0.3^2} \\ &= 21.0 \text{ MPa} \end{aligned}$$

Using Equation 6 in 5.3.3.1, the plastic collapse pressure $p_p$ is calculated as

$$\begin{aligned} p_p &= 2 \times \frac{t}{D} \times S \times \alpha_{fab} \\ &= 2 \times \frac{13.6 \text{mm}}{377.8 \text{ mm}} \times 552 \text{ MPa} \times 1 \\ &= 39.6 \text{ MPa} \end{aligned}$$

The collapse pressure $p_c$ is then found by solving Equation 5 in 5.3.3.1:

$$\left( p_c - p_{el} \right) \times \left( p_c^2 - p_p^2 \right) = p_c \times p_{el} \times p_p \times 2 \times \delta_0 \times D/t$$

$$\left( p_c - 21.0 \text{ MPa} \right) \times \left[ p_c^2 - \left( 39.6 \text{ Mpa} \right)^2 \right] = p_c \times 21.0 \text{ MPa} \times 39.6 \text{ MPa} \times 2 \times 0.01 \times \left( 377.8 \text{ mm} / 13.6 \text{ mm} \right)$$

The analytical solution of the above equation gives the collapse pressure $p_c$:

$$p_c = 15.6 \text{ MPa}$$

**Table A.5—External Overpressure Limits for Outer Riser**

| Condition | Design Factor ($F_D$) | Allowable External Pressure ($F_D$ $p_c$) | |
|---|---|---|---|
| | | MPa | psi |
| Extreme/Serviceability (ULS/SLS) | 0.70 | 10.9 | 1582 |
| Accidental (ALS) | 1.00 | 15.6 | 2260 |

### A.5.2.2 Inner Riser

To account for localized corrosion and wear, the minimum collapse pressure capacity is calculated using:

$$\begin{aligned} t &= t_{\text{fab}} - t_{\text{ca}} \\ &= 14.0\text{ mm} - 1.5\text{ mm} \\ &= 12.5\text{ mm} \end{aligned}$$

Using Equation 4 in 5.3.3.1, the elastic collapse pressure $p_{el}$ is calculated as

$$\begin{aligned} p_{\text{el}} &= \frac{2 \times E \times \left( t/D \right)^3}{1 - \nu^2} \\ &= \frac{2 \times 207{,}000\text{ MPa} \times \left( 12.5\text{ mm} / 301.6\text{ mm} \right)^3}{1 - 0.3^2} \\ &= 31.9\text{MPa} \end{aligned}$$

Using Equation 6 in 5.3.3.1, the plastic collapse pressure $p_p$ is calculated as

$$\begin{aligned} p_{\text{p}} &= 2 \times \frac{t}{D} \times S \times \alpha_{\text{fab}} \\ &= 2 \times \frac{12.5\text{ mm}}{301.6\text{ mm}} \times 655\text{ MPa} \times 1 \\ &= 54.1\text{MPa} \end{aligned}$$

The collapse pressure $p_c$ is then found by solving Equation 5 in 5.3.3.1:

$$\left( p_{\text{c}} - p_{\text{el}} \right) \times \left( p_{\text{c}}^2 - p_{\text{p}}^2 \right) = p_{\text{c}} \times p_{\text{el}} \times p_{\text{p}} \times 2 \times \delta_0 \times D/t$$

$$\left( p_{\text{c}} - 31.9\text{ MPa} \right) \times \left[ p_{\text{c}}^2 - \left( 54.1\text{ Mpa} \right)^2 \right] = p_{\text{c}} \times 31.9\text{ MPa} \times 54.1\text{MPa} \times 2 \times 0.01 \times \left( 301.6\text{ mm} / 12.5\text{ mm} \right)$$

The analytical solution of the above equation gives the collapse pressure $p_c$:

$$p_{\text{c}} = 23.6\text{ MPa}$$

**Table A.6—External Overpressure Limits for Inner Riser**

| Condition | Design Factor ($F_D$) | Allowable External Pressure ($F_D$ $p_c$) | |
|---|---|---|---|
| | | MPa | psi |
| Extreme/Serviceability (ULS/SLS) | 0.70 | 16.5 | 2395 |
| Accidental (ALS) | 1.00 | 23.6 | 3422 |

## A.6 Riser Components

### A.6.1 Riser Keel and Stress Joints

The keel joint and the stress joint are designed to accommodate high bending at the keel and at the seabed respectively. Table A.7 describes the keel joint and the stress joint sizes and materials.

**Table A.7—Riser Keel and Stress Joints**

| Joint Type | Material | Total Length | | Minimum Wall Thickness | | Maximum Wall Thickness | | Tapered Length | |
|---|---|---|---|---|---|---|---|---|---|
| | | m | ft | mm | in. | mm | in. | m | ft |
| Keel | X-80 | 20.4 | 67 | 15.1 | 0.594 | 73.7 | 2.9 | 2 × 9.1 | 2 × 30 |
| Stress | X-80 | 12.8 | 42 | 15.1 | 0.594 | 73.7 | 2.9 | 11.6 | 38 |

### A.6.2 Production Riser Tensioner Properties

In this example, the production riser is tensioned by a push-up style hydro-pneumatic tensioner. The top tension factor (TTF) is a parameter to define loads applied to the riser by the tensioning system. TTF is defined as the ratio of the tension at the tensioner attachment point to the riser wet weight hanging below the tension attachment point. Some tensioner details are given as follows:

— nominal TTF of 1.4;

— total stroke is 6.4 m;

— shall be polytropic.

NOTE The detailed design of the tensioners is described in Reference [142].

## A.7 Capacities of Outer Riser

Capacities of the outer riser are calculated from the riser properties given in Table A.2. The capacities of the outer riser are given in Table A.8.

**Table A.8—Capacities of the Outer Riser**

| Property | Symbol | Units | Value | Equation Reference | |
|---|---|---|---|---|---|
| | | | | Equation No. | Subsection |
| Burst pressure | $p_b$ | MPa<br>(psi) | 40.5<br>(5867) | (1) | 5.3.2 |
| Collapse pressure | $p_c$ | MPa<br>(psi) | 15.6<br>(2260) | (2) | 5.3.3 |
| Yield tension | $T_y$ | kN<br>(kips) | 9480<br>(2130) | (10) | 5.3.4 |
| Yield moment | $M_y$ | kNm<br>(kips-ft) | 861<br>(635) | (12) | 5.3.5 |
| Plastic moment | $M_p$ | kNm<br>(kips-ft) | 1097<br>(810) | (13) | 5.3.6 |

The calculations for burst and collapse pressures of the outer riser were shown earlier in A.5. The calculations for yield tension, yield moment and plastic moment of the outer riser are given as follows.

Yield tension $T_y$

$$
\begin{aligned}
T_y &= SA = S\pi(D-t)t \\
&= 552 \times \pi \times (377.8 - 15.1) \times 15.1 / 10^3 \\
&= 9480 \text{ kN } (2.130 \text{ kips})
\end{aligned}
$$

Yield moment $M_y$,

$$
\begin{aligned}
M_y &= \frac{\pi}{4} S(D-t)^2 t \\
&= \frac{\pi}{4} \times 552 \times (377.8 - 15.1)^2 \times 15.1 / 10^6 \\
&= 861 \text{ kNm } (635 \text{ kips-ft})
\end{aligned}
$$

Plastic Moment $M_p$,

$$
\begin{aligned}
M_p &= \frac{4}{\pi} \times M_y \\
&= \frac{4}{\pi} \times 861 \\
&= 1097 \text{ kNm } (810 \text{ kips-ft})
\end{aligned}
$$

## A.8 Combined Load Evaluation

### A.8.1 General

Static strength analysis of the riser in different load conditions is captured using snapshots of the worst motions of the production platform. Nominal pipe wall thickness is used in the analysis for both the risers.

From the analysis, the load case and the location in the riser with the highest utilization are identified. Combined loads at this location are evaluated using the methods specified in 5.4.3. Meeting any of the four methods, together with the other requirements in this standard, can lead to a safe design. Thus if any of Methods 1 through 4 have utilization factors less than 1 for all limit states, and all other requirements are met, the design has met the requirements of this standard. Users do not have to check all the four methods to conclude the design is safe. In the following example, the riser fails the combined load strength check for the Method 1 ALS Case but passes all checks for Methods 2 and 4. The designer could have stopped at Method 2.

In this example, completion/workover in 100-yr hurricane condition (ULS case) is the load case with the highest utilization, which occurs at the bottom of the keel joint. Survivability of the riser during completion/workover in a 1000-yr hurricane (ALS case) is checked. For ULS and ALS cases, loads on the outer riser at the bottom of the keel joint are obtained from the finite element analysis. These loads are evaluated using the four methods described in 5.4.3. In these cases, there is no annulus pressure in both the risers since well pressure is contained within the tubing. Pressure, bending and tension loads occurring at the bottom of the keel joint in the outer riser for ULS and ALS cases are given in Table A.9.

**Table A.9—Riser Loads at Bottom of Keel Joint**

| Riser Loads (Keel Joint Bottom) | Symbol | Units | ULS Case | ALS Case |
|---|---|---|---|---|
| Internal pressure | $p_i$ | MPa<br>(psi) | 2.12<br>(306) | 2.08<br>(300) |
| External pressure | $p_e$ | MPa<br>(psi) | 1.80<br>(260) | 1.80<br>(260) |
| Net internal pressure | $p$ | MPa<br>(psi) | 0.32<br>(46) | 0.28<br>(40) |
| Effective tension | $T$ | kN<br>(kips) | 3144<br>(707) | 5983<br>(1345) |
| Bending moment | $M$ | kN-m<br>(kips-ft) | 309<br>(228) | 443<br>(327) |

## A.8.2 Method 1

Method 1 limit check is met if the combined loads satisfy the following internal overpressure inequality given in 5.4.3.2.

$$\left|\frac{T}{T_y}\right| + \left|\frac{M}{M_y}\right| \le \sqrt{F_D^2 - \left(\frac{p}{p_b}\right)^2} \quad \text{or} \quad \frac{\left|\dfrac{M}{M_y}\right|}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2} - \left|\dfrac{T}{T_y}\right|} \le 1$$

The following are the calculations of Method 1 check for both the cases.

For the ULS case:

$$F_D = 0.8$$

$$\frac{\left|\dfrac{M}{M_y}\right|}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2} - \left|\dfrac{T}{T_y}\right|} = \frac{\left|\dfrac{309}{861}\right|}{\sqrt{0.8^2 - \left(\dfrac{0.32}{40.5}\right)^2} - \left|\dfrac{3144}{9480}\right|} = 0.77 \ (\leq 1)$$

For the ALS case:

$$F_D = 1.0$$

$$\frac{\left|\dfrac{M}{M_y}\right|}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2} - \left|\dfrac{T}{T_y}\right|} = \frac{\left|\dfrac{443}{861}\right|}{\sqrt{1.0^2 - \left(\dfrac{0.28}{40.5}\right)^2} - \left|\dfrac{5983}{9480}\right|} = 1.39 \ (\geq 1)$$

Thus, Method 1 check is met in the ULS case but fails in the ALS case

### A.8.3 Method 2

Method 2 limit check is met if the combined loads satisfy the following internal overpressure inequality given in 5.4.3.3.

$$\frac{M}{M_p} \leq \sqrt{F_D^2 - \left(\frac{p}{p_b}\right)^2} \cos\left(\frac{\pi}{2} \frac{\dfrac{T}{T_y}}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2}}\right) \text{ or } \frac{\dfrac{M}{M_p}}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2} \cos\left(\dfrac{\pi}{2} \dfrac{\dfrac{T}{T_y}}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2}}\right)} \leq 1$$

The following are the calculations of Method 2 check for both ULS and ALS cases.

For the ULS case:

$$F_D = 0.8$$

$$\frac{\dfrac{M}{M_p}}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2} \cos\left(\dfrac{\pi}{2} \dfrac{\dfrac{T}{T_y}}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2}}\right)} = \frac{\dfrac{309}{1097}}{\sqrt{0.8^2 - \left(\dfrac{0.32}{40.5}\right)^2} \cos\left(\dfrac{\pi}{2} \dfrac{\dfrac{3144}{9480}}{\sqrt{0.8^2 - \left(\dfrac{0.32}{40.5}\right)^2}}\right)} = 0.44 \ (\leq 1)$$

For the ALS case:

$$F_D = 1.0$$

$$\frac{\dfrac{M}{M_p}}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2}\cos\left(\dfrac{\pi}{2}\dfrac{\dfrac{T}{T_y}}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2}}\right)} = \frac{\dfrac{443}{1097}}{\sqrt{1.0^2 - \left(\dfrac{0.28}{40.5}\right)^2}\cos\left(\dfrac{\pi}{2}\dfrac{\dfrac{5983}{9480}}{\sqrt{1.0^2 - \left(\dfrac{0.28}{40.5}\right)^2}}\right)} = 0.74 \ (\leq 1)$$

Method 2 check is satisfied in both the cases. The Method 2 formula is based on plastic moment and takes into account the additional yield capacity beyond the limits set in Method 1. As a result the ALS case, which previously did not satisfy the Method 1 limit check, satisfies the Method 2 limit check.

Bending strain at the bottom of the keel joint for the ALS case is 0.0167 or 1.67 %. Therefore, the keel joint design is considered to be a strain-based design. Additional material requirements in 7.7 should be followed to ensure that the design is robust.

### A.8.4 Method 3

For an introduction to the implementation of the LRFD format of Method 3, see Appendix C of DNV-OS-F201.

### A.8.5 Method 4

Method 4 checks for tension and the bending separately. Tension limit check is met if the combined loads satisfy the following internal overpressure inequality given in 5.4.3.5.

$$\sqrt{\left(\frac{p_i - p_e}{p_b}\right)^2 + \left(\frac{T}{T_y}\right)^2} \leq F_D \quad \text{or} \quad \frac{\sqrt{\left(\dfrac{p_i - p_e}{p_b}\right)^2 + \left(\dfrac{T}{T_y}\right)^2}}{F_D} \leq 1$$

Bending limit check is met if the strain satisfies the following inequality given in 5.4.3.5:

$$\varepsilon \leq F_D \varepsilon_b$$

Buckling strain $\varepsilon_b$ of the outer riser is calculated as follows.

$$\varepsilon_b = \frac{t}{2D}$$

$$= \frac{15.1}{2 \times 377.8}$$

$$= 0.02 \text{ or } 2\ \%$$

The following are the calculations of tension and bending limit checks for both the cases.

For the ULS case:

Tension limit check,

$$F_{\mathrm{D}} = 0.9$$

$$\frac{\sqrt{\left(\frac{p_{\mathrm{i}} - p_{\mathrm{e}}}{p_{\mathrm{b}}}\right)^2 + \left(\frac{T}{T_{\mathrm{y}}}\right)^2}}{F_{\mathrm{D}}} = \frac{\sqrt{\left(\frac{0.32}{40.5}\right)^2 + \left(\frac{3144}{9480}\right)^2}}{0.9} = 0.37 \quad (<1)$$

Bending limit check,

$$F_{\mathrm{D}} = 0.5$$

Bending strain ($\varepsilon$) at the bottom of keel joint for the ULS case is 0.0019 or 0.19 %.

$$\varepsilon = 0.19\ \% \quad (\leq 0.5 \times \varepsilon_{\mathrm{b}})$$
$$0.19\ \% \leq 1\ \% \quad \text{(inequality satisfied)}$$

For the ALS case:

Tension limit check,

$$F_{\mathrm{D}} = 1.0$$

$$\frac{\sqrt{\left(\frac{p_{\mathrm{i}} - p_{\mathrm{e}}}{p_{\mathrm{b}}}\right)^2 + \left(\frac{T}{T_{\mathrm{y}}}\right)^2}}{F_{\mathrm{D}}} = \frac{\sqrt{\left(\frac{0.28}{40.5}\right)^2 + \left(\frac{5983}{9480}\right)^2}}{1.0} = 0.63 \quad (\leq 1)$$

Bending limit check,

$$F_{\mathrm{D}} = 1.0$$

Bending strain (ε) at the bottom of keel joint for the ALS case is 0.0167 or 1.67 %.

$$\varepsilon = 1.67\ \% \quad (\leq 1.0 \times \varepsilon_{\mathrm{b}})$$
$$1.67\ \% \leq 2\ \% \quad \text{(inequality satisfied)}$$

Thus, the tension and bending limit checks of the outer riser are met for both ULS and ALS cases.

However since bending strain at the bottom of the keel joint for the ALS case exceeds 0.5 %, the keel joint design is considered to be a strain-based design. Additional material requirements in 7.7 should be followed to ensure that the design is robust.

# Annex B
(informative)

# Example SCR Design

## B.1 Scope

This annex outlines the methodology for performing combined loading checks for ULS and ALS conditions for an 18-inch oil export SCR suspended from a semi-submersible in 2000 m of water in the Gulf of Mexico.

## B.2 Load Case Matrix

A typical load case matrix for strength design of an SCR is presented in Table B.1. Actual load cases should be determined by the project based on FMEA, HAZOP and design reviews.

**Table B.1—A Typical Load Case Matrix for SCR Design**

| Load Category API 2RD | Limit State API 2RD | Operational Condition | Mooring Condition | Environmental Condition |
|---|---|---|---|---|
| Operating | SLS | Shut-in | Intact | 10 yr winter storm |
| | SLS | Operating | Intact | 10 yr loop current |
| Extreme | ULS | Shut-down | Intact | 100 yr hurricane (max. wave) |
| | ULS | Shut-down | Intact | 100 yr hurricane (max. wind) |
| | ULS | Operating | Intact | 100 yr loop current |
| | ULS | Shut-down | One line failed | 10 yr hurricane (max. wave) |
| | ULS | Shut-down | One line failed | 10 yr hurricane (max. wind) |
| | ULS | Operating | One line failed | 10 yr loop current |
| Survival | ALS | Shut-down | Intact | 1000 yr hurricane (max. wave) |
| | ALS | Shut-down | Intact | 1000 yr hurricane (max. wind) |
| | ALS | Operating | Intact | 1000 yr loop current |
| | ALS | Shut-down | One line failed | 100 yr hurricane (max. wave) |
| | ALS | Shut-down | One line failed | 100 yr hurricane (max. wind) |
| | ALS | Operating | One line failed | 100 yr loop current |
| Installation | SLS | Empty | Intact | 1 yr winter storm |
| Test | SLS | Hydrostatic test | Intact | 1 yr winter storm |

## B.3 Case Study

### B.3.1 Design Data

The ULS and ALS load cases and the associated environmental conditions are given in Table B.2 and Table B.3. Table 5 lists the pipe properties used in the study. Vessel motions are based on response amplitude operators (RAOs).

**Table B.2—Load Case Matrix for SCR Performance Assessment**

| Limit State API 2RD | Operational Condition | Internal Pressure at Surface MPa | Mooring Condition | Offset % of water depth | Environmental Condition |
|---|---|---|---|---|---|
| ULS | Shut-down | 25 | Intact | 4 % | 100 yr hurricane |
| ALS | Shut-down | 25 | One line failed | 5 % | 100 yr hurricane |

**Table B.3—100-Year Hurricane Environmental Data**

| Environmental Condition | Significant Wave Height, $H_s$ m | Peak Period $T_p$ | Shape Parameter $\gamma$ | Surface Current m/s |
|---|---|---|---|---|
| 100 yr hurricane | 15.8 | 15.4 | 2.2 | 2.4 |

**Table B.4—Pipe Properties**

| Property | Symbol | Units | Value |
|---|---|---|---|
| Nominal outer diameter | $D$ | mm | 457.2 |
| Nominal wall thickness | $t$ | mm | 23.8 |
| Corrosion allowance | | | 0 |
| Material grade | | | X70 |
| Fabrication method | | | UOE |
| Specified minimum yield strength | $S$ | MPa | 482.6 |
| Minimum ultimate tensile strength | $U$ | MPa | 565.3 |
| Ovality | $\delta_0$ | | 0.01 |
| Fabrication factor | $\alpha_{fab}$ | | 0.85 |
| Internal fluid density | | kg/m$^3$ | 850 |
| Design pressure | | MPa | 25 |
| Reference elevation for design pressure | | m | 0 |
| NOTE No corrosion allowance is considered in this example. Corrosion allowance should be considered when applicable. | | | |

## B.3.2 Results

### B.3.2.1 Combined Loading Capacity Utilization

The capacity utilizations based on the four methods for checking combined loads in this standard are summarized in Table B.5. A more detailed calculation for the ULS case is shown in B.3.2.2. For comparison, the von-Mises utilization calculated in accordance with API 2RD, 1st Edition, Section 5.2.3, is also presented. The von-Mises stress utilizations are based on 80 % of the yield stress for the ULS case and 100 % of the yield stress for the ALS case. The utilization values for the hang-off location are reported at three meters away from the attachment point to account for the flex-joint extension piece.

For the ULS load case, the von-Mises stress utilizations at the hang-off and at the touch-down zone (TDZ) are 0.94 and 0.91 respectively while the sectional capacity utilizations based on Method 1 are 1.00 (at hang-off) and 0.94 (at TDZ). Thus utilizations given by Method 1 are similar to the von-Mises utilization in API 2RD, 1st Edition.

For the same locations, the utilizations computed using Method 2 are 0.60 (at hang-off) and 0.74 (at TDZ). Method 2, based on the plastic moment capacity of the pipe gives a lower utilization compared to Method 1, which is based on the yield moment capacity. This clearly illustrates that by employing Method 2, the designer can possibly reduce the pipe wall thickness (subject to other considerations such as fatigue) thus reducing the hang-off loads.

At the TDZ, the utilization given by Method 3 is 0.74 and at the same location Method 4 gives a utilization of 0.48. Method 4 gives the lowest utilization at the TDZ as the contribution of bending moment is not included in the utilization calculations. Instead, Method 4 checks the bending strains separately. The bending strain checks provide additional means to check for buckling due to bending. Similar trends are also observed for the ALS case, with Method 1 giving the highest utilization and Method 4 giving the lowest.

**Table B.5—Capacity Utilization for ALS and ULS Load Cases**

| Location | Limit State | Method 1 | Method 2 | Method 3 | Method 4 | API 2RD, 1st Edition |
|---|---|---|---|---|---|---|
| Hang-off | ULS | 1.00 | 0.60 | 0.50 | 0.68 | 0.94 |
| TDZ | | 0.94 | 0.74 | 0.74 | 0.47 | 0.91 |
| Hang-Off | ALS | 0.66 | 0.50 | 0.30 | 0.61 | 0.77 |
| TDZ | | 0.75 | 0.67 | 0.45 | 0.43 | 0.75 |

### B.3.2.2 Calculation for ULS Case

This section presents a calculation for the ULS case. The capacity of the pipe is presented in Table B.6. For step-by-step method for computing pipe capacity, see Annex A. The riser loads from the global analysis at the TDZ with the highest utilization value is presented in Table B.7.

**Table B.6—Summary of Pipe Capacity**

| Pipe Capacity | Symbol | Units | Value |
|---|---|---|---|
| Burst | $P_b$ | MPa | 51.8 |
| Burst capacity including strain hardening and wall thinning | $P_k$ | MPa | 57.2 |
| Collapse | $P_c$ | MPa | 33.5 |
| Yield tension | $T_y$ | kN | 15,638 |
| Tension capacity including strain hardening | $T_k$ | kN | 16,853 |
| Yield moment | $M_y$ | kNm | 1694 |
| Plastic moment | $M_p$ | kNm | 2157 |
| Moment capacity including strain hardening | $M_k$ | kNm | 2325 |

**Table B.7—Riser loads at TDZ for ULS**

| Property | Symbol | Units | Value |
|---|---|---|---|
| Internal pressure | $p_i$ | MPa | 41.8 |
| External pressure | $p_e$ | MPa | 20.1 |
| Effective tension | $T$ | kN | –68.6 |
| Bending moment | $M$ | kN-m | 1080.9 |
| Effective tension due to functional loads | $T_F$ | kN | 1048.6 |
| Bending moment due to functional loads | $M_F$ | kNm | 272.2 |
| NOTE 1 Internal and external pressures are calculated at 2000 m below the water line.<br>NOTE 2 Effective tension is negative (compressive) for this case at the TDZ. | | | |

Utilization using Method 1:

$$F_D = 0.8$$

$$\eta_1 = \frac{\left|\dfrac{M}{M_y}\right|}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2} - \left|\dfrac{T}{T_y}\right|} = \frac{\left|\dfrac{1080.9}{1694.5}\right|}{\sqrt{0.8^2 - \left(\dfrac{41.8 - 20.1}{51.8}\right)^2} - \left|\dfrac{-68.6}{15638}\right|} = 0.94 \quad (\leq 1)$$

Utilization using Method 2:

$$F_D = 0.8$$

$$\eta_2 = \frac{\dfrac{M}{M_p}}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2} \cos\left(\dfrac{\pi}{2} \dfrac{\dfrac{T}{T_y}}{\sqrt{F_D^2 - \left(\dfrac{p}{p_b}\right)^2}}\right)} = \frac{\dfrac{1080.9}{2157.5}}{\sqrt{0.8^2 - \left(\dfrac{41.8 - 20.1}{51.8}\right)^2} \cos\left(\dfrac{\pi}{2} \dfrac{\dfrac{-68.6}{15638}}{\sqrt{0.8^2 - \left(\dfrac{41.8 - 20.1}{51.8}\right)^2}}\right)} = 0.74 \quad (\leq 1)$$

Utilization using Method 3:

Method 3 based on LRFD philospohy, distinguishes between environmental loads and functional loads. For an introduction to the implementation of the LRFD format of Method 3, see Appendix C of DNV-OS-F201.

Utilization using Method 4:

Method 4 checks for tension and the bending separately. The tension limit check is given by:

$$F_D = 0.9$$

$$\eta_4 = \frac{\sqrt{\left(\dfrac{p_i - p_e}{p_b}\right)^2 + \left(\dfrac{T}{T_y}\right)^2}}{F_D} = \frac{\sqrt{\left(\dfrac{41.8 - 20.1}{51.8}\right)^2 + \left(\dfrac{-68.6}{15638}\right)^2}}{0.9} = 0.47 \quad (\leq 1)$$

The bending limit check limits the maximum bending strain to a fraction of the buckling strain $\varepsilon_b$ given by:

$$\varepsilon_b = \frac{t}{2D} = \frac{23.8}{2 \times 457.2} = 0.026 \text{ or } 2.6\%$$

The maximum bending strain $\varepsilon$ at the TDZ is 0.0016 or 0.16 %. The bending limit check is met if the strain satisfies the following inequality:

$$\varepsilon \leq F_D \times \varepsilon_b$$
$$F_D = 0.5$$
$$F_D \times \varepsilon_b = 0.5 \times 2.6\,\% = 1.3\,\%$$
$$\varepsilon = 0.16\,\%$$
$$0.16\,\% \leq 1.3\,\% \text{ (inequality satisfied)}$$

# Annex C
(informative)

## Supplemental Design Information

The design equations in Section 5 reconcile the pipe design criteria of four internationally recognized codes of practice:

— API 2RD, 1st Edition;

— API 1111, 3rd Edition;

— DNV-OS-F201:2001;

— API 17G.

These documents present four different methods for pipe design criteria, all of which were deemed to give safe designs. Significant discussion eventually resulted in a compromise by numbering the four methods and allowing the designer to choose the one he deemed most appropriate, or to start with the simplest to use and progress to another if necessary.

A separate technical report is planned to capture the discussions and rationale behind the reconciliation of the four design practices, including background of the load design factors.

# Bibliography


[1] API RP 2A-WSD, *Planning, Designing and Constructing Fixed Offshore Platforms—Working Stress Design*

[2] API 2FPS, *Planning, Designing, and Constructing Floating Production Systems*

[3] API Spec 2H, *Specification for Carbon Manganese Steel Plate for Offshore Structures*

[4] API RP 2RD, 1st Edition, *Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)*

[5] API Spec 2W, *Steel Plates for Offshore Structures, Produced by Thermo-Mechanical Control Processing (TMCP)*

[6] API Spec 2Y, *Specification for Steel Plates, Quenched-and-Tempered, for Offshore Structures*

[7] API Bull 5C3, *Formulas and Calculations for Casing, Tubing, Drill Pipe, and Line Pipe Properties*

[8] API RP 5C5, *Recommended Practice on Procedures for Testing Casing and Tubing Connections*

[9] API Spec 5DP, *Specification for Drill Pipe*

[10] API TR 6AF, *Technical Report on Capabilities of API Flanges Under Combinations of Loading*

[11] API TR 6AF1, *Technical Report on Temperature Derating of API Flanges Under Combination of Loading—Phase I*

[12] API TR 6AF2, *Technical Report on Capabilities of API Integral Flanges Under Combination of Loading—Phase II*

[13] API Spec 6D, *Specification for Pipeline Valves*

[14] API TR 6AM, *Material Toughness*

[15] API Spec 7-1, *Specification for Rotary Drill Stem Elements*

[16] API Spec 8C, *Specification for Drilling and Production Hoisting Equipment (PSL 1 and PSL 2)*

[17] API Spec 9A, *Specification for Wire Rope*

[18] API RP 9B, *Application Care, and Use Application Care Rope for Oil Field Service*

[19] API Spec 16A, *Specification for Drill-Through Equipment*

[20] API Spec 16C, *Choke and Kill Systems*

[21] API Spec 16D, *Control Systems for Drilling Well Control Equipment and Control Systems for Diverter Equipment*

[22] API Spec 16F, *Specification for Marine Drilling Riser Equipment*

[23] API RP 16Q, *Design, Selection, Operation and Maintenance of Marine Drilling Riser Systems*

[24] API Spec 16R, *Specification for Marine Drilling Riser Couplings*

[25] API RP 17A, *Design and Operation of Subsea Production Systems—General Requirements and Recommendations*

[26] API Spec 17D, *Specification for Subsea Wellhead and Christmas Tree Equipment*

[27] API Spec 17F, *Specification for Subsea Production Control Systems*

[28] API RP 17G, *Recommended Practice for Completion/Workover Riser Systems*

[29] API RP 64, *Diverter Systems Equipment and Operations*

[30] API RP 1110, *Pressure Testing of Steel Pipelines for the Transportation of Gas, Highly Volatile Liquids or Carbon Dioxide*

[31] API RP 1111, 3rd Edition, *Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines (Limit State Design)*

[32] ASME B1.1, 2.3.1—1989

[33] ASME Boiler and Pressure Vessel Code, Section VIII, Division 1: *Rules for Construction of Pressure Vessels*, and Division 2: *Alternative Rules*; Section IX, *Welding and Brazing Qualifications*

[34] ASME B31.1, *Power Piping*

[35] ASME B31.3, *Process Piping*

[36] AWS D1.1, *Structural Welding Code—Steel*

[37] AWS A5.14, *Specification for Nickel and Nickel Alloy Bare Welding Electrodes and Rods*

[38] BS 7910, *Guide to methods for assessing the acceptability of flaws in metallic structures*

[39] BS 7448, *Fracture mechanics toughness tests. Method for determination of fracture toughness of metallic materials at rates of increase in stress intensity factor greater than 3.0 MPa m0.5 s-1*

[40] BS 7201, *Hydraulic fluid power. Gas loaded accumulators. Specification for seamless steel accumulator bodies above 0.5 L water capacity*

[41] NORSOK L-005, *Compact flanged connections*

[42] NORSOK M-710, *Qualification of non-metallic sealing materials and manufacturers*

[43] ASTM A36, *Standard Specification for Carbon Structural Steel*

[44] ASTM A516, *Standard Specification for Pressure Vessel Plates, Carbon Steel, for Moderate- and Lower-Temperature Service*

[45] ASTM A537, *Standard Specification for Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel*

[46] ASTM G48, *Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution*

[47] ASTM B446, *Standard Specification for Nickel-Chromium-Molybdenum-Columbium Alloy (UNS N06625), Nickel-Chromium-Molybdenum-Silicon Alloy (UNS N06219), and Nickel-Chromium-Molybdenum-Tungsten Alloy (UNS N06650)* Rod and Bar*

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

[49] ASTM A508, *Standard Specification for Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels*

[50] ASTM A703, *Standard Specification for Steel Castings, General Requirements, for Pressure-Containing Parts*

[51] ASTM D2240, *Standard Test Method for Rubber Property—Durometer Hardness*

[52] ASTM B850, *Standard Guide for Post-Coating Treatments of Steel for Reducing the Risk of Hydrogen Embrittlement*

[53] ASTM E8, *Standard Test Methods for Tension Testing of Metallic Materials (for non-ferrous alloys)*

[54] ASTM E10, *Standard Test Methods for Brinell Hardness of Metallic Materials*

[55] ASTM E18, *Standard Test Method for Rockwell Hardness of Metallic Materials*

[56] ASTM E23, *Standard Testing Methods for Notched Bar Impact Testing of Metallic Ma*terials

[57] ASTM E140, *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness*

[58] ASTM E165, *Standard Practice for Liquid Penetrant Examination for General Industry*

[59] ASTM E399, *Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness KIc of Metallic Materials*

[60] ASTM E709, *Standard Guide for Magnetic Particle Testing*

[61] ASTM E1290, *Standard Test Method for Crack-Tip Opening Displacement (CTOD) Fracture Toughness Measurement*

[62] EN 288-2, *Specification and approval of welding procedures for metallic materials. Welding procedures specification for arc welding*

[63] EN 287-1 (ISO 9606-1), *Qualification test of welders. Fusion welding. Steels*

[64] EN 1418, *Welding personnel. Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials*

[65] AISC 303, *Code of Standard Practice for Steel Buildings and Bridges*

[66] ASNT SNT-TC-1A, *Personnel Qualification and Certification in Non-destructive Testing*

[67] DNV-OS-C105, *Structural Design of TLPs (LRFD Method)*

[68] DNV-OS-C106, *Structural Design of Deep Draught Floating Units/Spars (LRFD and WSD Method)*

[69] DNV-OS-C501, *Composite Components*

[70] DNV-OS-H101, *Marine Operations, General*

[71] DNV-OSS-101, *Rules for Classification of Offshore Drilling and Support Units*

[72] DNV-OSS-301, *Certification and Verification of Pipelines*

[73] DNV-OSS-302, *Offshore Riser Systems*

[74] DNV-RP-B401, *Cathodic Protection Design*.

[75] DNV-RP-F101, *Corroded Pipelines*

[76] DNV-RP-F104, *Mechanical Pipeline Couplings*

[77] DNV-RP-F105, *Free Spanning Pipelines*

[78] DNV-RP-O501, *Erosive Wear in Piping Systems*

[79] DNV-RP-A203, *Qualification Procedures for New Technology*

[80] DNV-RP-C203, *Fatigue Design of Offshore Steel S*tructures

[81] DNV-RP-F106, *Factory Applied External Pipeline Coatings for Corrosion Control*

[82] DNV-RP-F108, *Fracture Control for Pipeline Installation Methods Introducing Cyclic Plastic S*train

[83] DNV-RP-F201, *Design of Titanium Risers*

[84] DNV-RP-F202, *Composite Risers*

[85] DNV-RP-F203, *Riser Interference*

[86] DNV-RP-F204, *Riser Fatigue*

[87] DNV-RP-H101, *Risk Management In Marine and Subsea Operations*

[88] ISO 148-1, *Metallic materials—Charpy pendulum impact test—Part 1: Test method*

[89] ISO 377, *Steel and steel products—Location and preparation of samples and test pieces for mechanical testing*

[90] ISO 783, *Metallic materials—Tensile testing at elevated temperature*

[91] ISO 1461, *Hot dip galvanized coatings on fabricated iron and steel articles—Specifications and test methods*

[92] ISO 2566-1, *Steel—Conversion of elongation values—Part 1: Carbon and low alloy steels*

[93] ISO 4885, *Ferrous products—Heat treatments—Vocabulary*

[94] ISO 6892, Metallic *materials—Tensile testing at ambient temperature*

[95] ISO 9327-1, *Steel forgings and rolled or forged bars for pressure vessels—Technical delivery conditions—Part 1: General requirements*

[96] ISO 9606-1 (EN 287-1), *Approval testing of welders—Fusion welding—Part 1: Steels*

[97] ISO 9712, *Non-destructive testing—Qualification and certification of personnel*

[98] ISO 9934, *Non-destructive testing—Magnetic particle testing*

[99] ISO 10432, *Petroleum and natural gas industries—Downhole equipment—Subsurface safety valve equipment*

[100] ISO 10474, *Steel and steel products—Inspection documents*

[101] ISO 10945, *Hydraulic fluid power—Gas-loaded accumulators—Dimensions of gas ports*

[102] ISO 13628-4, *Petroleum and natural gas industries—Design and operation of subsea production systems—Part 4: Subsea wellhead and tree equipment*

[103] ISO 13628-5, *Petroleum and natural gas industries—Design and operation of subsea production systems—Part 5: Subsea umbilicals*

[104] ISO 13533, *Petroleum and natural gas industries—Drilling and production equipment—Drill-through equipment*

[105] ISO 15579, *Metallic materials—Tensile testing at low temperature*

[106] ISO 15589-2, *Petroleum and natural gas industries—Cathodic protection of pipeline transportation systems—Part 2: Offshore pipelines*

[107] ISO 15590-1, *Petroleum and natural gas industries—Induction bends, fittings and flanges for pipeline transportation systems—Part 1: Induction bends*

[108] ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

[109] ISO 17776, *Petroleum and natural gas industries—Offshore production installations—Guidelines on tools and techniques for hazard identification and risk assess*ment

[110] ISO 21329, *Petroleum and natural gas industries—Pipeline transportation systems—Test procedures for mechanical connectors*

[111] ISO 23936, *Petroleum, petrochemical and natural gas industries—Non-metallic materials in contact with media related to oil and gas production—Part 1: Thermoplastics*

[112] EFC Publ. no. 16, *Guidelines on Material Requirements for Carbon and Low Alloy Steels in H2S-Containing Environments in Oil and Gas Production*

[113] IEC 60079, *Electrical apparatus for explosive gas atmospheres*

[114] IEC 61892, *Mobile and fixed offshore units—Electrical installations*

[115] MSS SP-25, *Standard Marking Systems for Valves, Fittings, Flanges and Unions*

[116] NFPA 70, *National Electrical Code*

[117] SAE AS 4059D, *Aerospace Fluid Power—Cleanliness Classification for Hydraulic Fluids*

[118] Bridge, C (2005) *Effects of Seabed Interaction on Steel Catenary Risers*, PhD Thesis, University of Surrey

[119] Bridge, C., Laver, K., Clukey, E., and Evans, T. (2004) *Steel catenary riser touchdown point vertical interaction model*, Offshore Technology Conference, Houston, Texas, OTC 16628

[120] Bridge, C.D. and Howells, H.A. (2007) *Observations and modeling of steel catenary riser trenches*, Proc. 17th International Offshore and Polar Engineering Conference, Lisbon, ISOPE-2007-468

[121] Clukey, E.C., Ghosh, R., Mokarala, P. and Dixon, M. (2007), *Steel catenary riser (SCR) design philosophy issues at touch down area*; Proc. International Offshore and Polar Engineering Conference, Lisbon

[122] Clukey, E.C., Haustermans, L., and Dyvik, R. (2005) *Model tests to simulate riser-soil interaction effects in touchdown point region*, International Symposium on Frontiers in Offshore Geotechnics, Perth, Australia, September, pp. 651-658

[123] Clukey, E.C., Young, A.G., Garmon, G.S. and Dobias, J.R. (2008) *Soil response and stiffness laboratory measurements of SCR pipe/soil interaction*, Offshore Technology Conference, Houston, OTC 19303

[124] Det Norske Veritas (2005) Recommended Practice DNV-RP-C203: *Fatigue Design of Offshore Steel Structures*

[125] Hahn, G.D., Shanks, J.M. and Masson, C. (2003) *An assessment of steel catenary riser trenching*, Deep Offshore Technology International Conference, Marseille

[126] Langner, C.G. (2003) *Fatigue life improvement of steel catenary risers due to self-trenching at the touchdown point*, Offshore Technology Conference, Houston, OTC 15104

[127] Thethi, R. and Moros,T. (2001) *Soil interaction effects on simple catenary riser response*, Deepwater Pipeline & Riser Technology Conference, Houston Texas

[128] Chen, W. and Randolph, M.F. (2007a*). Radial stress changes and axial capacity for suction caissons in soft clay*. Géotechnique, 57(6), 499-511

[129] Chen, W. and Randolph, M.F. (2007b). *Uplift capacity of suction caissons under sustained and cyclic loading in soft clay*. J. of Geotechnical and GeoEnvironmental Eng, ASCE, 133(11), 1352-1363

[130] Clukey E.C. and Morrison M.J. (1993), *A Centrifuge Analytical Study to Evaluate Suction Caissons for TLP-Applications in the Gulf of Mexico, Design and Performance of Deep Foundations*, pp. 141-156

[131] Clukey, E. C., Randolph, M. F., Templeton, J, S., and Philipps, R., (2004) *Suction Caisson Response Under Sustained Loop Current Loads*, Proceedings of the 36th Offshore Technology Conference, Houston, May

[132] Dendani H. and Colliat-Dangus J.L. (2002), *Girassol: Design analysis and installation of the suction anchors*, Proc. Offshore Technology Conf. (OTC14209)

[133] Dendani H. (2003), *Suction anchors: Some critical aspects for their design and installation in clayey soils*, Proc. Offshore Technology Conf. (OTC15376)

[134] Randolph M.F. and House A.R. (2002), *Analysis of Suction Caisson Capacity in Clay*, Proceedings of the 2002 Offshore Technology Conference, OTC 14236

[135] Bruton, D.A.S., White, D.J., Cheuk, C.Y., Bolton, M.D. & Carr, M.C. (2006). *Pipe-soil interaction behaviour during lateral buckling, including large amplitude cyclic displacement tests by the Safebuck JIP*. Proc. Offshore Technology Conference, Houston, OTC17944

[136] Bruton D., Carr M. & White D.J. (2007). *The influence of pipe-soil interaction on lateral buckling and walking of pipeines: the SAFEBUCK JIP*. Proc. 6th Int. Conf. on Offshore Site Investigation and Geotechnics, London. 133-150

[137] Cathie, D.N., Jaeck, C., Ballard, J.C. & Wintgens, J-F. (2005). *Pipeline geotechnics—state-of-the-art*. Proc. Int. Symposium on Frontiers in Offshore Geotechnics, Perth, Australia, 95-114

[138] Langford, T.E., Dyvik, R. & Cleave, R. (2007) *Offshore pipeline and riser geotechnical model testing: practice and interpretation*; OMAE2007-29458; Proc. Conference on Offshore, Marine and Arctic Engineering

[139] Sharma, P.P., C.P. Aubeny, (2011), *Advances in pipe-soil interaction methodology and application for SCR fatigue design*, Proceedings of the 2011 Offshore Technology Conference (OTC 21179)

[140] Sharma, P.P., Song, R., O'Donnell, J.; Mørk, K.J, & Kavanagh, W.K., (2010), *Design methods in ISO 13628-12 and implications for Gulf of Mexico SCRs*, Proceedings of the 2010 Offshore Technology Conference (OTC 20778)

[141] Verley, R. & Lund, K.M. (1995). *A soil resistance model for pipelines placed on clay soils*. Proc. International Conference on Offshore Mechanics & Arctic Engineering (OMAE), Copenhagen, Denmark, 5: 225-232

[142] Yu, A., Cheng, Y., and Bhat, S.; *Evaluation of Key Hydraulic Tensioner Performance Parameters for Ultra Deep Water Applications*, Paper No. OMAE2008-57465, ASME 2008 27th International Conference on Offshore Mechanics and Arctic Engineering, Volume 3: Pipeline and Riser Technology; Ocean Space Utilization, Estoril, Portugal, June 15–20, 2008

# EXPLORE SOME MORE

Check out more of API's certification and training programs, standards, statistics and publications.

**API Monogram™ Licensing Program**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: certification@api.org
Web: www.api.org/monogram

**API Quality Registrar (APIQR™)**

- ISO 9001
- ISO/TS 29001
- ISO 14001
- OHSAS 18001
- API Spec Q1®
- API Spec Q2™
- API Quality*Plus*™
- Dual Registration

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: certification@api.org
Web: www.api.org/apiqr

**API Training Provider Certification Program (API TPCP®)**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: tpcp@api.org
Web: www.api.org/tpcp

**API Individual Certification Programs (ICP™)**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: icp@api.org
Web: www.api.org/icp

**API Engine Oil Licensing and Certification System (EOLCS™)**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: eolcs@api.org
Web: www.api.org/eolcs

**Motor Oil Matters™**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: motoroilmatters@api.org
Web: www.motoroilmatters.org

**API Diesel Exhaust Fluid™ Certification Program**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: apidef@api.org
Web: www.apidef.org

**API Perforator Design™ Registration Program**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: perfdesign@api.org
Web: www.api.org/perforators

**API WorkSafe™**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: apiworksafe@api.org
Web: www.api.org/worksafe

**API-U®**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: training@api.org
Web: www.api-u.org

**API eMaintenance™**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: apiemaint@api.org
Web: www.apiemaintenance.com

**API Standards**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Email: standards@api.org
Web: www.api.org/standards

**API Data™**

Sales: 877-562-5187
(Toll-free U.S. and Canada)
(+1) 202-682-8041
(Local and International)
Service: (+1) 202-682-8042
Email: data@api.org
Web: www.api.org/data

**API Publications**

Phone: 1-800-854-7179
(Toll-free U.S. and Canada)
(+1) 303-397-7956
(Local and International)
Fax: (+1) 303-397-2740
Web: www.api.org/pubs
global.ihs.com

AMERICAN PETROLEUM INSTITUTE

1220 L Street, NW
Washington, DC 20005-4070
USA

202-682-8000

**Additional copies are available online at www.api.org/pubs**

| | | |
|---|---|---|
| Phone Orders: | 1-800-854-7179 | (Toll-free in the U.S. and Canada) |
| | 303-397-7956 | (Local and International) |
| Fax Orders: | 303-397-2740 | |

Information about API publications, programs and services is available on the web at www.api.org.

**Product No. G2RD02**