

Dynamic Risers for Floating Production Systems

API STANDARD 2RD
SECOND EDITION, SEPTEMBER 2013

REAFFIRMED, SEPTEMBER 2020



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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 H₂S-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 H₂S 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_i internal cross section of the pipe

A_o external cross section of the pipe

α_{fab} fabrication factor

CE_{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_{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
δ_0	ovality
E	Young's modulus
ε	bending-induced strain in pipe
ε_b	bending strain at which buckling occurs
F_D	design factor
σ_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 S_i 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
ν	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:

$$p_b = k(S + U) \ln(D / (D - 2t)) \quad (1)$$

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.

$$p_c = \frac{P_y p_{el}}{\sqrt{P_y^2 + p_{el}^2}} \quad (2)$$

where

P_y is the yield collapse pressure, given by Equation 3;

p_{el} is the elastic collapse pressure, given by Equation 4.

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