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**Petroleum and natural gas industries —  
Design and operation of subsea  
production systems —**

**Part 7:  
Completion/workover riser systems**

*Industries du pétrole et du gaz naturel — Conception et exploitation  
des systèmes de production immergés —*

*Partie 7: Systèmes de liaison surface/fond de mer pour  
complétion/reconditionnement*



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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13628-7 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 4, *Drilling and production equipment*.

ISO 13628 consists of the following parts, under the general title *Petroleum and natural gas industries — Design and operation of subsea production systems*:

- *Part 1: General requirements and recommendations*
- *Part 2: Unbonded flexible pipe systems for subsea and marine applications*
- *Part 3: Through flowline (TFL) systems*
- *Part 4: Subsea wellhead and tree equipment*
- *Part 5: Subsea umbilicals*
- *Part 6: Subsea production control systems*
- *Part 7: Completion/workover riser systems*
- *Part 8: Remotely Operated Vehicle (ROV) interfaces on subsea production systems*
- *Part 9: Remotely Operated Tool (ROT) intervention systems*
- *Part 10: Specification for bonded flexible pipe*
- *Part 11: Flexible pipe systems for subsea and marine applications*

## Introduction

This part of ISO 13628 has been prepared to provide general requirements, recommendations and overall guidance for the user to the various areas requiring consideration during development of subsea production system. The functional requirements defined in this part of ISO 13628 allow alternatives in order to suit specific field requirements.

This part of ISO 13628 constitutes the overall C/WO riser system standard. Functional requirements for components comprising the system and detailed requirements for riser pipe and connector design and analysis are included herein.

This part of ISO 13628 was developed on the basis of API RP 17G:1995, and other relevant documents on subsea production systems.

It is necessary that the users of this part of ISO 13628 be aware that further or different requirements might be needed for individual applications. This part of ISO 13628 is not intended to inhibit a vendor from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application.

This is probably particularly applicable where there is innovative or developing technology. Where an alternative is offered, it is the vendor's responsibility to identify any variations from this part of ISO 13628 and provide details.

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# Petroleum and natural gas industries — Design and operation of subsea production systems —

## Part 7: Completion/workover riser systems

### 1 Scope

This part of ISO 13628 gives requirements and recommendations for the design, analysis, materials, fabrication, testing and operation of subsea completion/workover (C/WO) riser systems run from a floating vessel.

It is applicable to all new C/WO riser systems and may be applied to modifications, operation of existing systems and reuse at different locations and with different floating vessels.

This part of ISO 13628 is intended to serve as a common reference for designers, manufacturers and operators/users, thereby reducing the need for company specifications.

This part of ISO 13628 is limited to risers, manufactured from low alloy carbon steels. Risers fabricated from special materials such as titanium, composite materials and flexible pipes are beyond the scope of this part of ISO 13628.

Specific equipment covered by this part of ISO 13628 is listed as follows:

- riser joints;
- connectors;
- workover control systems;
- surface flow trees;
- surface tree tension frames;
- lower workover riser packages;
- lubricator valves;
- retainer valves;
- subsea test trees;
- shear subs;
- tubing hanger orientation systems;
- swivels;
- annulus circulation hoses;

- riser spiders;
- umbilical clamps;
- handling and test tools;
- tree cap running tools.

Associated equipment not covered by this part of ISO 13628 is listed below:

- tubing hangers;
- internal and external tree caps;
- tubing hanger running tools;
- surface coiled tubing units;
- surface wireline units;
- surface tree kill and production jumpers.

## 2 Normative references

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

ISO 148, *Steel — Charpy impact test (V-notch)*

ISO 377, *Steel and steel products — Location and preparation of samples and test pieces for mechanical testing*

ISO 783, *Metallic materials — Tensile testing at elevated temperature*

ISO 898-1, *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 1: Bolts, screws and studs*

ISO 898-2, *Mechanical properties of fasteners — Part 2: Nuts with specified proof load values — Coarse thread*

ISO 1461, *Hot dip galvanized coatings on fabricated iron and steel articles — Specifications and test methods*

ISO 3183 (all parts), *Petroleum and natural gas industries — Steel pipe for pipelines — Technical delivery conditions*

ISO 2566-1, *Steel — Conversion of elongation values — Part 1: Carbon and low alloy steels*

ISO 4885, *Ferrous products — Heat treatment — Vocabulary*

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

ISO 6892, *Metallic materials — Tensile testing at ambient temperature*

ISO 9327-1, *Steel forgings and rolled or forged bars for pressure purposes — Technical delivery conditions — Part 1: General requirements*

ISO 9606-1, *Approval testing of welders — Fusion welding — Part 1: Steels*



ISO 9712, *Non-destructive testing — Qualification and certification of personnel*

ISO 10423:2003, *Petroleum and natural gas industries — Drilling and production equipment — Wellhead and christmas tree equipment*

ISO 10432, *Petroleum and natural gas industries — Downhole equipment — Subsurface safety valve equipment*

ISO 10474, *Steel and steel products — Inspection documents*

ISO 10945, *Hydraulic fluid power — Gas-loaded accumulators — Dimensions of gas ports*

ISO 11960:2001, *Petroleum and natural gas industries — Steel pipes for use as casing or tubing for wells*

ISO 11961, *Petroleum and natural gas industries — Steel pipes for use as drill pipe — Specification*

ISO 13533:2001, *Petroleum and natural gas industries — Drilling and production equipment — Drill-through equipment*

ISO 13535, *Petroleum and natural gas industries — Drilling and production equipment — Hoisting equipment*

ISO 13628-2, *Petroleum and natural gas industries — Design and operation of subsea production systems — Part 2: Unbonded flexible pipe systems for subsea and marine applications*

ISO 13628-4:1999, *Petroleum and natural gas industries — Design and operation of subsea production systems — Part 4: Subsea wellhead and tree equipment*

ISO 13628-5, *Petroleum and natural gas industries — Design and operation of subsea production systems — Part 5: Subsea umbilicals*

ISO 13628-6:2000, *Petroleum and natural gas industries — Design and operation of subsea production systems — Part 6: Subsea production control systems*

ISO 14693, *Petroleum and natural gas industries — Drilling and well-servicing equipment*

ISO 15156-1, *Petroleum and natural gas industries — Materials for use in H<sub>2</sub>S-containing environments in oil and gas production — Part 1: General principles for selection of cracking-resistant materials*

ISO 15156-2:2003, *Petroleum and natural gas industries — Materials for use in H<sub>2</sub>S-containing environments in oil and gas production — Part 2: Cracking-resistant carbon and low alloy steels, and the use of cast irons*

ISO 15156-3, *Petroleum and natural gas industries — Materials for use in H<sub>2</sub>S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys*

ISO 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 15579, *Metallic materials — Tensile testing at low temperature*

API <sup>1)</sup> Spec 7 <sup>2)</sup>, *Rotary Drill Stem Elements*

API Spec 16C, *Specification for Choke and Kill Systems*

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

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1) American Petroleum Institute, 1220 L Street, North West Washington, DC 20005-4070, USA.

2) For the purposes of this part of ISO 13628, API Spec 7 will be replaced by ISO 10424-1 and ISO 10424-2 when they become publicly available.

ASME <sup>3)</sup>, *Boiler and pressure vessel code, Section VIII:2001, Rules for construction of pressure vessels, Division 1*

ASME, *Boiler and pressure vessel code, Section IX:2001, Welding and brazing qualification*

ASTM A193, *Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service*

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

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

ASTM <sup>4)</sup> A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*

ASTM A508, *Standard Specification for Quenched and Tempered Vacuum-Treated Carbon and Alloy Steel Forgings for Pressure Vessels*

BS <sup>5)</sup> 7201, *Hydro-pneumatic accumulators for fluid power purposes — Part 1: Specification for seamless steel accumulator bodies above 0,5 l water capacity*

EN <sup>6)</sup> 287-1, *Qualification test of welders — Fusion welding — Part 1: Steels*

EN 288 (all parts), *Specification and approval of welding procedures for metallic materials*

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*

IEC <sup>7)</sup> 60089-0, *Electrical apparatus for explosive gas atmospheres — Part 0: General Requirements, Fourth Edition*

MSS <sup>8)</sup> SP-25, *Standard Marking Systems for Valves, Fittings, Flanges and Unions*

SAE <sup>9)</sup> AS 4059, *Aerospace fluid power — Cleanliness classification for hydraulic systems*

### 3 Terms, definitions, abbreviated terms and symbols

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

#### 3.1 Terms and definitions

##### 3.1.1

##### **accidental load**

load(s) which are imposed on the C/WO riser system under abnormal and unplanned conditions

EXAMPLES Loss of vessel station-keeping and heave compensator lock-up.

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3) ASME International, Three Park Avenue, New York, NY 10016-5990, USA.

4) American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

5) British Standards Institution, 389 Chiswick High Road, London W4 4AL, UK.

6) European Committee for Standardization, 36 rue de Stassart, B-1050, Brussels, Belgium.

7) International Electrotechnical Commission, IEC Central Office, 3, rue de Varembe, P.O. Box 131, CH-1211 Geneva 20, Switzerland.

8) Manufactures Standardization Society of the Valve & Fitting Industry, 127 Park Street, N.E., Vienna, VA 22180, USA.

9) SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, USA.

**3.1.2****agreement**

unless otherwise indicated, “by agreement” means “by agreement between manufacturer and purchaser at the time of enquiry and order”

**3.1.3****apparent weight****weight in water****wet weight****net lift****submerged weight****effective weight**

submerged weight including content minus buoyancy

**3.1.4****attachment weld**

fillet or full penetration weld used for attachment of components to pipe or coupling

**3.1.5****auxiliary line**

conduit (excluding choke and kill lines) attached to the outside of the riser main pipe

EXAMPLES Hydraulic supply line and annulus circulation line.

**3.1.6****ball joint**

ball and socket assembly having a central through-passage equal to or greater than the riser internal diameter

NOTE This can be positioned in the riser string to reduce local bending stresses.

**3.1.7****barrier**

one or several barrier elements that are designed to prevent unintended flow of formation fluid

**3.1.8****barrier element**

device that, alone, cannot prevent flow from one side to the other side of itself

**3.1.9****bearing stress**

average normal stress on the contact surfaces of mating surfaces

**3.1.10****blow-out preventer****BOP**

device installed at the wellhead to contain well-bore pressure either in the annular space between the casing and the tubulars or in an open hole during drilling, completion, testing or workover

**3.1.11****BOP stack**

assembly of well control equipment including BOPs, spools, valves, hydraulic connectors, and nipples that connect to the subsea wellhead

NOTE As commonly used, this term sometimes includes the LMRP.

**3.1.12**

**BOP adapter joint**

**BOP spanner joint**

tubing hanger orientation joint

specialized C/WO riser joint used when the C/WO riser is deployed inside a drilling riser and subsea BOP to install and retrieve an orientated subsea tubing hanger

**3.1.13**

**BOP stack**

assembly of well control equipment including BOPs, spools, valves, hydraulic connectors and nipples that connects to the subsea wellhead

NOTE As commonly used, this term sometimes includes the LMRP.

**3.1.14**

**buoyancy module**

structure of low-mass material, usually foamed polymers strapped or clamped to the exterior of riser joints, to reduce the submerged mass of the riser

**3.1.15**

**calculation**

use of analytical-based formulas or numerical-based methods, e.g. finite element method or boundary element method, to investigate the structural safety of a component/system

**3.1.16**

**Charpy V-notch test**

test to indicate fracture toughness in terms of energy absorbed or lateral expansion or fracture appearance

**3.1.17**

**choke-and-kill line**

external conduits, arranged laterally along the riser pipe, and used to circulate fluids into and out of the wellbore to control well pressure

**3.1.18**

**connector**

mechanical device used to connect adjacent components in the riser system to create a structural joint resisting applied loads and preventing leakage

EXAMPLES Threaded types, including (i) one male fitting (pin), one female fitting (integral box) and seal ring(s), or (ii) two pins, a coupling and seal sea ring(s); flanged types, including two flanges, bolts and a gasket/seal ring; clamped hub types, including hubs, clamps, bolts and seal ring(s); dog-type connectors.

**3.1.19**

**control module**

assembly of subsea control equipment for piloted or sequential hydraulic or electrohydraulic operations from surface

NOTE Can be configured as a riser control module used for operation of landing strings in tubing hanger mode or as a workover control module in tree mode for operation of the lower workover package.

**3.1.20**

**completion riser**

temporary riser that is designed to run inside a BOP and drilling riser to allow for well completion

NOTE Completion operations are performed within the drilling riser. A completion riser can also be used for open-sea workover operations.

**3.1.21****completion/workover riser****C/WO riser**

temporary riser used for completion or workover operations

**3.1.22****component**

part of the pressure-containing equipment, which can be considered as an individual item for the calculation

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

**3.1.23****corrosion allowance**

amount of wall thickness added to the pipe or component to allow for corrosion, scaling, abrasion, erosion, wear and all forms of material loss

**3.1.24****crack tip opening displacement****CTOD**

measure of crack severity that can be compared against a critical value at the onset of crack propagation

**3.1.25****design basis**

set of project-specific design data and functional requirements that are not specified or are left open in the general standard

**3.1.26****design check**

assessment of a component for a load case by means of an application rule

**3.1.27****design criteria**

quantitative formulations which describe each failure mode the conditions shall fulfil

**3.1.28****design factor**

factor (usage factor) used in working stress design

**3.1.29****design life**

period for which a riser can be used for its intended purpose with anticipated maintenance but without substantial repair or replacement being necessary including storage and working periods

NOTE The design life includes the entire period from start of manufacture to condemnation of the C/WO riser system or part of the system.

**3.1.30****design load**

combination of load effects

**3.1.31****design material strength**

stress used for structural strength calculation

**3.1.32****design pressure**

maximum difference between internal pressure and external pressure that is unlikely to be exceeded during the life of the riser, referred to a specified reference height

NOTE Design pressure is often named maximum allowable pressure or rated working pressure or maximum allowable.

EXAMPLE Design pressure is the maximum pressure considering shut-in pressure at the wellhead (seabed) or at the top of the riser with subsea valves open, maximum well fracturing pressure, maximum well injection pressure, maximum surge pressure or maximum well kill pressure.

**3.1.33  
designer**

individual or organization that takes the responsibility for the design of C/WO riser systems conforming with requirements of this part of ISO 13628

**3.1.34  
drift**

cylindrical mandrel for verifying drift diameter of individual and assembled equipment

**3.1.35  
meter**

minimum diameter that allows for the passage of the drift

**3.1.36  
drift-off**

unintended lateral movement of a dynamically positioned vessel off its intended location relative to the wellhead, generally caused by loss of station-keeping control or propulsion

**3.1.37  
drill pipe riser**

single string of drill pipe with an attached hydraulic control umbilical and annulus umbilical

**3.1.38  
drilling riser**

system used with floating drilling vessel for guiding the drill string and circulating fluids between the drilling vessel and the subsea BOP

**3.1.39  
drive-off**

unintended movement of a dynamically positioned vessel off location driven by the vessel's main propulsion or station-keeping thrusters

**3.1.40  
dynamic positioning**

computerized means of maintaining a vessel on location by selectively activating thrusters

**3.1.41  
effective tension**

axial tension calculated at any point along a riser by considering only the top tension and the apparent weight of the riser and its contents (tension positive)

NOTE Global buckling and geometric stiffness is governed by the effective tension.

**3.1.42  
emergency disconnect package**

subsea equipment package that typically forms part of the lower workover riser package and provides a disconnection point between the riser and subsea equipment

NOTE This equipment is used when it is required to disconnect the riser from the well, typically in case of a vessel drift-off or other emergency that could move the vessel away from the well location.

**3.1.43****emergency quick-disconnect**

automatic activation of an emergency shutdown followed by an automatic disconnect of the riser

**3.1.44****emergency shutdown**

controlled sequence of events that ensures that the well is secured against accidental release of hydrocarbons into the environment, i.e. closing of barrier elements

**3.1.45****environmental loads**

loads due to the environment

EXAMPLES Waves, current and wind.

**3.1.46****environmental seal**

outermost pressure-containing seal at a connector interface

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

**3.1.47****fabricator**

individual or organization that takes the responsibility for the fabrication of CWO riser systems conforming with the requirements of this part of ISO 13628

**3.1.48****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

**3.1.49****fail-safe**

term applied to equipment or a system so designed that, in the event of failure or malfunction of any part of the system, devices are automatically activated to stabilize or secure the safety of the operation

**3.1.50****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

EXAMPLE Structural failure (excessive yielding, buckling, rupture, leakage) or operational limitations (slick joint protection length, clearance).

**3.1.51****false rotary**

component that sits on the drilling rotary and provides a slip profile for single, dual or triple tubing strings

NOTE This allows the workover control system umbilical to feed into the drilling riser without interfering with the slips.

**3.1.52****fatigue analysis**

conventional stress-life fatigue analysis using material S-N curves and specified fatigue design factors

**3.1.53****fatigue crack growth analysis**

analysis of crack growth from assumed initial defect size under the action of cyclic loading

NOTE Used to determine fabrication inspection requirements and in-service inspection plans.

**3.1.54**

**finite element analysis**

numerical method for analysing 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.

**3.1.55**

**flex 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

**3.1.56**

**floating vessel**

buoyant installation that is floating and positioned relative to the sea bottom by station-keeping systems

NOTE The following types of station-keeping systems are normally considered: catenary mooring systems and dynamic positioning systems based on thrusters. Combination of station-keeping systems can be considered.

EXAMPLE Semi-submersible drilling vessels and drill ships.

**3.1.57**

**fluid**

gases, liquids and vapour in pure phases as well as mixtures thereof

**3.1.58**

**fractile**

$p$ -fractile (or percentile) and the corresponding fractile value  $X_p$  is defined as  $F(X_p) = p$ , where  $F$  is the distribution function for  $X_p$

**3.1.59**

**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

**3.1.60**

**frequency domain**

dynamic analysis method based on the assumption that any applied irregular process is a superposition of fundamental, regular processes

NOTE Frequency domain analysis is usually associated with linear systems.

**3.1.61**

**functional load**

load caused by the physical existence of the riser system and by the operation and handling of the system, excluding pressure loads

**3.1.62**

**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 insufficient 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.



**3.1.63****gasket**

deformable material (or combination of materials) intended to be clamped between flanges to prevent leakage of fluid

**3.1.64****gimbal**

device that interfaces with the spider and the riser joint and enables the riser to rotate about the horizontal axis, thereby reducing the bending moments, which can otherwise occur due to vessel roll/pitch motions

**3.1.65****global analysis**

analysis of the complete riser string from the sea floor (wellhead) to top drive including tensioner joint, utilizing beam element

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.

**3.1.66****global buckling**

elastic Euler buckling

**3.1.67****grip length**

combined thickness of all the elements clamped together by the bolts and nuts, including washers, gaskets and joint members

**3.1.68****gross structural discontinuity**

structural or material discontinuity which affects the stress or strain distribution across the entire wall thickness over a region of significant area

EXAMPLE End-to-pipe junction, connector-to-pipe junction, the junction of two pipes of different diameters, thickness or material, or a stiffener-to-pipe junction.

**3.1.69****hang-off**

riser when disconnected from seabed

NOTE Hang-off is usually differentiated from disconnected. Disconnected is normally the condition directly after disconnecting the riser. Hang-off is normally associated with the riser suspended from the rotary table.

**3.1.70****heat-affected zone**

region around a weld that has been affected by welding

**3.1.71****heave**

floating vessel motion in the vertical direction

**3.1.72****horizontal tree**

subsea tree with production and annulus bore valves located external to the tree, where the tubing hanger or dummy tubing hanger is installed after the tree

**3.1.73****hydraulic connector**

mechanical connector that is activated hydraulically

**3.1.74**

**hydrodynamic loads**

flow-induced loads caused by the relative motion between the riser and the surrounding water

**3.1.75**

**integral riser**

integral style C/WO riser is a riser in which the pressure-containing conduits are mounted into a common assembly or joint

NOTE 1 An integral riser is typically classified as either jacketed or non-jacketed. The integral riser joint allows the production and annulus lines to be made up simultaneously.

NOTE 2 A jacketed C/WO riser can also contain hydraulic control lines inside the structural housing. This type of riser is typically used in applications where high tensile or bending loads are anticipated.

**3.1.76**

**jumper**

short piece of flexible pipe

**3.1.77**

**landing string**

all the equipment of the riser above the tubing hanger that is contained wholly or partly within the BOP stack and up to the first standard riser joint

NOTE For live well operations, the landing string typically consists of a tubing hanger running tool, subsea test tree, shear sub, retainer valve and lubricator valve. For killed well operations, the landing string typically consists of a tubing hanger running tool and tubing hanger orientation joint or slick joint.

**3.1.78**

**leak-tight**

leakage that is acceptable for a particular component

NOTE See 6.4.11.5.

**3.1.79**

**lifting device**

tool dedicated for lifting

**3.1.80**

**limit analysis**

method used to compute the resistance of a component made of ideally (rigid) plastic material

**3.1.81**

**load**

physical influence which causes stress and/or strains in the riser system

**3.1.82**

**load case**

combination of simultaneously acting loads

**3.1.83**

**local buckling**

buckling mode implying deformations of the cross-section

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

**3.1.84**

**load effect**

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

**3.1.85****low-frequency vessel motion**

motion response at frequencies below wave frequencies typically with periods ranging from 30 s to 300 s

**3.1.86****lower marine riser package****LMRP**

upper section of a two-section subsea BOP stack consisting of the hydraulic connector, annular BOP, ball/flex joint, riser adapter, jumper hoses for the choke, kill and auxiliary lines and subsea control modules

NOTE The LMRP interfaces with the BOP stack.

**3.1.87****lower riser package**

subsea equipment package which forms part of the lower workover riser package and typically consists of a WCT-BOP and tree running tool

**3.1.88****lower workover riser package**

lowermost equipment package in the riser string when configured for subsea tree installation/workover and including any equipment between the riser stress joint and the subsea tree, and typically consisting of a lower riser package and emergency disconnect package

NOTE The lower workover riser package permits well control and ensures a safe operating status whilst performing coiled tubing/wireline and well servicing operations.

**3.1.89****lubricator valve**

valve assembly typically situated below the surface tree and used to isolate the reservoir from the environment when deploying long wireline/coiled tubing tool assemblies

**3.1.90****maintenance**

total set of activities performed during the service life of the riser to preserve its function

**3.1.91****make-up tool**

tool to facilitate the make-up of the riser joint connectors

**3.1.92****manufacturer**

individual or organization that is normally responsible for the design and manufacture of the C/WO riser and its conformance with this part of ISO 13628

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

**3.1.93****manufacturing procedure specification**

document prepared by the manufacturer to demonstrate how the specified properties can be achieved and verified through the proposed manufacturing route

**3.1.94****mean static offset**

**<of vessel>** mean static offset includes static offset due to steady forces from current, wind and wave, offset due to low-frequency motions and active positioning of the vessel

**3.1.95****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 tightness

**3.1.96**

**nominal value**

dimensions as specified on the drawings and specifications

**3.1.97**

**non-integral riser**

riser which is made up of independent production and annulus strings or bores

NOTE This type of riser is normally run with joints slightly staggered to allow conventional tubing or drill pipe-handling tools to be used for make-up of joints. Clamping the tubular members as they are assembled provides ease of handling and some structural stiffening. A non-integral C/WO riser can be grouped into two types: a drill pipe riser and a tubing riser.

**3.1.98**

**notch stress range**

sum of the primary stress range plus the secondary stress range plus the peak stress range, forming the total stress range (see Annex C), as applied to fatigue assessment of unwelded parts

**3.1.99**

**operating envelope**

limited range of parameters in which operations will result in safe and acceptable equipment performance

**3.1.100**

**operating mode**

condition that arises from the use and application of the equipment or riser system

NOTE Typical operating modes are racking of riser components, running/retrieval, landing/connecting, overpull to verify lockdown, system pressure testing, normal operation, surface shut-in, subsea shut-in, disconnecting, hang-off, overpull to retrieve tubing hanger, failure of dynamic positioning system, failure of tensioner system and failure of anchors or anchor lines.

**3.1.101**

**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.

**3.1.102**

**ovalization**

deviation of the circumference from a circle which has the form of an elliptic cross-section

**3.1.103**

**qualified personnel**

individuals with characteristics or abilities gained through theory and training and/or experience as measured against the manufacturer's established requirements

**3.1.104**

**peak stress**

part of stress, which is additive to the respective primary and secondary stresses, to form the total stress

NOTE Peak stresses do not cause any noticeable distortion and are only important to fatigue and brittle fracture in conjunction with primary and secondary stresses.

**3.1.105**

**pitch**

nominal distance between two adjacent threads roots or crests

**3.1.106****primary load**

load which is independent of structural deformation in the riser and induces an internal force that is necessary to satisfy the laws of static equilibrium

NOTE The internal force acts as long as the load is applied, and does not diminish when yielding occurs.

EXAMPLE Internal pressure, external hydrostatic pressure, self-weight, contents and buoyancy of the riser.

**3.1.107****primary stress**

stress that satisfies the laws of equilibrium of pressure, external force and moment (i.e. load effects)

NOTE 1 Regarding the mechanical behaviour of a structure, the basic characteristic of this type of stress is that in case of (non-admissible) increment of external load, the deformations upon full plasticification of the section considerably increases without being self-limiting.

NOTE 2 Regarding primary stress, distinction is made between membrane stress and bending stress with respect to their distribution across the cross-section governing the load-carrying behaviour. Primary membrane stress is defined as the average value of the respective stress components distributed over the section governing the load-carrying behaviour. Primary bending stress is defined as primary stress distributed linearly across the considered section and proportional to the distance from the neutral axis.

NOTE 3 Regarding the distribution of membrane stress along the wall, distinction is made between general primary membrane stress and local primary membrane stress. Membrane stress due to gross structural discontinuities (e.g. integral attachments) is considered as local.

**3.1.108****process shutdown**

controlled sequence of events that ensures that the well is secured against accidental release of hydrocarbons to the environment

**3.1.109****prying**

magnification of an external load by a pseudo-lever action when the load is an eccentric tensile load

**3.1.110****pup joint**

joint of pipe or tubing shorter than standard length

**3.1.111****purchaser**

organization that buys the CWO riser system on behalf of the user and/or operator or for its own use

**3.1.112****ratcheting**

progressive inelastic deformation or strain which can occur in a component that is subjected to variations of mechanical stress, thermal stress, or both (thermal stress ratcheting is partly or wholly caused by thermal stress)

NOTE Ratcheting results in a plastic deformation, which increases by about the same amount at each cycle and quickly leads to an unacceptable value.

**3.1.113****re-entry spool**

uppermost part of a subsea tree to which the CWO riser is attached to gain vertical well access or the uppermost part of a lower workover riser package to which an emergency disconnect package connector is attached to provide a single disconnect point

**3.1.114**

**resistance**

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

**3.1.115**

**response amplitude operator**

**RAO**

relationship between wave surface elevation amplitude and the vessel response amplitude, and the phase lag between the two

**3.1.116**

**retainer valve**

valve assembly in the C/WO riser used to retain fluid within the riser and hence preventing its escape to the environment during a riser disconnect operation

NOTE Typically located just above the disconnect point.

**3.1.117**

**return period**

average period of time between occurrences of a given event

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

**3.1.118**

**riser disconnect**

operation of unlatching a riser connector

EXAMPLE Disconnecting the emergency disconnect package from the lower riser package and/or disconnecting the riser from the subsea test tree.

**3.1.119**

**riser joint**

joint consisting of a tubular member(s) midsection, with riser connectors at the ends

NOTE Riser joints are typically provided in 9,14 m to 15,24 m (30 ft to 50 ft) lengths. Shorter joints, pup joints, can also be provided to ensure proper space-out while running the subsea tree, tubing hanger, or during workover operations.

**3.1.120**

**riser model**

structural model, established from the tabulated data of the riser, to describe the actual riser, and used in a global analysis of the riser system

**3.1.121**

**riser pipe**

seamless pipe which forms the principal conduit of the riser joint

EXAMPLE The riser pipe is the conduit for containing the production fluid flow from the well to the surface tree.

**3.1.122**

**riser system**

comprises the riser and all integrated components including subsea and surface equipment

EXAMPLE In tubing hanger mode, the system includes all components from tubing hanger to the top drive; in tree mode, the system includes all components from the wellhead to the top drive.

**3.1.123**

**rotary table**

device used to apply torque to the drill string during drilling and normally located in the centre of the drill floor

NOTE Can be rotated and can support wear bushing or spider.

**3.1.124****running tool**

specialized tool used to run equipment in a well

EXAMPLE Wireline running tool or various types of tubing-type running tools.

**3.1.125****wave scatter diagram**

table listing occurrence of sea-states in terms of significant wave height and wave peak period or mean upcrossing period

**3.1.126****seal**

barrier to prevent the passage of fluids

**3.1.127****seamless pipe**

tubular product made without a welded seam, manufactured in a hot-forming process using an extrusion or drawing process that can be followed by cold sizing or cold finishing to produce the desired shape, dimensions and properties

**3.1.128****secondary load**

load induced by structural deformation (or the prevention thereof) in the riser which is necessary to satisfy the laws of compatibility of strain and deformation

NOTE The internal forces induced by a secondary load diminish when yielding occurs. Secondary loads do not have to be taken into account where they do not affect the resistance of the member/component to resist other loads. Preload of bolts in flanges is an example. During make-up of a flange, the torque/tension applied by the tool on the bolts is primary, but after make-up, the residual bolt preload is secondary.

EXAMPLE An example of a secondary load is the bending caused in the C/WO riser during operation within the drilling riser due to flex joint/ball joint angles. Bending moments that exceed yield, in this case, do not generally cause excessive yielding and failure. Other examples are differential temperature in restrained sections and residual stresses after welding.

**3.1.129****secondary stress**

stress developed by constraint due to a geometrical discontinuity, by the use of materials of different elastic moduli under external load, by constraint due to differential thermal expansion, or by assembly load (preload) that does not impair the sealing performance of a connector

NOTE 1 Only stresses that are distributed linearly across the thickness are considered secondary stresses. For non-linearly distributed stresses, the secondary stresses are those of the equivalent linear distribution.

NOTE 2 With respect to the mechanical behaviour of the structure, the basic characteristic of secondary stresses is that they lead to plastic deformation when equalizing different local distortions in the case of excess of the yield strength. Characteristic for a secondary stress is that it is self-limiting, i.e. local flow deformation leads to a limitation of the stress.

NOTE 3 Secondary stresses can be of the membrane or bending type.

NOTE 4 Bending stresses caused by gross structural discontinuities and acting across the wall thickness of the pipe are classified as secondary stresses.

**3.1.130****secure status**

establishment of two independent barriers between the reservoir and the environment

**3.1.131**

**service life**

duration of time in which the equipment performs under the specified design conditions, i.e. time in active operation excluding storage periods

NOTE The service life is normally a small fraction of the design life.

**3.1.132**

**shearing valve**

gate valve or ball valve designed to shear wireline or coiled tubing and that can seal the bore

**3.1.133**

**slick joint**

special riser joint designed to prevent damage to the riser and control umbilical where they pass through the rotary table

NOTE Usually included in C/WO risers and is sometimes named "cased wear joint".

**3.1.134**

**S-N curve**

graphical presentation of the dependence of fatigue life,  $N$ , on fatigue strength,  $S$

NOTE It is also known as the Wöhler curve.

**3.1.135**

**sour service**

service conditions with  $H_2S$  content exceeding the minimum specified by ISO 15156 (all parts) at the design pressure

**3.1.136**

**specified minimum yield strength**

minimum yield strength at room temperature prescribed by the specification or standard under which the material is purchased

**3.1.137**

**spider**

device having retractable jaws or dogs used to support the riser on the uppermost connector support shoulder during running of the riser

NOTE The handling spider sits either on the rotary bushing or in the rotary table. It provides a hang-off point for the integral C/WO riser. Some spiders will lock to the rotary via the kelly drive pinholes in the master bushing. With the pins engaged, the spider can resist torque. For non-integral risers, tubing slips and false rotaries are used in lieu of the spider.

**3.1.138**

**splash zone**

part of the riser subjected to repeated wetting and drying by seawater

**3.1.139**

**stab**

mating box and pin assembly that provides pressure-tight engagement of two pipe joints

NOTE An external mechanism is normally used to keep the box and pin engaged. For example, riser joint annulus stabs can be retained in the stab mode by the make-up of the riser coupling.

**3.1.140**

**stab sub**

male half of sealing mechanism between component interfaces

NOTE Stab subs can use elastomeric or metal seals or both.



**3.1.141****strength**

mechanical property of a material, usually given in units of stress

**3.1.142****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, which occur in the riser component.

**3.1.143****stress intensity factor**

(fracture mechanics) factor used 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

**3.1.144****stress joint**

specialized riser joint designed with a tapered cross-section, in order to control curvature and reduce local bending stresses

NOTE It is the lowermost riser joint in the riser string when configured for workover.

**3.1.145****stress range**

difference between stress maximum and stress minimum in a stress cycle

**3.1.146****stroke**

total upward and downward vertical movements of the riser relative to the vessel, i.e. travel of the riser tensioner, draw works and slick joint

NOTE It includes effects from environmental loads, functional loads (i.e. top tension, temperature and mean static vessel offset) and pressure.

**3.1.147****subsea test tree**

assembly of valves positioned above the tubing hanger running tool located inside the subsea BOP and equivalent to the lower workover riser package

NOTE It is used to secure the well and provides a disconnect point for the C/WO riser. The subsea test tree can be configured for operation on horizontal or vertical trees.

**3.1.148****subsea tree**

assembly of valves attached to the uppermost connection of the subsea wellhead and used to control well production

**3.1.149****subsea wellhead**

wellhead assembly used during drilling and completion operations that has provisions to lock and seal to a subsea BOP stack and to the subsea tree

**3.1.150****surface tree**

device which provides flow control of the production and/or annulus bores during both tubing hanger installation and subsea tree installation/workover operations

NOTE It can also have provisions to support the mass of the C/WO riser system.

**3.1.151**

**surface tree adapter joint**

crossover from the standard riser joint connector to the connection at the bottom of the surface tree

NOTE Its bore configuration is consistent with the standard riser joint. This speciality joint is usually made up to the surface tree prior to installation.

**3.1.152**

**support shoulder**

shoulder or projection on the external surface of a connector or the riser component for supporting the riser system or well control equipment during riser running operations

**3.1.153**

**surge**

vessel motion along the fore/aft axis

**3.1.154**

**surge pressure**

pressure produced by sudden changes in the velocity of the moving stream of fluids inside the riser

**3.1.155**

**sway**

vessel motion along the port/starboard axis

**3.1.156**

**system pressure test**

field hydrostatic leak-tightness pressure test of the complete riser system performed after installation and before start of operation

**3.1.157**

**system test pressure**

test pressure applied to the riser during system field pressure test of the C/WO riser system performed after installation and before start of operation

**3.1.158**

**minimum design metal temperature**

lowest metal temperature likely to be reached in operation, normally taken as the lowest fluid temperature to which the riser will be exposed in service

**3.1.159**

**room temperature**

any temperature between 4 °C and 40 °C (40 °F and 104 °F), i.e. temperature corresponding to the test conditions of the material

**3.1.160**

**tension joint**

special riser joint that provides a means for tensioning the C/WO riser with the floating vessel's tensioning system during open-sea workover mode

NOTE When in use, the tension joint is located below the slick joint, which has a provision for attaching the tensioner unit to the riser.

**3.1.161**

**tension ring**

attachment point on the tension joint for the floating vessel tensioning lines

**3.1.162**

**tensioner system**

device that applies a close to constant 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

**3.1.163****time domain**

timewise, incremental simulation of riser response

NOTE Offers the capability of modelling hydrodynamic and structural non-linearity.

**3.1.164****top tensioned riser**

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

**3.1.165****tree running tool**

device used to run and land the subsea tree on the subsea wellhead

**3.1.166****tubing**

pipe used in wells to conduct fluid from the well's producing formation into the subsea tree

**3.1.167****tubing hanger**

component used to support the downhole completion tubing string

NOTE It is also typically used to seal and contain the completion annulus from the environment.

**3.1.168****tubing hanger running tool**

device used to run, land and lock the tubing hanger inside the wellhead, tubing spool, or subsea tree

**3.1.169****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.

**3.1.170****umbilical**

flexible hose consisting of a group of electrical cables, optical fibre cables, hoses, pipes, either on their own or with combinations of each other, cabled together for flexibility and oversheathed and/or armoured for mechanical strength, used to transmit fluid/electrical signals to and from a power source to a remote station

**3.1.171****umbilical clamp**

clamp used to attach the umbilical(s) to the riser joints

**3.1.172****user and/or operator**

organization that uses and/or operates the C/WO riser system

**3.1.173****verification**

examination to confirm that an activity, a product or a service is in accordance with specified requirements

**3.1.174****vessel mean offset**

offset created by steady forces from current, wind and waves

**3.1.175**

**vessel offset**

total offset of the vessel, taking into account the vessel mean offset, wave frequency motions and low-frequency wind and wave motions

**3.1.176**

**vertical tree**

subsea tree with either multiple or concentric bores and production valves located in the vertical bore of the tree, where the tubing hanger is installed before the tree

**3.1.177**

**vortex-induced vibration**

in-line and transverse oscillation of a riser caused by current-induced periodic shedding of vortices

**3.1.178**

**wave frequency motion**

motion of the vessel at the frequencies of incident waves

**3.1.179**

**wear bushing**

bushing to be installed in the rotary table, to provide a smooth lateral support to the workover riser at drill floor level

**3.1.180**

**well completion**

well operations including tubing installation, well perforation and test production

**3.1.181**

**wireline/coiled tubing BOP**

**WCT-BOP**

subsea BOP that attaches to the top of a subsea tree to facilitate wireline or coiled tubing intervention

NOTE WCT-BOP rams are designed to shear wireline or coiled tubing and seal the bore, in one operation.

**3.1.182**

**work**

all activities to be performed within relevant contract(s) issued by designer, owner, operator, contractor, fabricator or manufacturer

**3.1.183**

**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 can be retrieved in severe environmental conditions

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

**3.2 Abbreviated terms**

ASTM	ASTM International
BOP	blow-out preventer
CTOD	crack tip opening displacement
C/WO	completion/workover
EDP	emergency disconnect package
EN	European Standard

FAT	factory acceptance test
FMECA	failure mode, effects and criticality analysis
GPS	global positioning system
HAZOP	hazard and operability
HV	Vickers hardness
IMO	International Maritime Organization
LMRP	lower marine riser package
MPI	magnetic particle inspection
NA	not applicable
NDT	non-destructive testing
OOR	out of roundness
PWHT	post-weld heat treatment
RAO	response amplitude operator
SCF	stress concentration factor
SCSSV	surface controlled subsurface safety valve
SSC	sulfide stress-cracking
UT	ultrasonic testing
WCT-BOP	wireline/coiled tubing BOP

### 3.3 Symbols

$A_{b,r}$	bolt root area
$A_{b,s}$	bolt stress cross-sectional area
$A_c$	pipe cross-section area
$A_{int}$	internal cross-section area of the pipe
$A_o$	external cross-section area of the pipe giving buoyancy if submerged
$A_{TTS}$	tensile test specimen cross-section area
$A_5$	elongation after rupture, expressed in percent; for a tensile test piece with gauge length, $L_0 = 5,65\sqrt{A_{TTS}}$ or $5d_d$
$a$	crack depth for surface flaws or half depth for embedded crack
$a_f$	final crack size
$a_0$	initial crack size
$\bar{a}$	characteristic fatigue strength or intercept of the design S-N curve with the log $N$ axis

$\bar{a}_1$	intercept of the design S-N curve with the log $N$ axis, left part of S-N curve
$\bar{a}_2$	intercept of the design S-N curve with the log $N$ axis, right part of S-N curve
$\bar{a}_{1,\text{thick}}$	intercept of the design S-N curve with the log $N$ axis, left part of S-N curve, size corrected
$\bar{a}_{2,\text{thick}}$	intercept of the design S-N curve with the log $N$ axis, right part of S-N curve, size corrected
$C$	constant crack growth-rate parameter
$C_f$	design condition factor
$D_{\text{FAT}}$	fatigue damage
$D_F$	design fatigue factor
$D_{\text{align}}$	pipe/connector alignment (line-up tolerance) on diameter
$D_{\text{clear}}$	minimum drift clearance on diameter
$D_{\text{drift}}$	major drift diameter
$D_{\text{int}}$	inside diameter of pipe
$D_{\text{int,min}}$	minimum inside diameter of pipe
$D_o$	specified or nominal pipe outside diameter
$D_{o,\text{max}}$	maximum outside diameter at any cross-section
$D_{o,\text{min}}$	minimum outside diameter at any cross-section
$D_{\text{SN}}$	accumulated long-term fatigue damage or Miner-Palmgren damage ratio
$D_{\text{SN},ij}$	fatigue damage in the sea-state, $j$ , and wave direction, $i$
$D_{\text{weld}}$	weld root bead finish (height) on weld root diameter
$d$	minor drift diameter
$d_b$	nominal (basic major diameter) bolt diameter
$d_{b,f}$	mean effective bolt diameter
$d_{bh}$	bolt hole diameter
$d_d$	tensile test specimen diameter
$d_{\text{max}}$	maximum depth below the surface for a blend
$d_n$	effective contact diameter of nut-bearing surface
$d_{nf}$	nut diameter across flats
$d_t$	effective contact diameter of the threads
$E$	modulus of elasticity
$e$	axial misalignment (eccentricity or centre-line mismatch)

$e_0$	misalignment (eccentricity) inherent in the S-N data
$e_{\text{OOR,max}}$	maximum misalignment resulting from out of roundness
$e_{\text{t,max}}$	maximum misalignment resulting from difference in wall thickness
$F_b$	pipe burst design factor
$F_d$	design factor
$F_{\text{hb}}$	pipe hoop buckling (collapse) design factor
$F_{\text{w,c}}$	wave and current forces
$f(S_{\text{a,lm}})$	Weibull probability density function for the stress amplitude, $S_{\text{a,lm}}$
$f_m$	stress range reduction factor
$f_s(S)$	stress cycles probability density function
$f_0$	initial pipe ovality
$g$	acceleration due to gravity
$H_s$	significant wave height
$H_{\text{wrf}}$	weld root bead finish
$h$	height difference between the actual location and the internal pressure reference point
$I$	moment of inertia of section
$I_n$	$n$ th order response spectral moment
$I_{\text{pitch}}$	pitch of the threads
$I_0$	zero-order moment of stress spectrum
$I_2$	second-order moment of stress spectrum
$i$	summing index
$J$	polar moment of inertia of section
$j$	summing index
$\Delta K$	stress intensity factor
$K_F$	flex-joint rotational stiffness
$K_m$	geometric stress concentration factor
$K_{\text{notch}}$	notch stress concentration factor
$\Delta K_{\text{th}}$	threshold stress intensity factor range below which fatigue crack growth does not occur
$k$	number of stress range bins (blocks)
$k_{\text{cg}}$	crack growth exponent

$k_1$	thickness exponent on fatigue strength
$L_c$	clearance
$L_F$	calculated fatigue life
$L_S$	service life
$L_{SO}$	vessel static offset
$L_0$	tensile test-specimen gauge length
$l_b$	bolt clamp length (clear distance between engaged threads)
$l_{se}$	length of stud engagement
$M_{bm}$	bending moment
$M_{b,max}$	maximum torque during make-up
$M_{b,nom}$	nominal torque during make-up
$\Delta M_{bm}$	bending moment range
$M_c$	single load ultimate bending capacity
$M_f$	bending moment required to bend C/WO riser
$M_G$	global bending moment acting below marine riser flex-joint
$M_{pc}$	plastic bending moment capacity of the pipe
$M_T$	applied torque
$m$	negative inverse slope of the S-N curve
$m_1$	negative inverse slope of the S-N curve, left part
$m_2$	negative inverse slope of the S-N curve, right part
$N$	number of cycles to failure at constant stress range
$N_i$	number of cycles to failure at constant stress range $S_i$ in each stress bin (block) $i$
$N_p$	design operating cycles to failure
$N_1$	point of discontinuity on a bilinear S-N curve
$N_{1,a}$	point of discontinuity on a bilinear S-N curve, in air or non-corrosive environment
$N_{1,sw}$	point of discontinuity on a bilinear S-N curve, in seawater with cathodic protection
$n_i$	number of occurrences in stress range bin $i$
$n_{thr}$	number of threads per inch
$P_{br}$	average bearing stress
$P_{bs}$	primary bending stress



$P_l$	local primary membrane stress
$P_m$	general membrane primary stress
$P_{sh}$	primary average shear stress
$p_b$	burst pressure of the pipe
$p_{b,min}$	minimum pipe burst pressure
$p_c$	pipe hoop buckling (collapse) pressure
$p_{c,min}$	minimum pipe hoop buckling (collapse) pressure
$p_{ec}$	single load ultimate pressure capacity due to end cap effect
$p_{el}$	elastic hoop buckling (collapse) pressure (instability) of pipe cross-section
$p_{el,min}$	minimum elastic hoop buckling (collapse) pressure (instability) of pipe cross-section
$p_{FAT}$	hydrostatic FAT test pressure
$p_{int}$	internal pressure at a reference point
$p_{int,d}$	internal design pressure
$p_{int,min}$	minimum hydrostatic internal pressure
$p_{int,o}$	internal operating pressure
$p_{l,int}$	local internal pressure at a specified point
$p_o$	external pressure at a reference point
$p_{od}$	external design pressure
$p_{o,min}$	minimum external hydrostatic pressure
$p_p$	plastic pressure at hoop buckling (collapse) of the pipe cross-section
$p_{p,min}$	minimum plastic pressure at hoop buckling (collapse) of the pipe cross-section
$Q_{ms}$	secondary membrane stress
$Q_s$	secondary stress
$q_i$	probability of wave direction $i$
$q_j$	probability of sea-state $j$
$R_a$	arithmetical average roughness
$R_{c,test}$	ultimate capacity (resistance)
$R_d$	design capacity (resistance)
$R_m$	specified minimum ultimate tensile strength at room temperature
$R_{m/T}$	specified minimum ultimate tensile strength at a specific temperature

$R_{nc}$	normal operation capacity
$R_{t0,5}$	specified minimum yield strength for 0,5 % total elongation at room temperature
$R_{t0,5/T}$	specified minimum yield strength for 0,5 % total elongation at a specific temperature
$R_{t0,5/T,stud}$	specified minimum yield strength for 0,5 % total elongation at a specific temperature for a stud
$R_{t0,5/T,tapped}$	specified minimum yield strength for 0,5 % total elongation at a specific temperature for tapped hole material
$R_{uc}$	plastic collapse or ultimate capacity
$r$	pipe mean radius
$r_m$	mean section radius
$r_s$	section radius
$S$	stress range
$S_{a,lm}$	local stress maxima (amplitude)
$S_b$	bending component of the primary plus secondary principal stress range
$S_d$	design load effect
$S_{gs}$	geometric stress concentration stress range
$S_i$	constant stress range in each stress block
$S_m$	membrane (average) component of the primary plus secondary principal stress range
$S_{notch}$	notch stress range
$S_{P+Qs}$	primary plus secondary stress range
$S_{P+Qs+F}$	maximum primary plus secondary plus peak stress range
$S_1$	stress range at the point of discontinuity (bi-linear S-N curve)
$S_{1,thick}$	stress range with thickness correction
$S_{\sigma\sigma}$	autospectral density of the stress response
$T_{b,max}$	maximum bolt preload (tension) during make-up
$T_{b,min}$	minimum bolt preload (tension) during make-up
$T_{b,nom}$	nominal bolt preload (tension) during make-up
$T_c$	single load ultimate tension capacity
$T_e$	effective tension
$\Delta T_e$	cyclic effective tension range
$T_{eq}$	equivalent effective tension due to bending moment

$T_{e,tot}$	total effective tension from the marine riser and C/WO riser acting at the flex-joint
$T_p$	wave peak period
$T_{pc}$	plastic tension capacity of the pipe
$T_{tot}$	total axial load
$T_v$	vertical tension component of $T_{e,tot}$
$T_w$	true wall tension
$T_z$	wave zero-upcrossing period
$t$	pipe wall thickness
$t_{ca}$	corrosion/wear/erosion allowance
$\Delta t_{fab}$	is the absolute value of the negative tolerance taken from the material specification/standard
$t_n$	nominal (specified) pipe wall thickness
$\Delta t_{neg}$	percentage negative wall thickness tolerance
$t_{n,max}$	maximum nominal wall thickness
$t_{n,min}$	minimum nominal wall thickness
$\Delta t_{pos}$	percentage positive wall thickness tolerance
$t_{ref}$	reference thickness equal to 25 mm (0,984 in) for welded connections and bolts (stress diameter)
$t_1$	minimum pipe wall thickness without allowances and fabrication tolerances as appropriate
$t_2$	pipe wall thickness without allowances
$V_c$	current velocity
$V_{se}$	shear force acting at the flex-joint due to environmental loading on the marine riser and BOP
$V_{sh}$	total shear force acting at the marine riser flex-joint
$V_w$	wave velocity
$w_{BOP}$	submerged weight of the BOP and LMRP including bore contents
$w_e$	effective (apparent) weight
$w_p$	weight of the pipe
$x_{pca}$	pipe/connector alignment tolerance
$Y$	stress intensity correction factor
$Y_u$	ultimate tensile strength reduction factor at elevated temperature
$Y_y$	yield strength reduction factor at elevated temperature
$Z$	pipe plastic section modulus

$z$	variable in the gamma function
$\alpha$	Weibull distribution scale parameter
$\alpha_{bm}$	pipe cross-section slenderness parameter
$\alpha_L$	linear coefficient of thermal expansion
$\beta$	Weibull distribution dimensionless shape parameter
$\beta_{thr}$	half-angle of the threads, equal to 30° for UN threads
$\Gamma(\cdot)$	gamma function
$\Gamma( ; )$	complementary incomplete gamma function
$\gamma( ; )$	incomplete gamma function
$\Delta_b$	bolt transfer loss for tension tool
$\delta_1$	horizontal distance between the flex-joint and point of interest
$\delta_2$	horizontal distance from the BOP centre of gravity to the point of interest
$\varepsilon$	scatter in preload during make-up
$\varepsilon_{peq}$	equivalent plastic strain
$\varepsilon_t$	scatter in applied torque during make-up
$\theta_{dev}$	deviation angle of the BOP and high-pressure wellhead housing vertical axis relative to the global vertical axis
$\theta_B$	marine riser upper ball-joint angle relative to diverter vertical axis
$\theta_F$	marine riser lower flex-joint angle relative to BOP vertical axis
$\theta_G$	global marine riser lower flex-joint angle relative to the global vertical axis
$\theta_W$	main wave direction
$\mu_n$	coefficient of friction between nut and bearing surface
$\mu_t$	coefficient of friction between nut and bolt threads
$\hat{\mu}_{st}$	statistical moment for local maxima
$\nu$	Poisson's ratio
$\nu_0$	average zero-crossing frequency of the stress response
$\nu_{0,S}$	average zero-crossing frequency for the service life
$\rho_{int}$	density of the internal fluid
$\rho_o$	density of sea water
$\sigma$	stress

$\sigma_{act}$	actual average (minimum three specimens) yield strength from test specimens at test temperature
$\sigma_b$	bending stress
$\sigma_{br}$	average bearing stress
$\sigma_{eq}$	von Mises equivalent stress
$\Delta\sigma_{eq}$	equivalent von Mises stress range
$\sigma_{HS}$	structural hotspot stress
$\sigma_{int}$	stress at inside of section/wall
$\sigma_m$	membrane stress
$\sigma_{max}$	maximum cyclic principal stress
$\sigma_{mean}$	mean cyclic stress
$\sigma_{min}$	minimum cyclic principal stress
$\sigma_N$	notch stress
$\sigma_o$	stress at outside of section/wall
$\sigma_{SD}$	standard deviation of the stress response process
$\hat{\sigma}_{st}$	statistical moment for local maxima
$\sigma_u$	ultimate tensile strength to be used in design at maximum design temperature
$\sigma_y$	yield strength to be used in design at maximum design temperature
$\sigma_1, \sigma_2, \sigma_3$	principal stresses in directions 1, 2 and 3, respectively
$(\Delta\sigma)_1, (\Delta\sigma)_2, (\Delta\sigma)_3$	principal stress ranges in directions 1, 2 and 3, respectively
$(\sigma_{br})_{P+Qs}$	average primary plus secondary bearing stress
$(\sigma_{eq})_P$	primary membrane von Mises stress
$(\sigma_{eq})_{Pm+Qms+Pbs}$	primary membrane plus secondary membrane plus secondary bending von Mises stress
$(\Delta\sigma_{eq})_{P+Qs}$	primary plus secondary von Mises stress range
$(\sigma_{eq})_{Pl}$	local primary membrane von Mises stress
$(\sigma_{eq})_{Pm}$	general primary membrane von Mises stress
$\tau$	time
$\tau_{r\theta}$	average shear stress

$\tau_{ss}$	duration of short-term sea-states
$(\tau_{sh})_{Pm}$	average primary shear stress
$\phi_{A5}$	ductility reduction factor
$\phi$	variable in the gamma function
$\omega_{SR}$	angular frequency of stress response

## 4 System requirements

### 4.1 Purpose

Clause 4 specifies system requirements for C/WO riser systems.

### 4.2 Description of C/WO riser systems

A completion riser is used to run the tubing hanger and tubing through a drilling riser and BOP into the wellbore. A workover riser is typically used in place of a drilling riser to re-enter the well through the subsea tree in open sea, and may also be used to install the subsea tree. A completion and workover riser may be a common system with items added or removed to suit the task being performed.

Both riser types provide communication between the wellbore and the surface equipment. Both resist external loads and pressure loads and accommodate tools for necessary operations. The completion riser is exposed to external loading such as curvature of the drilling riser, especially at the upper and lower joints (flex-joint/ball-joint angles). The workover riser is exposed to ocean environmental loads such as hydrodynamic loads from waves and current in addition to vessel motions.

### 4.3 System engineering

System engineering shall be performed to ensure that engineering activities are performed in such a manner that the C/WO riser system complies with the provisions of this part of ISO 13628, purchaser's specification(s) and regulatory requirements. System engineering shall as a minimum include the following:

- establishment of a design basis, see 11.3 and Annex F;
- establishment of the system definition, see 4.4;
- system design, see 4.5;
- system review, see 4.6;
- verification, see 4.17.

A typical engineering-process flow chart is shown in Figure 1.

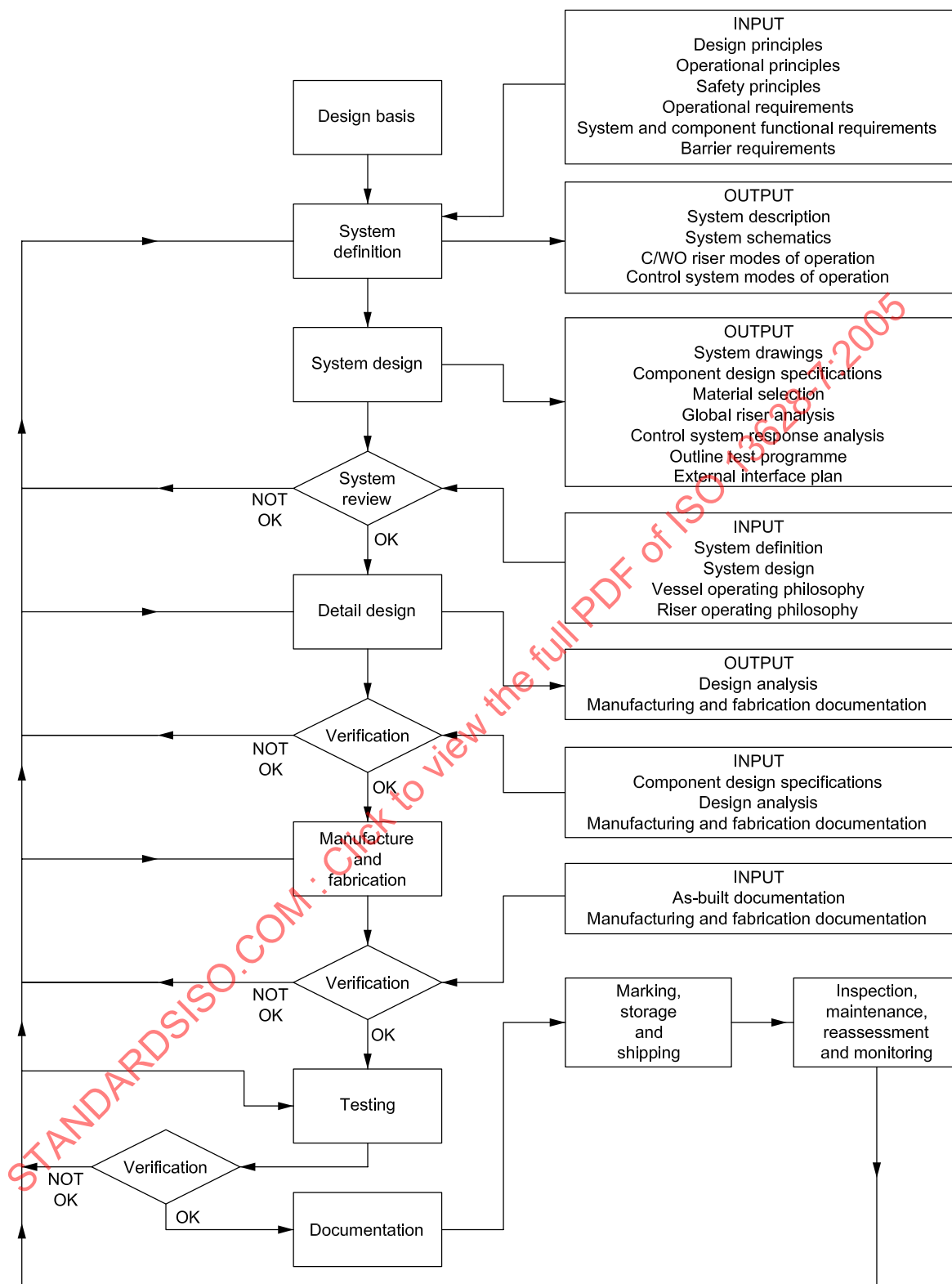


Figure 1 — Typical engineering-process flow chart

#### 4.4 System definition

A system solution shall be defined that meets the following requirements:

- a) regulatory requirements;
- b) barrier requirements; see 4.11;
- c) purchaser specification requirements; see Annex F;
- d) design basis; see 11.3 and Annex F;
- e) design principles, see 4.8;
- f) operational principles; see 4.9;
- g) safety principles; see 4.10;
- h) operational requirements; see 4.13 and Annex B;
- i) system and component functional requirements; see 5.2 and 5.4.

The system definition shall as a minimum be defined in terms of the following:

- system description;
- system schematics;
- riser system modes of operation; see 4.7.1;
- workover control system modes of operation; see 4.7.2.

#### 4.5 System design

System design shall be based on the design basis and the system definition. The system design shall as a minimum be defined in terms of the following:

- system drawings;
- component design specifications;
- material selection; see 6.4.3 and 7.2.1;
- global riser analysis; see Clause 6 and Annex B;
- workover control system analysis including emergency shutdown and disconnect response times; see 5.5.5 and 5.5.6;
- outline test programme;
- external interface plan.



## 4.6 System review

### 4.6.1 General

A systematic review or analysis shall be performed according to a clearly defined review basis and shall include the following:

- verification of system compliance;
- risk assessment.

### 4.6.2 System compliance

A systematic review shall be performed to verify that the C/WO riser system complies with the following:

- regulatory requirements;
- barrier requirements; see 4.11;
- purchaser specification requirements; see Annex F;
- design basis; see 11.3 and Annex F;
- design principles; see 4.8;
- operational principles; see 4.9;
- safety principles; see 4.10;
- operational requirements; see 4.13;
- system and component functional requirements; see 5.2 and 5.4.

### 4.6.3 Risk assessment

The operator shall specify the extent of the risk assessments and the risk assessment methods. The extent of the assessment or analysis shall reflect the criticality of the C/WO riser system, the criticality of the operations and previous experience with similar systems and operations.

Although the integrity of the C/WO riser system is the primary concern, the risk assessments shall encompass a larger scope, including the subsea well, drilling riser and BOP, surface vessel, environmental conditions and system interfaces at the top and bottom of the C/WO riser.

The purpose of the risk assessments shall be to identify possible critical items, operations or activities, which could cause or aggravate a hazardous condition, and to ensure that effective corrective measures are taken (e.g. either by design or operational procedures).

Quantitative risk analysis may be conducted to provide an estimation of the overall risk to health and safety, environment and assets and typically includes the following:

- hazard identification;
- assessment of probabilities of failure events;
- accident developments;
- consequences and risk assessment.

NOTE It should be noted that legislation in some countries requires risk analysis to be performed, at least at an overall level to identify critical scenarios that might jeopardize the safety and reliability of the C/WO riser system. Other methodologies for identification of potential hazards are failure mode and effect analysis and HAZOP studies.

Conditions that may require system review or risk analysis include:

- new or non-standard operations;
- operations in new areas;
- operations to be performed by new or modified vessel or installation;
- operations using new or modified equipment;
- operations including contractor(s) not familiar with the surface vessel, area or operation;
- operations that are considered hazardous (e.g. high temperature/high pressure, dynamic positioning, simultaneous operations, deep water or cold climate).

## 4.7 Modes of operation

### 4.7.1 Riser system

The C/WO riser system is normally used for the following operations:

- a) well completion, i.e. run/retrieve tubing and tubing hanger through the drilling riser and BOP;
- b) run/retrieve the subsea tree;
- c) workover operations to provide wireline/coiled tubing access into the production and/or annulus wellbores.

A typical arrangement for a connected C/WO riser in tree mode is illustrated in Figure 2. In the tubing hanger mode, see Figure 3 for a typical arrangement, the system is used to run the downhole completion through the drilling riser and BOP stack. The typical modes of operation for vertical and horizontal subsea trees are listed in Table 1.

Table 1 — Typical modes of operation

Operation <sup>a</sup>	Tubing hanger mode	Tree mode
Well completion	b + c	c
Well intervention — open sea	NA	b + c
Well intervention — inside drilling riser	b + c	NA
Full workover	b + c	c
<sup>a</sup> These modes of operation are typical for horizontal and vertical trees. Other modes of operation may apply for existing and future tree designs. <sup>b</sup> Horizontal tree. <sup>c</sup> Vertical tree.		

Typical schematics for each mode of operation and for both types of subsea trees are shown in Figures 4 to 7.

#### 4.7.2 Workover control system

The modes of operation for the control system shall be defined for each mode of operation (i.e. tubing hanger and tree mode) and subsequent operations. The following shall be defined for each mode:

- automatic shutdown and disconnect sequences including sequenced response times, time delay functions and interlock functions;
- control function failure mode, where applicable (i.e. fail-safe close or fail as is);
- function type (i.e. hydraulic, electrical, pneumatic or chemical injection);
- line number, line size, displaced volume and maximum line pressure;
- instrumentation location and type;
- chemical/methanol injection points, injection pressure and flow rate.

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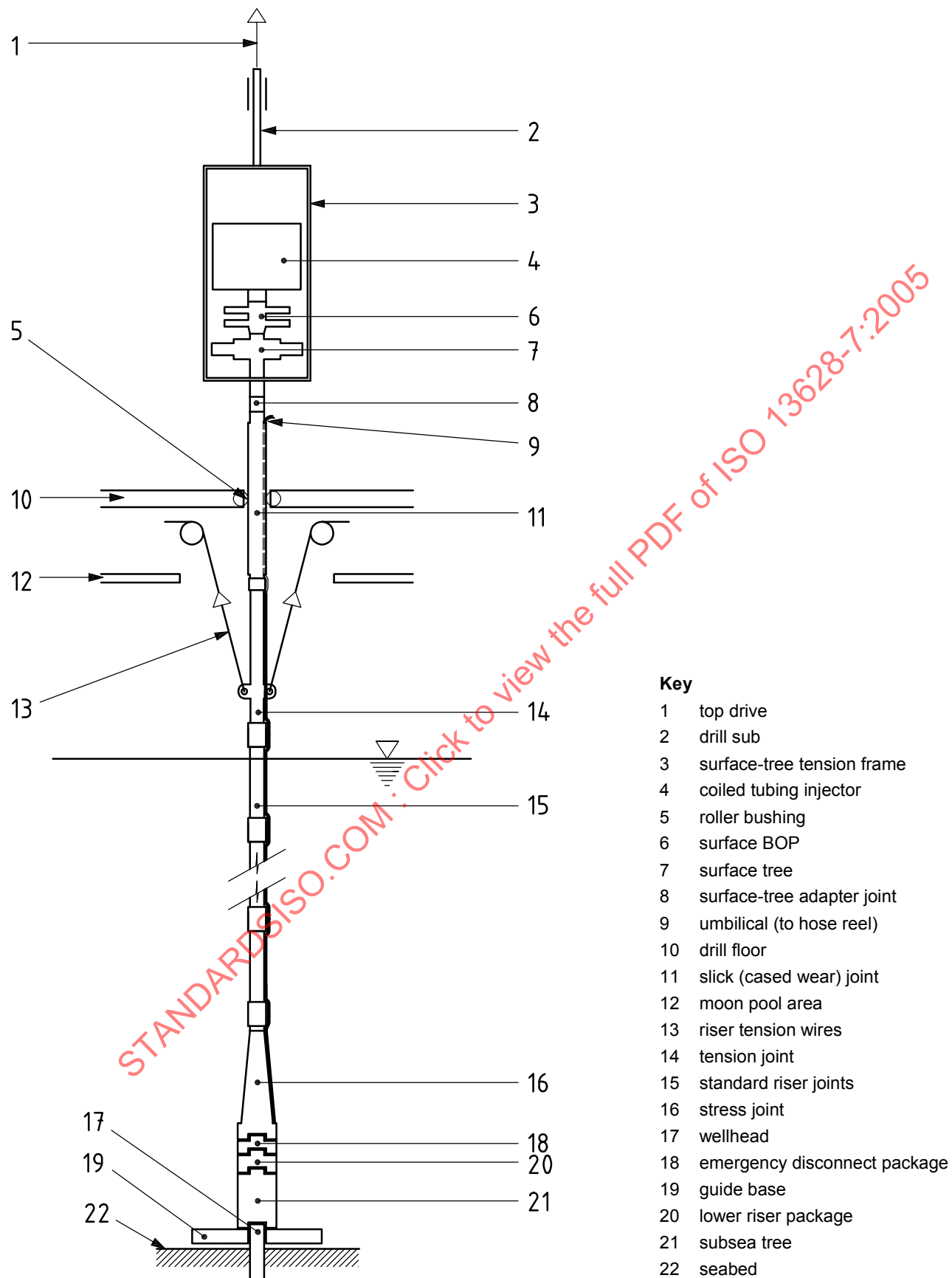


Figure 2 — Typical C/WO riser general arrangement — Tree mode

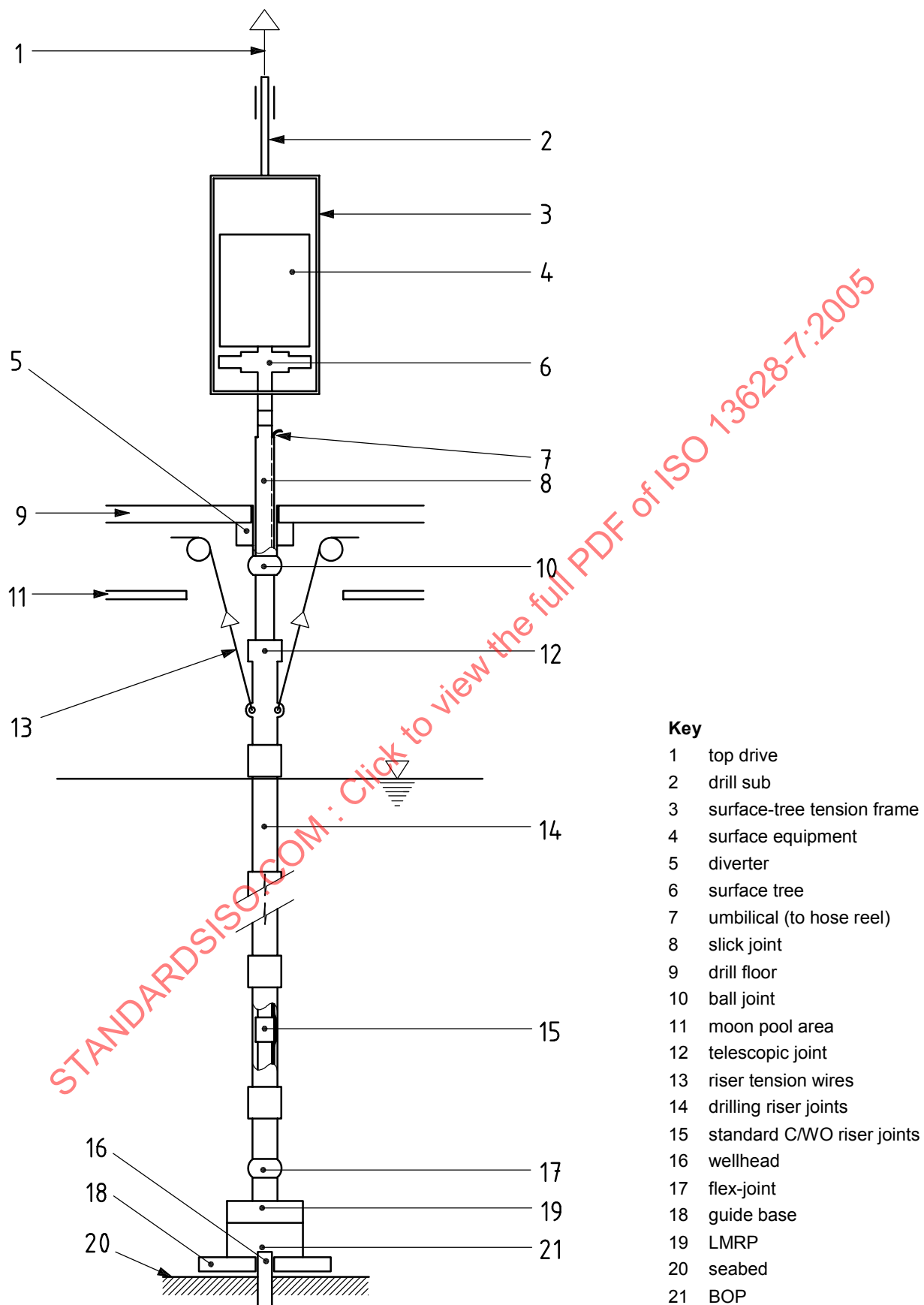
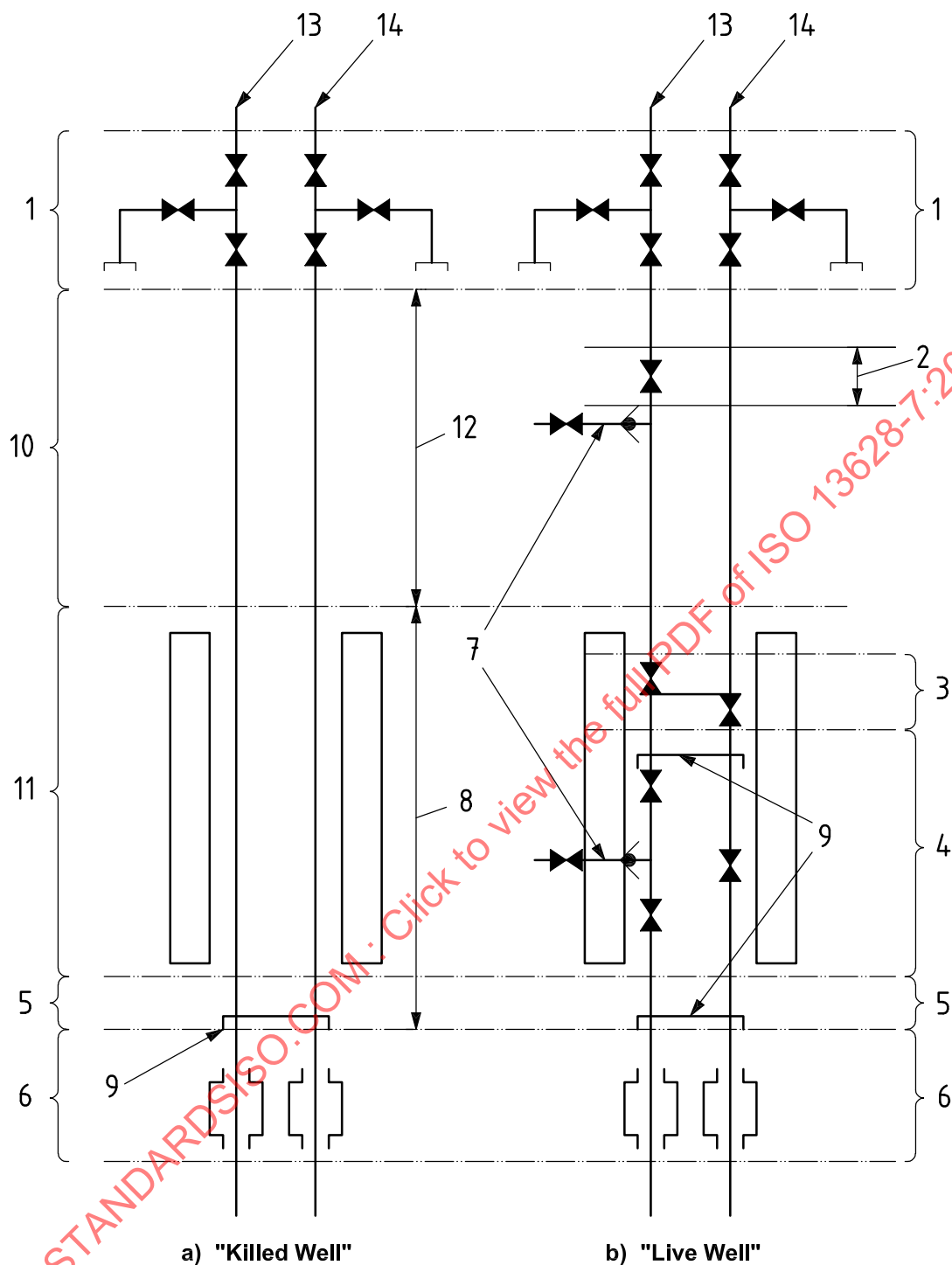


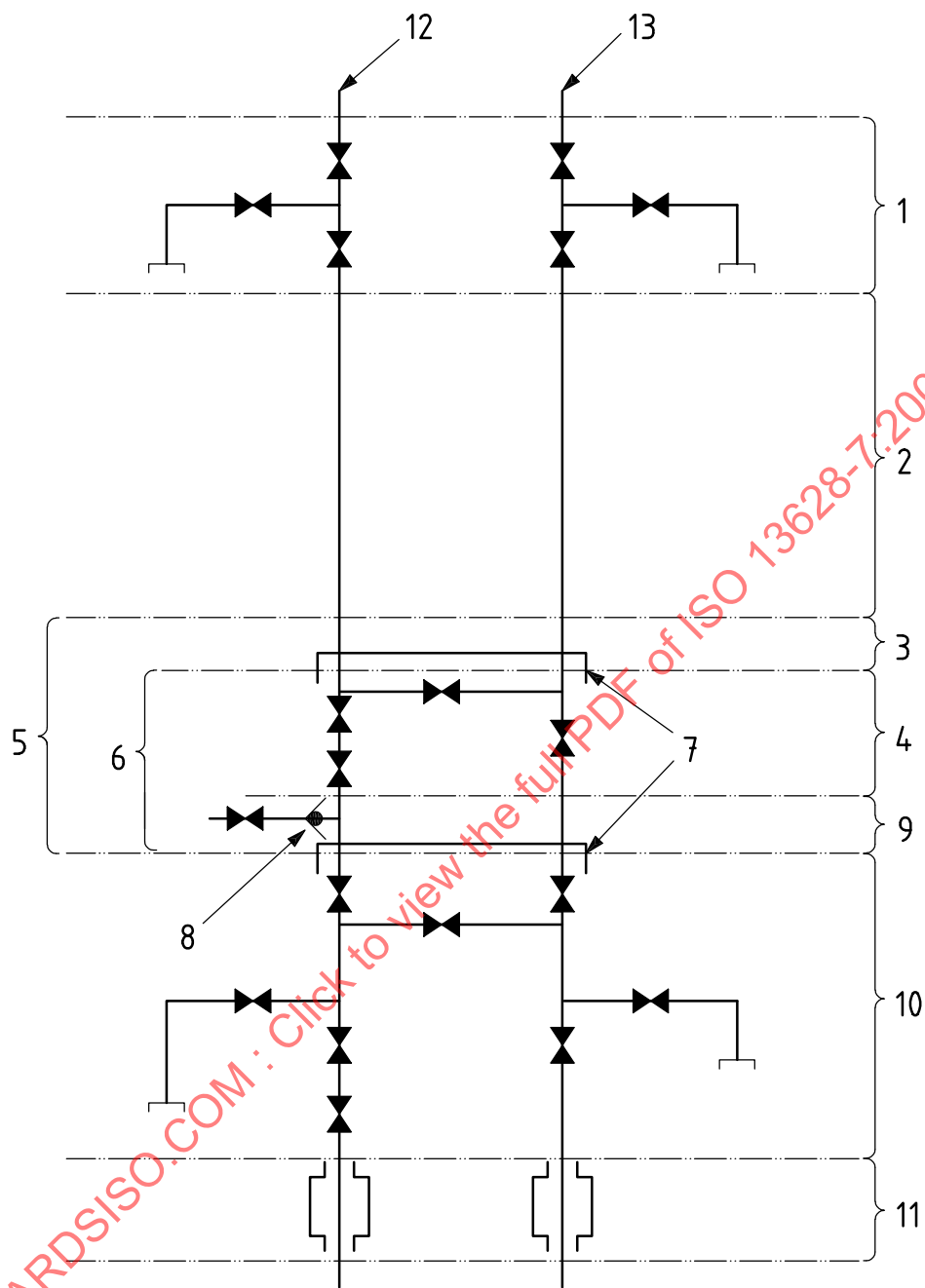
Figure 3 — Typical C/WO riser general arrangement — Tubing hanger mode



**Key**

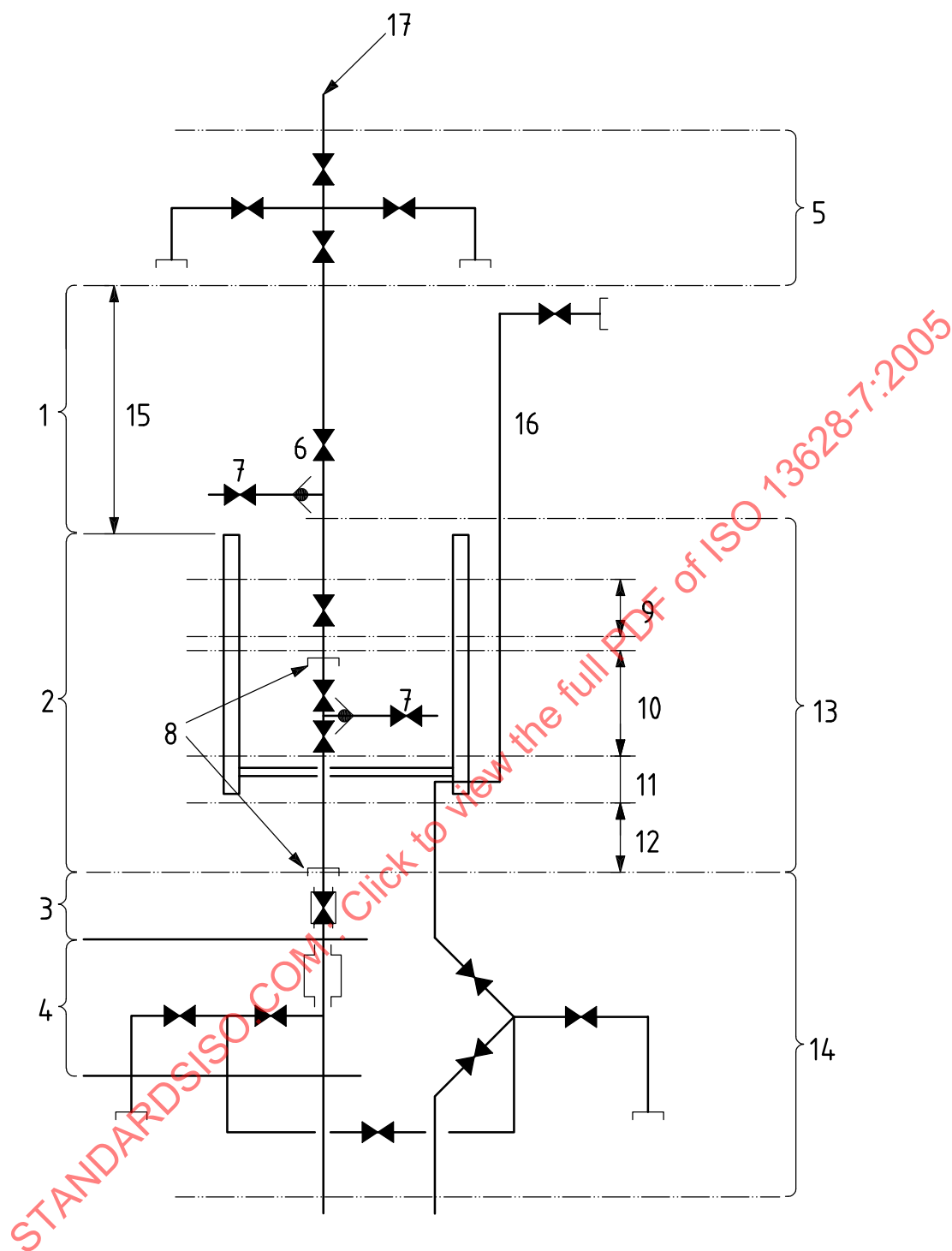
- |                              |                      |                    |
|------------------------------|----------------------|--------------------|
| 1 surface tree               | 6 tubing hanger      | 11 BOP Stack       |
| 2 lubricator valve           | 7 chemical injection | 12 C/WO riser      |
| 3 retainer valve             | 8 landing string     | 13 production bore |
| 4 subsea test tree           | 9 disconnect point   | 14 annulus bore    |
| 5 tubing hanger running tool | 10 marine riser      |                    |

**Figure 4 — Typical C/WO riser system schematic — Vertical tree — Tubing hanger mode**

**Key**

- |   |                              |    |                     |    |                 |
|---|------------------------------|----|---------------------|----|-----------------|
| 1 | surface tree                 | 6  | lower riser package | 11 | tubing hanger   |
| 2 | C/WO riser                   | 7  | disconnect point    | 12 | production bore |
| 3 | emergency disconnect package | 8  | chemical injection  | 13 | annulus bore    |
| 4 | WCT-BOP                      | 9  | tree running tool   |    |                 |
| 5 | lower workover riser package | 10 | vertical tree       |    |                 |

**Figure 5 — Typical C/WO riser system schematic — Vertical tree — Tree mode**

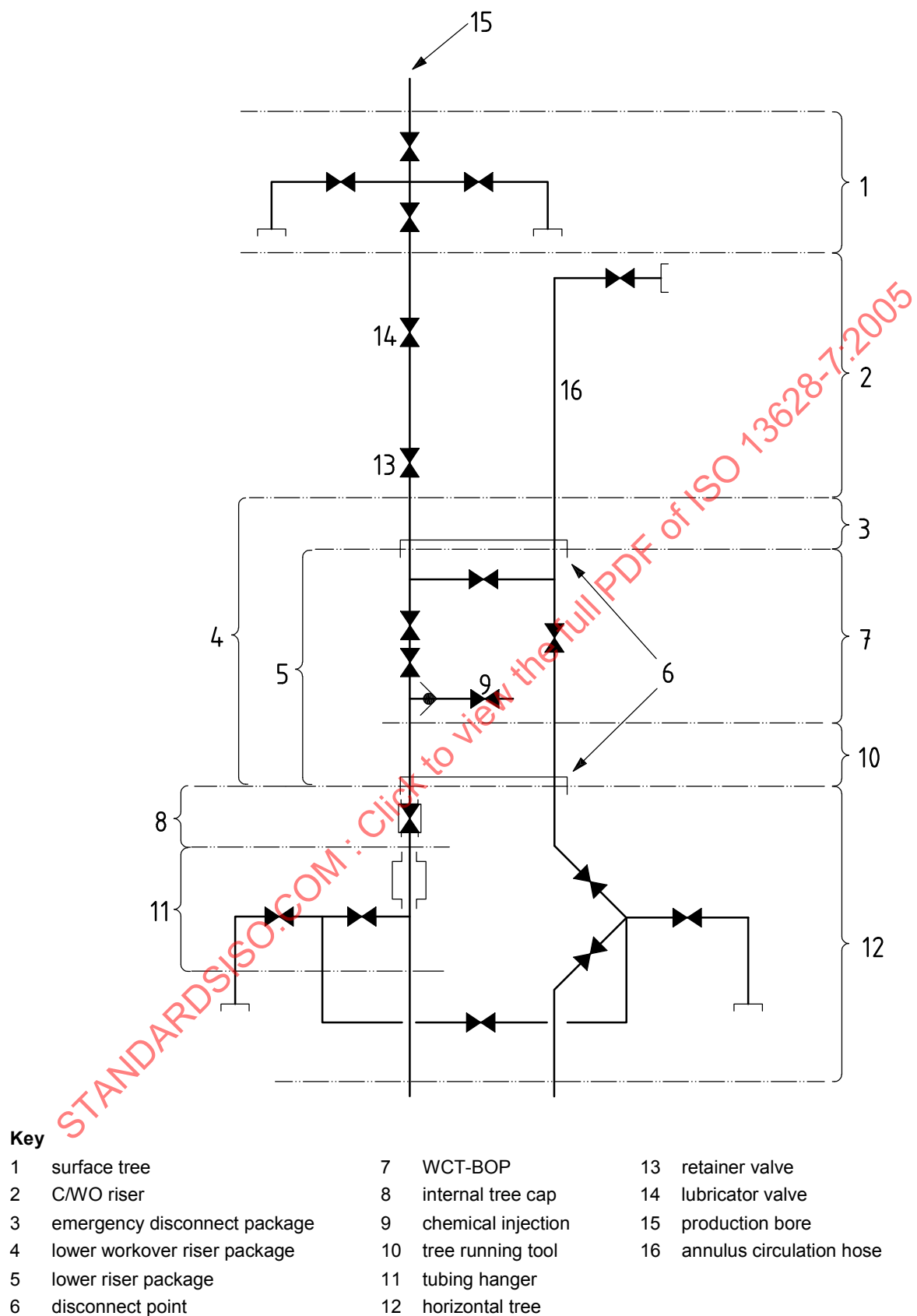


**Key**

1	marine riser	7	chemical injection	13	landing string
2	BOP stack	8	disconnect point	14	horizontal tree
3	internal tree cap	9	retainer valve	15	C/WO riser
4	tubing hanger	10	subsea test tree	16	choke/kill line
5	surface tree	11	slick joint	17	production bore
6	lubricator valve	12	tubing hanger or tree cap running tool		

**Figure 6 — Typical C/WO riser system schematic — Horizontal tree — Tubing hanger mode**





**Figure 7 — Typical C/WO riser system schematic — Horizontal tree — Tree mode**

#### 4.8 Design principles

All equipment in the C/WO riser system included in the scope of this part of ISO 13628 shall be designed in accordance with the requirements specified in this part of ISO 13628.

The overall system design shall be fail-safe.

The system shall be designed to ensure that no single failure will cause an unacceptable risk to personnel safety, the environment and to loss of financial assets.

The possibility of common cause failures shall be identified and measures shall be implemented to minimize their probability of occurrence.

#### 4.9 Operational principles

The C/WO riser system shall be operated in accordance with the requirements specified in 4.13 and the guidance given in Annex B.

As far as practical, all activities associated with the C/WO riser system shall be conducted in such a manner that single failures shall not lead to an unacceptable risk to personnel safety, the environment and to loss of financial assets. This applies both to operational errors and to failure of equipment used directly in operations, as well as equipment used for auxiliary functions.

For all operations, the system design shall account for the most unfavourable combination of functional, environmental and accidental loads, which can be predicted to occur simultaneously, see 6.3. Furthermore, it shall be possible to document that during the development of an unforeseen situation (i.e. loss of vessel station-keeping, heave compensator lock-up, etc.), the C/WO riser system is unable to transmit forces of such magnitude as to threaten the barriers. This requirement applies, both locally (i.e. C/WO system and its barrier elements) and globally (i.e. drilling riser, BOP, horizontal tree, wellhead, conductor, etc.).

The operation of the C/WO riser system shall be limited by the weakest component in the system.

**NOTE** This requirement is applicable to component design pressure, design temperature and allowable external loads.

#### 4.10 Safety principles

The safety within this part of ISO 13628 requires that gross errors (human errors) shall be controlled by requirements to organization of the work, competence of persons performing the work, verification, and quality assurance during all relevant phases.

To ensure total system safety, the manufacturer shall apply the following principles, in the order presented, when selecting appropriate solutions:

- a) eliminate or reduce hazards as far as is reasonably practicable;
- b) apply appropriate protection measures against hazards which cannot be eliminated;
- c) if appropriate, inform users of residual hazards and indicate whether it is necessary to take appropriate special measures to reduce the risks at the time of installation, use and/or retrieval.

If a potential for misuse is known or can be clearly foreseen, the C/WO riser system shall be designed to prevent danger from such misuse or, if that is not possible, adequate warning shall be given so that the C/WO riser system is not subject to misuse.

#### 4.11 Barrier requirements

For all operations, a barrier philosophy shall be established and implemented to meet the national regulations under which the C/WO riser shall be operating. General guidance on barrier philosophy can be found in ISO 13628-1 [22].

At least two independent and tested barriers between the reservoir and the environment should be available in order to prevent unintentional flow from the well.

No single failure of a barrier or a barrier element, whether caused by operator error or equipment failure, shall lead to a loss of well control.

#### 4.12 Regulations, codes and standards

The C/WO riser system shall comply with the applicable regulatory requirements. User/operator shall specify the regulatory jurisdictions in which the system is intended to operate.

The C/WO riser system equipment included in the scope of this part of ISO 13628 shall be designed, manufactured, and tested in accordance with the references, codes and standards specified in Table 2.

Components which are outside the scope of this part of ISO 13628, and have an influence on the design, manufacture, test and operation of the C/WO system shall be accounted for and shall be included in the system review.

**Table 2 — Equipment references, codes and standards**

C/WO workover riser system components	Functional requirements	Design requirements	Materials and manufacturing requirements	Component qualification testing	System integration test
Tubing hanger	ISO 13628-4	ISO 13628-4	ISO 13628-4	ISO 13628-4	Clause 8
Tubing hanger running tool	ISO 13628-4	ISO 13628-4	ISO 13628-4	ISO 13628-4	Clause 8
Tree cap running tool (horizontal trees)	ISO 13628-4	ISO 13628-4	ISO 13628-4	ISO 13628-4	Clause 8
Tubing hanger orientation system	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Subsea test tree	Clause 5	Clause 6	Clause 7	Clause 8 ISO 10432 <sup>b</sup>	Clause 8
Shear sub	Clause 5	Clause 6	Clause 7	Clause 5 Clause 8	Clause 8
Retainer valve	Clause 5	Clause 6	Clause 7	Clause 8 ISO 10432 <sup>b</sup>	Clause 8
Lubricator valve	Clause 5	Clause 6	Clause 7	Clause 8 ISO 10432 <sup>b</sup>	Clause 8
Lower workover riser package	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Subsea WCT-BOP	Clause 5	Clause 6 ISO 13628-4 <sup>e</sup> ISO 13533 <sup>e</sup>	ISO 13628-4 <sup>a f</sup>	Clause 8 ISO 13628-4 <sup>a c</sup> ISO 13533 <sup>c d</sup>	Clause 8
Emergency disconnect package connector	Clause 5	Clause 6 ISO 13628-4 <sup>e</sup>	ISO 13628-4 <sup>a f</sup>	Clause 5 ISO 13628-4 <sup>a</sup>	Clause 8

Table 2 — Equipment references, codes and standards (continued)

C/WO workover riser system components	Functional requirements	Design requirements	Materials and manufacturing requirements	Component qualification testing	System integration test
Tree running tool	Clause 5 ISO 13628-4	Clause 6 ISO 13628-4 <sup>e</sup>	ISO 13628-4 <sup>a f</sup>	ISO 13628-4 <sup>a</sup>	Clause 8
Riser connector	Clause 5	Clause 6	Clause 7	Annex I	Clause 8
Stress joint	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Riser joints	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Tension joint	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Slick joint	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Surface tree adapter joint	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Swivel	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Surface tree	Clause 5	Clause 6 ISO 10423 <sup>e</sup>	ISO 10423 <sup>a f</sup>	Clause 8 ISO 10423 <sup>a c d</sup>	Clause 8
Wireline/coiled tubing adapters	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Surface tree tension frame	Clause 5	Clause 6	Clause 7	Clause 8	Clause 8
Riser spider	Clause 5	ISO 14693	ISO 14693	Clause 8 ISO 14693	Clause 8
Handling and test tools	Clause 5	Clause 6 ISO 13535	Clause 7	Clause 8 ISO 13535	Clause 8
Umbilical clamps	Clause 5	Manufacturer's written spec.	Manufacturer's written spec.	Clause 5 Clause 8	Clause 8
Annulus circulation line	Clause 5	API Spec 16C API RP 17B ISO 13628-2	API RP 17B ISO 13628-2	Clause 5 Clause 8	Clause 8
Workover control system	Clause 5	Clause 5 ISO 13628-6	ISO 13628-6	ISO 13628-6	Clause 8
Control umbilical	Clause 5	ISO 13628-5	ISO 13628-5	ISO 13628-5	Clause 8

<sup>a</sup> Product specification level, material class and performance requirement level as designated in ISO 10423 and ISO 13628-4 shall be specified by the purchaser.

<sup>b</sup> Class of service as designated in ISO 10432, any wireline and coiled tubing cutting requirements and more stringent leak-tightness criteria shall be specified by purchaser, if applicable.

<sup>c</sup> Any wireline and coiled tubing cutting requirements and more stringent leak-tightness criteria shall be specified by purchaser, if applicable.

<sup>d</sup> Components qualified in accordance with ISO 10423 and ISO 13533 are qualified for pressure and temperature loading conditions only. ISO 10423 and ISO 13533 components that are connected to a C/WO riser shall be qualified for their intended use.

<sup>e</sup> It is standard industry practice to design and qualify this type of equipment for designated sizes and rated working pressures. Design methods in ISO 13628-4:1999, 5.1 and ISO 13533:2001, 5.4 are based on rated working pressure and hydrostatic test pressure only. For C/WO riser applications, it is normal industry practice to ensure that the load combinations determined in this part of ISO 13628 (i.e. normal, extreme and accidental loading conditions) do not exceed the equipment rated capacity. In cases where the rated capacity is exceeded, the equipment may be designed, manufactured and qualified in accordance with this part of ISO 13628.

<sup>f</sup> More stringent material Charpy V-notch impact energy values may be specified to meet regulatory and purchaser requirements.

## 4.13 Operational requirements

### 4.13.1 General

A C/WO riser is classified as a temporary riser and normally has a limited operating envelope. In situations where operating conditions are expected to exceed the allowable, the riser shall either be disconnected and hung-off or retrieved.

C/WO riser system operational parameters shall be monitored to ensure that the riser is being operated within prescribed limits; see 10.4 and Annex B. The operational parameters can include parameters such as wave height and period, vessel heave, vessel offset and top tension.

Operational requirements shall be documented in a "Riser Installation and Operation Manual", see 11.9 and Annex B. The manual should be prepared jointly by the designer and the operator and shall define how to safely install, operate and maintain the riser system and its components. Operational considerations include operational philosophy, vessel motions and environmental limits, vessel interfaces, riser installation and retrieval, in-service operations, inspection and maintenance philosophy.

Safe operation of a riser requires that

- a) the designer takes into account all realistic conditions under which the riser will be operated;
- b) the operations personnel are aware of and comply with its limits for safe operation.

Vessel motion and station-keeping performance can have a significant effect on the riser design and operation. Certain operations such as riser running or pulling, workover and through-bore operations can be restricted or require shutdown, depending on vessel motions and environmental limits. Sequences for both planned and emergency shutdowns and disconnects should be accounted for. These sequences shall comply with both national regulatory and operator requirements.

There are two levels of riser disconnection: normal or planned disconnection and quick or emergency disconnection. Quick or emergency disconnection of the riser system can be necessary if vessel or well system emergencies occur, the vessel station-keeping system fails or the weather suddenly and unpredictably deteriorates beyond the riser's operating envelope.

### 4.13.2 Operations from a dynamically positioned vessel

Special consideration shall be given to C/WO riser system operations from dynamically positioned vessels.

Preventative measures to reduce both the probability and consequences of drift-off/drive-off shall be implemented. Type and degree of implementation of preventative measures shall be determined in a system review, see 4.6.

Preventative measures relating to drift-off/drive-off can be split into two main categories:

- a) measures directed towards reducing the probability of experiencing a drift-off/drive-off situation;
- b) measures directed towards reducing the consequences following a drift-off/drive-off.

The consequences following a drift-off/drive-off can be split in three main categories:

- possibility of blow-out due to drift-off or drive-off;
- consequences for the subsea equipment (including BOP, subsea tree, wellhead, etc.);
- consequences for risers (C/WO riser, drilling riser, LMRP, etc.) and the topside equipment (derrick, draw works, drill floor, jumpers, etc.).

Typical preventative measures for reducing the probability of drift-off/drive-off are listed in Table 3.

**Table 3 — Typical preventative measures to reduce the probability of drift-off/drive-off**

System	Preventative measures	Comments
Dynamic positioning system	Specification of dynamic positioning consequence class	Typically IMO consequence class 3. Not less than IMO, class 2 <sup>[23]</sup>
Reference system	Specification of minimum number of independent position reference systems, positioning accuracy and repeatability	A minimum of three independent systems is recommended, irrespective of dynamic positioning class
	For shallow water (< 350 m), special consideration shall be given to positioning accuracy and repeatability	Typical reference systems: GPS Hydro-acoustic Taut wire Riser angle
Power system	Maximum utilization of the dynamic positioning system during operation	Weather criteria for the 80 % limit should be established and documented
	Should not exceed 80 % of total capacity	

Typical preventative measures for reducing the consequences following drift-off/drive-off are listed in Table 4.

**Table 4 — Typical preventative measures to reduce the consequences of drift-off/drive-off**

System	Preventative measures	Comments
Reservoir	Operations performed with well in overbalance	—
Drilling riser and CWO riser	Weak link philosophy	Risers unable to transmit forces of such magnitude as to threaten the barriers
BOP, LMRP, lower workover riser package, subsea test tree	Rapid emergency shutdown and emergency disconnect response	Fully automated and tested emergency disconnect systems
Vessel	Active positioning of vessel	Suitable for drift-off only. Increase time to reach critical limits
BOP, LMRP, subsea test tree	Procedures	Combined operating procedures for drilling riser and CWO riser systems

The factors listed below should be included in the system review as aid to the determination of the consequences of dynamic positioning system failure and the selection of preventative measures:

- mode of operation (tree mode or tubing hanger mode);
- resulting vessel offset due to loss of vessel station-keeping (i.e. drift-off, drive-off);
- environmental conditions (i.e. water depth, sea-state and current);
- CWO riser system emergency shutdown and emergency disconnect sequences and response times;
- emergency disconnect package disconnect angle;
- structural capacity of subsea barriers (i.e. wellhead, subsea tree, lower workover riser package, subsea test tree, etc.);
- pull-out of upper landing string assembly from drilling riser BOP;

- h) clearance of surface tree to drill floor;
- i) stroke of the vessel's draw works constant tension motion compensator;
- j) drilling riser's BOP emergency shutdown and emergency disconnect sequences and response times.

#### 4.14 Requirements for organization and personnel qualifications

The organization of key personnel with defined responsibilities and lines of communication shall be established prior to start of any work covered by this part of ISO 13628. The organization of the work during all phases shall be such that it will ensure that the work is carried out safely and in accordance with good engineering practice.

All personnel shall have the necessary qualifications and practical training and have adequate opportunity to carry out their assigned work satisfactorily. Key personnel shall have sufficient verbal and written communication skills in the common language used for conveyance of work. Documentation for the qualifications of personnel shall be available.

#### 4.15 Quality system

A quality system shall be applied to assist compliance with the requirements of this part of ISO 13628.

NOTE ISO 9000-1 <sup>[20]</sup> gives guidance on the selection and use of quality systems.

#### 4.16 Documentation, records and traceability

Documentation required in order to ensure that operations of the C/WO riser system are carried out in accordance with this part of ISO 13628 shall be prepared. The documentation shall be available during the different phases, i.e. design, manufacture, fabrication, operation and storage. Requirements and criteria related to equipment and components of significance to safety shall be specified. The documentation shall include a description of the testing and the maintenance required in order to maintain a specified safety level. All documentation requirements shall be reflected in a document register.

Documentation shall be available to the purchaser or the purchaser's agents. Submittals and/or approval procedures shall be agreed. The documentation shall be presented in such a form that it is readily applicable for review and verification. Design documentation shall include construction drawings, parts lists and design calculations. Documents that are considered proprietary and confidential shall be available for review.

Records of the C/WO riser system shall be kept and maintained to demonstrate compliance with the requirements of this part of ISO 13628 throughout its lifetime.

There shall be traceability for all relevant data, which have significant influence on the safety and operational capability of the C/WO riser throughout its lifetime.

#### 4.17 Verification

Verification of design, fabrication and testing shall be carried out and implemented in accordance with an overall and clearly defined verification programme and verification basis. Regarding the organizing and reporting, there shall be independence in organization between those who carry out the work, and those who are responsible for the verification.

It shall be verified that provisions contained in this part of ISO 13628, purchaser's specification(s) and regulatory requirements have been met.

The extent of the verification and the verification method in the various phases shall be assessed. The consequences of any failure or defects that can occur during construction of the C/WO riser and its anticipated use shall receive particular attention in this assessment.



The design verification shall be performed to confirm that the C/WO riser system meets the requirements of this part of ISO 13628 with regard to materials, design details and dimensions and that the requirements of procedures and personnel can be met during fabrication and operation.

The verification shall be documented.

The verification may take the form of a checking of analyses, drawings and fabrication by reviewing the work conducted, or by carrying out independent analyses. The verification may also include trials or testing of equipment and systems.

Design reviews involving multiple disciplines may also be used as part of the verification.

#### 4.18 Purchaser/user's responsibility

It is the responsibility of the purchaser/user or his designated agent to provide a user's design specification for the C/WO riser system to be constructed in accordance with this part of ISO 13628. The design specification shall contain sufficient details to provide a complete design basis for the design of a C/WO riser that complies with this part of ISO 13628. The purchasing guidelines in Annex F give a sample format for the user's design specification.

#### 4.19 Manufacturer's responsibility

The manufacturer is responsible for conformance with all requirements of this part of ISO 13628 which are required to meet the conditions in the purchaser's/user's design specification and provided in the manufacturer's documentation in accordance with Clause 11.

Requirements not specifically required by the purchaser, that can affect the design, materials, manufacturing, and fabrication, testing and operating of the C/WO riser system shall be specified by the manufacturer.

### 5 Functional requirements

#### 5.1 Purpose

Clause 5 specifies the functional requirements for the C/WO riser system, subsystems and components.

#### 5.2 System functional requirements

The C/WO riser system shall fulfil the following requirements as appropriate:

- allow for well testing, well servicing with wireline and coiled tubing and well isolation;
- provide a conduit from the individual bores of a subsea tree or tubing hanger to the surface workover vessel;
- allow passage of fluid and tools through the single or multiple bores of the subsea tree/tubing hanger from the workover vessel;
- provide a conduit to contain all fluids for the application and permit their circulation to and from the wellbore;
- act as a guide for all tools and equipment being run into or pulled out of the wellbore;
- provide for the means for connecting workover riser components together in a safe and efficient manner on the drill floor or designated work area;
- serve as a running string for the subsea tree;



- serve as a running string for the tubing hanger;
- allow for running the C/WO riser through the drilling riser and BOP system;
- allow for running the completion riser through the open sea;
- provide a means for attaching external or connecting internal control lines to the subsea tree or running tools if required.

### 5.3 Drift requirements

The drift requirements stated here apply to the riser components in addition to any drift requirements specified by other documents.

The purchaser shall state the drift requirements of the tubing hanger through-bores.

Each tubular section of a C/WO riser, or component within the riser, that requires a tool to be passed through it, shall be drift-tested.

If possible, the riser components should be designed and drift-tested in accordance with one of the drift classes specified in Table 5. Drift type and lengths are shown in Figure 8.

Deviation from these drift sizes may be agreed.

As an alternative to these drift sizes, the actual tool profile may be used as a drift.

Consideration should be given to riser pipe deflections, flow-by area during tool string operations, changes in centre lines and steps in equipment packages when selecting the actual minimum tubular inside diameter.

**Table 5 — Drift dimensions**

Drift class	Minor diameter $d$		Major diameter $D_{\text{drift}}$		Corresponding ISO 10423 valve/nominal flange size
	mm $^{+0,71}_0$	(in $^{+0,027}_0$ )	mm $^{+0,71}_0$	(in $^{+0,027}_0$ )	
1a	35,51	(1,398)	38,51	(1,516)	2-1/16
1b	37,03	(1,458)	40,03	(1,576)	2-1/16
1c	45,29	(1,783)	48,29	(1,901)	2-1/16
1d	48,56	(1,912)	51,56	(2,030)	2-1/16
2a	67,82	(2,670)	72,82	(2,867)	3-1/16
2b	71,96	(2,833)	76,96	(3,030)	3-1/16
3a	91,36	(3,598)	97,36	(3,833)	4-1/16
3b	96,36	(3,794)	102,36	(4,030)	4-1/16
4a	123,29	(4,854)	129,29	(5,090)	5-1/8
4b	115,08	(4,581)	121,08	(4,767)	5-1/8
5a	153,04	(6,025)	161,04	(6,340)	6-3/8
5b	149,45	(5,884)	155,45	(6,120)	6-3/8
5c	145,44	(5,726)	151,44	(5,962)	6-3/8
6	164,69	(6,484)	170,69	(6,720)	NA
7	172,56	(6,794)	178,56	(7,030)	7-1/16
8	221,84	(8,734)	227,84	(8,970)	9

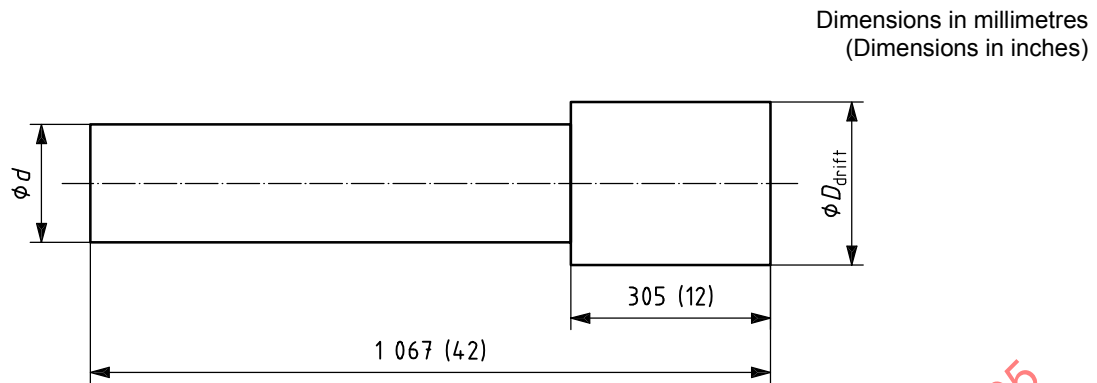


Figure 8 — Drift type and lengths

## 5.4 Component requirements

### 5.4.1 Purpose

In 5.4, the requirements for the individual components that comprise the C/WO riser system are specified. Each component is defined in terms of its function and system interfaces.

### 5.4.2 Common requirements

Requirements that are common to all components in the riser assembly are listed below.

- a) The design of the C/WO system shall also consider the maintainability of the components. Inspection and cleaning shall be easily carried out both externally and internally. BOP adapter joints and other parts of the system where seawater or well fluids can become trapped in enclosed volumes shall be easily dismantled. Seals and gaskets shall be available for inspection and easily replaceable on the workover vessel.
- b) All components in the C/WO riser system shall be qualified for all relevant make/break loads, pressures, temperatures and external loads.
- c) Resilient, elastomeric or metal-to-metal seals may be used as primary seals to contain hydrocarbons, well control, completion and kill fluids on riser system assembly interfaces and riser connectors. Where metal-to-metal seals are not utilized, redundant seals (primary plus backup) shall be provided.
- d) Connection pressure separation loads shall be based on worst-case sealing conditions (i.e. leakage to the largest diameter redundant seal shall be assumed, unless relief is provided).
- e) In the event an environmental seal is used, consideration should be given to pressurizing control lines by possible communication with the production or annulus bore. Effects of pressure end loads acting over the area enclosed by the environmental seal should also be considered in the design since one or more of the interior seals could leak.
- f) Connections subjected to net external pressure shall be provided with a seal system(s) design with external and internal integrity.
- g) All seals shall be qualified for all relevant pressures, temperatures, fluids and services.
- h) Component body and connector leak-tightness shall comply with 6.4.11.5.
- i) Well barrier elements shall be leak-tight after an accidental condition has occurred; see 6.4.11.5.

- j) Component through-bore leak-tightness requirements that are more stringent than the applicable codes and standards, see Table 2, shall be according to purchaser's specification.
- k) The inside surfaces of all vertical bores shall be smooth and free of sharp shoulders, and shall be able to pass appropriate drift tools.
- l) All valves in the vertical bore(s) shall be driftable.
- m) All valves shall be capable of closing in the flowing direction under maximum flow and pressure conditions.
- n) A corrosion allowance shall be assumed whenever relevant, unless corrosion-resistant materials are used. A corrosion allowance and/or the use of corrosion-resistant materials shall be considered given the types of hydrocarbons, well completion, stimulation and kill fluids that will be introduced into the system and the maintenance and storage conditions; see 6.4.4.
- o) All components which can be subject to net external pressure (e.g. from hydrostatic head) shall be designed to withstand hydrostatic collapse; see 6.5.2.3 and 6.5.3.3.
- p) For all components that can be subject to BOP pressure (e.g. BOP test pressure, BOP choke and kill pressures), account shall be taken of any axial load effects due to differential seal areas (i.e. piston effect) in combination with other loading conditions.
- q) The workover riser system shall be designed for either guideline or guideline-less installation and retrieval where applicable.
- r) Design of guidance systems shall address seal make-up tolerance, angle of re-entry and release, damage to control interfaces and seal surfaces, ability to access existing guidelines, posts or re-entry funnels, wherever appropriate.
- s) Padeyes and other lifting devices used for general handling of equipment shall be designed in accordance with ISO 13628-4:1999, 5.1.3.7.
- t) Bolted flange connections shall be assembled and made up in accordance with a written procedure which has been qualified by test to achieve the specified bolt pretension. A general guideline on bolted flange joint assembly is given in ASME PCC 1-2000 [37].
- u) Bolted flange connections shall be assembled by qualified bolted-connection assemblers. Bolted-connection assemblers shall be qualified by test to demonstrate that they can apply the qualified procedure and achieve the specified bolt pretension.

#### 5.4.3 Landing string

The landing string shall comprise all the equipment required to install and retrieve the tubing hanger in a safe manner.

The landing string shall

- permit orientation alignment of the tubing hanger if required;
- permit testing of the BOP when installed within the bore of the BOP stack;
- provide the same structural and functional requirements (e.g. axial load support, fluid and pressure transmission) as a standard C/WO riser joint;
- be designed to withstand external pressure (i.e. BOP pressure testing, BOP choke and kill pressures, etc.) in combination with other applicable loading conditions;

- allow the well to be isolated by the BOP or by components within the landing string if the BOP cannot isolate the well;
- provide a means of disconnecting the landing string from the tubing hanger;
- provide the control-line termination at its top and route all hydraulic/electrical lines from there to the equipment within the landing string and tubing hanger as required by the system;
- provide a contingency method of disconnecting the riser from the tubing hanger and leaving the well in a secure status.

The landing string assembly and its individual components shall include anti-rotation feature(s) to permit torque transfer during orientation of the tubing hanger and to prevent application of torque to the hydraulic stabs. Maximum expected rotation required for tubing hanger orientation and the torsional resistance of the downhole completion and C/WO riser shall form the basis for determining requirements for torque capacity. The torsional resistance shall account for both static and dynamic effects (i.e. orientation at maximum landing speed). For non-oriented tubing hangers, anti-rotation features might not be required.

#### 5.4.4 Subsea test tree

The subsea test tree shall be fail-safe and ensure the well can be left in a secure status.

The subsea test tree shall be configured such that it can be contained entirely within the envelope of the BOP stack and provide a disconnect point to permit retrieval of the riser independently from the subsea test tree.

The subsea test tree should include an upper isolation valve and lower shear/seal valve. The shear/seal valve shall be capable of cutting coiled tubing and wireline as per purchaser's requirements.

The subsea test tree should include a minimum of two fail-safe close safety valves. If both valves are shear-and-seal type the lower valve should be the primary shear valve. The shear/seal valve(s) shall be capable of cutting coiled tubing, braided wireline and slick line as per purchaser's requirements.

The valves shall be able to retain pressure from below without the aid of control-line pressure. One of the valves shall also be able to retain pressure from above to permit pressure testing of the C/WO riser string. However, control-line pressure assist may be used to satisfy this requirement.

The subsea test tree shall provide pump-through capability that permits the well to be killed by bullheading through the closed valves in the event of hydraulic system failure. Valves shall automatically reseal upon pressure equalization.

If the design of the subsea test tree includes a grip/hold device for coiled tubing, this shall be incorporated in the design of the lower valve while the upper valve acts as the primary shear valve. The grip/hold valve shall have bi-directional sealing capabilities and be capable of suspending the full weight of the coiled tubing below the subsea test tree. The distance between the upper and lower valves shall be sufficient to allow fishing of trapped/suspended coiled tubing. The sheared coiled tubing shall be centralized after cutting to enable engagement by an overshoot-fishing tool. The shear valve shall be designed such that the orifice of the suspended sheared coiled tubing has sufficient flow area to enable circulation of the coiled tubing.

The subsea test tree should include an integral slick joint to allow for closure of a BOP pipe ram between the tubing hanger and subsea test tree. The slick joint shall include a load shoulder at its lower end. The load shoulder reacting against the closed pipe ram shall prevent release of the subsea test tree in the event of an unintentional unlock of the tubing hanger running tool. The slick joint shall be provided with hydraulic through-putting to facilitate control of necessary tubing hanger running tool/tubing hanger functions.

The disconnect point shall be above the isolation valve and below the BOP's blind shear ram to ensure that the BOP can isolate the wellhead.

For closure of BOP rams, sufficient clearance shall be provided to account for stack-up tolerances in the BOP stack and landing string.

Distance between the top of the subsea test tree disconnect connector (latch) and the bottom of the blind shear ram shall be sufficient to allow milling and fishing. An internal fish-neck may be provided as back up for running an overshoot tool.

The subsea test tree disconnect connector shall be designed for remote make-up of the main bore(s) and control lines and shall include full orientation prior to final connection. The connector shall have an active pressurized latch function to be engaged during the entire operation. The connector shall be designed to allow for tagging on a BOP ram.

The hydraulic couplers in the disconnect connector (latch) shall be designed such that trapped pressure is vented when disconnecting the riser. Ingress of ambient fluid shall be minimized to avoid contamination of the hydraulic lines. Pressure testing from surface shall be possible to verify sealing integrity after make-up.

An interlock shall be incorporated to prevent unlatch of the disconnect connector without a minimum of one of the subsea test tree safety valves being closed. The interlock may be either physical or via control system logic. It shall be possible to override the interlock at any time.

The subsea test tree configuration shall not prevent the BOP from isolating the wellhead at any time during operations.

The subsea test tree should include independent primary and secondary disconnect and cutting features. Safety features shall be incorporated to avoid unintentional activation of both primary and secondary cutting and disconnect functions.

The subsea test tree design shall have a contingency procedure/method that will operate the valves and connectors of the subsea test tree in the correct sequence to secure the well. This would be used in case of failure of the primary control system.

The subsea test tree shall include a chemical injection line/port with a dual sealing/backflow valve arrangement, located between the valves.

The subsea test tree shall incorporate an anti-rotation feature to permit torque transfer during orientation of the tubing hanger and to prevent application of torque to the hydraulic stabs.

#### **5.4.5 Shear sub**

A shear sub may be included in the landing string to allow isolation of the well by closing of the BOP shear ram.

The shear sub shall be located at the BOP shear ram elevation and above the subsea test tree.

The shear sub shall be designed for shearing by the BOP shear ram without damaging the other components in the landing string.

Hydraulic piping shall be clamped to the shear sub in a manner that ensures cutting by the shear ram and to prevent difficulties in engaging a fishing tool during recovery operations.

The shear sub can be the weakest component within the riser string.

Shear ram qualification shearing trials of the shear sub shall be conducted by the purchaser/user. The shear trials qualification specimen shall include external hydraulic lines and internal, slick line, braided wire and coiled tubing (single or multiple) as specified by the purchaser.

The orifice of the sheared tubing shall have sufficient flow area to allow for bullheading.

#### 5.4.6 Retainer valve

##### 5.4.6.1 General

A retainer valve may be used in tubing mode and tree mode.

The valve shall be remotely operated, "fail in position" or "fail-safe close".

The failure mode of the valve shall be determined from a system FMECA and/or HAZOP study.

##### 5.4.6.2 Tubing hanger mode

The valve shall be designed to isolate the C/WO riser bore(s) from the drilling riser prior to disconnect.

The valve shall be capable of sealing full design pressure from above.

The valve shall be positioned as close to the subsea test tree disconnect connector as practically possible.

If designed for closure of the BOP annular preventer around the valve housing, the valve shall be designed to withstand the combined loading of the closed annular preventer compression forces and external pressure.

The valve shall include features to facilitate pressure equalization between the C/WO riser bore(s) and the drilling riser prior to disconnection.

There shall be an interlock between the retainer valve and the subsea test tree such that the C/WO riser string cannot be unlatched unless the retainer valve has reached its fully closed position. This shall prevent leakage of pressurized gas into the drilling riser.

The interlock may be either physical or via control system logic. It shall be possible to override the interlock at any time.

The retainer valve may include facilities for circulation of the C/WO riser.

##### 5.4.6.3 Tree mode

The valve shall be designed to isolate the C/WO riser bore(s) from the environment prior to disconnect.

The valve shall be capable of sealing full design pressure from above.

There shall be an interlock between the retainer valve and the lower workover riser package such that the C/WO riser string cannot be disconnected unless the retainer valve has reached its fully closed position.

It shall be possible to override the interlock at any time (e.g. automatically during an emergency quick disconnect).

The retainer valve may include facilities for circulation of the C/WO riser.

#### 5.4.7 Lubricator valve

A lubricator valve may be used in tubing hanger mode and tree mode.

The valve shall be designed to isolate the reservoir from the environment when deploying long wireline/coiled tubing tool strings.

The valve shall be designed to retain pressure from below without the aid of control-line pressure to provide reservoir isolation.

The valve shall be designed to retain pressure from above to permit pressure testing of the lubricator section of the CWO riser. Control-line pressure assist may be used to satisfy this requirement.

In the event of hydraulic system failure, the lubricator valve shall permit the well to be killed by bullheading. This requirement may be achieved by, but not limited to, either overriding the valve to open, use of an isolated bypass line or by designing the valve to be pumped through when in the closed position.

The lubricator valve assembly shall be situated below the surface tree.

If installed inside a drilling riser, the lubricator valve shall be located outside the stroke of the inner barrel of the drilling riser telescopic joint (slip joint).

The valve shall be remotely operated, "fail in position".

A chemical injection port with an isolation check valve may be implemented.

#### 5.4.8 Tubing hanger orientation system

The orientation system may be active or passive. A passive orientation system is one in which the tubing hanger is orientated during the initial lowering of the tubing hanger into the wellhead/tree. An active orientation system is one in which additional operations (other than the initial lowering) are required to orientate the tubing hanger.

The design of the orientation system shall address the following:

- torque transmission through the riser string;
- accumulated rotational misalignment due to tolerance stack-up;
- positive indication of tubing hanger alignments;
- variations in BOP stack configurations (if specified by purchaser).

The orientation system shall allow orientation of the landing string prior to engaging an installed tubing hanger.

NOTE For concentric tree designs, orientation of the tubing hanger might not be required.

#### 5.4.9 Lower workover riser package

The lower workover riser package shall include all the equipment necessary to perform safe well servicing by coiled tubing and wireline equipment. The equipment used in the lower workover riser package shall ensure that the well can be left in a secure status and the riser system disconnected from the subsea tree at any time.

A lower workover riser package may include an emergency disconnect package, WCT-BOP and tree running tool, compatible with the subsea tree; see Figure 9 b) and c).

The tree running tool shall interface with the subsea tree's re-entry spool and may be integral with the WCT-BOP or a separate item. For separate tree running tool designs, a standard interface to the WCT-BOP is proposed in Annex A, for vertical trees. The tree running tool shall comply with the requirements specified in ISO 13628-4:1999, 7.15.

The WCT-BOP may be equipped with an upper re-entry spool to interface with an emergency disconnect package or with a connection to mate with the lower end of the riser.

Both interfaces should include control-line connections to interface with the WCT-BOP and the subsea tree, as required.

Other interfaces may be a guidance structure for re-entry and/or diver or remotely operated vehicle control function interfaces, as required.

Unless otherwise agreed, the WCT-BOP for vertical subsea trees should be configured with its re-entry spool connector profile identical to that on the subsea tree, so that the subsea tree may be run by the emergency disconnect package without the WCT-BOP.

The lower workover riser package should include a crossover loop between the riser tubing bores to allow for circulation prior to subsea disconnection. The crossover loop shall include an isolation valve.

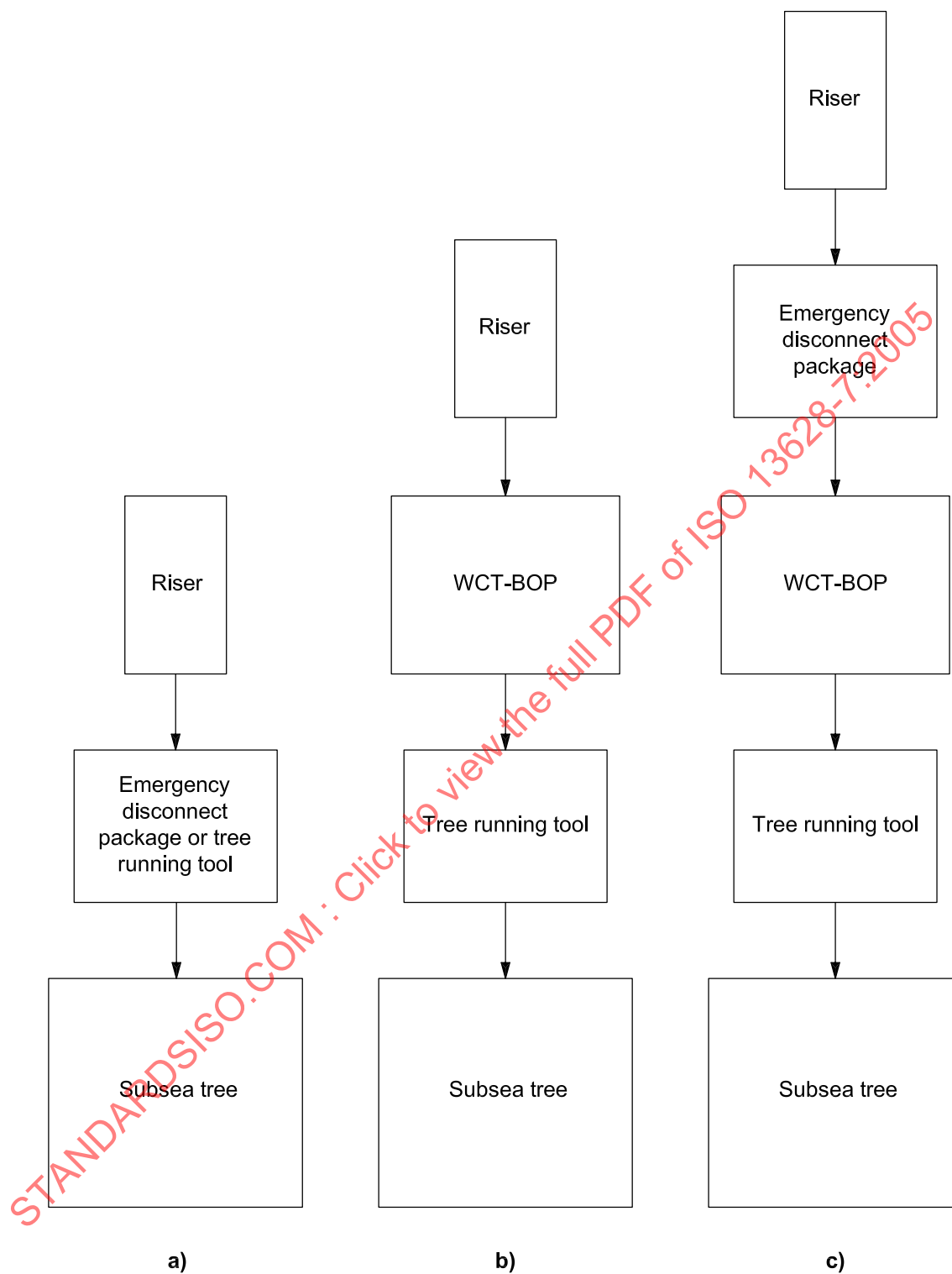
The lower workover riser package should allow for pressure testing of the riser to a point below the disconnection point and above the WCT-BOP valves.

Bores in the lower workover riser package should be the same or larger than the bore of the subsea tree. Necessary transitions shall be provided in mating riser components to accommodate changes in bore sizes or bore spacing of the tree, to allow for the passage of required drifts.

The lower workover riser package should include a guidance system for installation and retrieval of the riser with or without guidelines as applicable.

Consideration shall be given to the possibility of overhead clearance problems when stacking or handling the lower workover riser package and subsea tree together in the cellar deck. Stack-up height will affect riser design relative to moment loading at the subsea tree and lower workover riser package interfaces. Allowable stack-up height shall therefore be agreed in each case.





**Figure 9 — Lower workover riser package interface configurations**

#### 5.4.10 Emergency disconnect package

The emergency disconnect package shall provide a quick disconnect of the riser in the event of a loss of vessel station-keeping or unexpected environmental conditions (e.g. dunnings).

The emergency disconnect package may be located just above the WCT-BOP [see Figure 9 c)], or, alternatively, the emergency disconnect point may be at the tree re-entry spool interface [see Figure 9 a)]. Choice of configuration will depend on the type of subsea tree and system requirements, see 4. For example, for vertical tree systems, in the case shown in Figure 9 a), the tree running tool may serve as the emergency disconnect package and the tree valves may be used for well shut-in.

The emergency disconnect package shall include a remotely operated lower connector suitable for mating with the WCT-BOP re-entry spool (or optionally with the tree spool).

The upper end of the emergency disconnect package shall have a connection to mate with the lower end of the riser. A flange, hub or a proprietary riser connector may be used.

The emergency disconnect package should include control line connections at its lower connector to interface with the WCT-BOP (or, optionally, with the subsea tree).

A guidance structure, either guideline or guideline-less shall be included for re-entry onto the WCT-BOP re-entry spool.

The lower connector shall provide for high-angle (moment) release.

The minimum allowable disconnect angle of the emergency disconnect package shall allow for an emergency quick-disconnect of the riser at the maximum operating conditions specified for the C/WO riser system. The minimum disconnect angle should be 10°. A verification of the minimum required disconnect angle shall be conducted in the system review; see 4.6.

Disconnect angles shall be qualified by testing.

#### 5.4.11 Subsea wireline/coiled tubing BOPs (WCT-BOP) and shearing valves

The interface at the lower end of the WCT-BOP or shear valve package shall be compatible with the tree running tool. The upper end shall be compatible either with the emergency disconnect package or the connection on the lower end of the riser.

Interface connections shall be compatible with the size and bore of the subsea tree.

The number of BOP rams or shearing valves used in the WCT-BOP may vary depending on the design of the closure device and purchaser requirements. The WCT-BOP shall include as a minimum the following valves:

- an upper bi-directional isolation valve in every through-bore;
- a shearing valve or ram in any bore that will have coiled tubing or wireline equipment (or any other tool/device) in the bore that cannot be withdrawn from the bore during an emergency shutdown.

The WCT-BOP body shall provide all mechanical support and be able to withstand the combined effects of both riser tension and bending as well as internal and external pressure.

Shearing/cutting devices may shear in either a “single shear” or “double shear” manner. A double shear device will leave a slug of coiled tubing or wireline behind when activated. In such cases, the system shall be designed to accommodate the spent slug.

If the design of the WCT-BOP includes a grip/hold device (i.e. pipe/slip ram) for coiled tubing, it shall be located below the shear ram. The pipe slip ram shall have bi-directional sealing capabilities and be capable of suspending the full weight of the coiled tubing below the WCT-BOP. The distance between the shear ram and the pipe/slip ram shall be sufficient to allow fishing of trapped/suspended coiled tubing. The sheared coiled

tubing shall be centralized after cutting to enable engagement by an overshoot fishing tool. Provision may be made to allow for circulation of the suspended sheared coiled tubing. To enable circulation, the shear ram shall be designed such that the orifice of the suspended sheared coiled tubing has sufficient flow area.

Provision shall be made for circulation of the C/WO riser and circulation/bullheading of the production tubing via the annulus bore.

All valves/rams shall be capable of closing in the flowing direction under maximum flow and pressure conditions.

All valves shall be capable of opening with a differential pressure across the valve equal to the maximum working pressure.

The WCT-BOP should include a methanol injection line/port with a dual sealing/backflow valve arrangement, with the injection point being between the upper isolation valve and the lower shearing valve or ram.

A pressure sensor may be located in the production bore, between the upper isolation valve and the lower shearing valve or ram.

The effects of unidirectional or bi-directional sealing of the bore cavities shall be considered in the system design.

The system shall be designed to accommodate field-replaceable seals.

The ram assemblies with actuators should be designed for offshore/in-situ redressing/change out, without breaking the hydraulic circuits.

All valves/rams shall have position indicators observable by ROV/diver.

Rams with bi-direction hydraulic actuators shall include an automatic and mechanical locking system to prevent unintentional opening.

All valves/rams shall include an override from closed to open.

In addition to testing and documentation of the WCT-BOP or shearing valve assembly as specified in Clause 8, the following guidelines for acceptance shall be followed.

- a) Qualification testing of rams shall be conducted in accordance with procedures specified in ISO 13533:2001, 5.5.
- b) Hydrostatic proof testing of WCT-BOPs shall be conducted in accordance with procedures specified in ISO 13533:2001, 8.5.8.6.
- c) Qualification testing of shear valves shall be conducted as specified in ISO 10423 followed by shear/seal testing according to the manufacturer's written specification.
- d) Shear specimen sizing shall be in accordance with the purchaser's requirements.

#### **5.4.12 Connectors**

##### **5.4.12.1 General**

The connector shall allow for multiple make-up and breaks applicable for the application and design life.

The internal bore should be smooth to allow for passage of tooling, etc.

The design shall ensure that any trapped fluid does not interfere with the installation or operation of the connector.

Multiple bore designs shall have seal subs or gaskets to isolate each bore.

The connector shall be provided with seals that keep the connector tight for both internal and external pressure during running, installation and operation, see also Annex H.

Where multiple bore seals are enclosed within an outer environmental or secondary seal, bi-directional seals close to the bore shall be provided to prevent cross-communication between individual bores.

If an environmental seal is used, consideration to pressurizing control lines by possible communication with the production or annulus bore should be given.

Effects of pressure end loads acting over the area enclosed by the environmental seal should also be considered in the design since one or more of the interior seals could leak.

Connector pressure separation loads shall be based on worst-case sealing conditions (i.e. leakage to the largest diameter redundant seal shall be assumed, unless relief is provided).

All seals shall be qualified for all relevant make-up/break-out loads, pressures, temperatures, external loads, fluids and services.

The design of the connector shall also consider the maintainability of the components. Inspection and cleaning shall be easily carried out both externally and internally. Areas where seawater or well fluids can become trapped in enclosed volumes shall be easily dismantled.

Seals and gaskets shall be available for inspection and easily replaceable on the surface vessel. Reuse of seals, seal rings/gaskets shall be as specified by manufacturer.

The connector and/or associated running tool(s) should provide positioning and alignment of mating components such that connection can be accomplished without damage to sealing surfaces or structural connection devices.

The external profile shall not restrict the passage of equipment and special tooling required.

All vertical bore(s) including seals and gaskets shall be driftable; see 5.3.

#### **5.4.12.2 Emergency disconnect package connectors**

The connectors shall provide a means for quick and reliable connecting and disconnecting in a manner consistent with the assumptions made in the design analysis used to demonstrate compliance with strength, leakage and fatigue criteria.

The connectors should be designed and preloaded such that the relative movements between parts and sealing faces are minimized due to the cyclic nature of the external loading. For normal operating conditions, the connector mating hub faces shall remain preloaded. For accidental loads, the connector mating hub faces can be allowed to separate provided that the connector seals remain fluid-tight.

The connector shall be hydraulic, remotely operated. The connector design shall provide greater unlocking force than locking force, typically 25 % greater.

The connector shall be designed to prevent release due to loss of hydraulic locking pressure. This may be achieved by the connector self-locking mechanism or backed up using a mechanical locking device or other demonstrated means. The design of the locking device shall consider release in the event of malfunction.

The connector shall be designed with a secondary release method which may be hydraulic or mechanical. Hydraulic open and close line piping shall be positioned to allow cutting by ROV/diver or contain a means to vent pressure if needed for the secondary release function.

Metal-to-metal seals shall be used as primary seals on the emergency disconnect package connector.

An external position indicator shall be provided suitable for observation by ROV/diver.

The connector should allow for low-pressure back seal testing to ensure that the connector/seal is correctly made-up.

Machining tolerances and clearances shall be set such that all connectors of the same size and configuration are interchangeable. Production dimensional control shall be performed to ensure interchangeability.

The design shall ensure that any trapped water/fluid does not interfere with the connection/disconnection or operation of the connector.

#### 5.4.12.3 C/WO riser joint connector

The connector type shall be of a robust and reliable type, and allow for quick and reliable make-up, break-out, running and retrieval of the riser joints.

The riser joint connector shall permit for interchangeability between connector halves to allow riser joints to be run in any sequence.

The level of safety against failure by yielding, leakage and fatigue should be on a level that is comparable to that of the attached pipe.

The connector design shall prevent loosening under the dynamic conditions of operation.

The connector may also provide a support to transmit the weight of the suspended riser string to the riser-handling spider while installing or retrieving the riser including possible hang-off.

Riser connectors should be designed with rotational orientation to enable monitoring of tubing hanger angular orientation prior to landing or subsea test tree latch angular orientation prior to re-entry.

Connector torque capacity shall be sufficient to allow for the following where applicable:

- connector make-up and break-out;
- vessel weather vaning;
- tubing hanger orientation;
- subsea test tree connector orientation during re-entry;
- shearing of any mechanical secondary release mechanisms.

In cases where the connector provides support for auxiliary lines or buoyancy, the induced support loads shall be included in the connector design.

The connector bore should match the internal diameter of the adjoining pipe (flush with no obstructions).

Sealing surfaces in riser connections shall be designed to minimize damage during handling of the riser joints.

Sealing surfaces should be corrosion-resistant inlay welded or coated with a corrosion-resistant overlay. Corrosion-resistant overlays shall be suitably qualified for the application.

Resilient, elastomeric or metal-to-metal seals may be used as primary seals on C/WO riser connectors. If metal-to-metal seals are not utilized, redundant seals (primary plus backup) shall be provided.

Connector pressure separation loads shall be based on worst-case sealing conditions (i.e. leakage to the largest diameter redundant seal shall be assumed).

The connection may provide a means for pressure testing of the connection after make-up without pressurizing the C/WO riser. A back-seal test, i.e. a low-pressure test to check correct installation of seal can achieve this.

Machining tolerances and clearances shall be set such that all connectors of the same size and configuration are interchangeable. In production, dimensional control may be performed with go/no-go gauges in place of regular interchangeability tests.

#### 5.4.13 Stress joint

The stress joint shall provide the riser system with a transition zone of stiffness intermediate to those of the subsea tree and the riser. It shall be efficient in reducing highly localized stresses, thereby increasing fatigue life and improving the operating envelope of the system.

The upper end of the stress joint shall connect to the lowermost riser joint using a riser connector compatible with a standard riser joint.

The lower end of the stress joint shall be suitable for connecting to either the emergency disconnect package connector or the tree running tool. A suitable flange, a hub, or a proprietary riser connector may be used.

The length and stiffness distribution of the stress joint shall be carefully coordinated with the global riser system analysis and the subsea tree and wellhead system design, to avoid overloading of individual components.

The diameter of the stress joint (including connectors) shall be small enough to pass down through the rotary table.

Ease of field installation of the stress joint to the lower workover riser package in the moon-pool shall be emphasized.

#### 5.4.14 Riser joints

Standard riser joints should have a minimum length of 13,7 m (45 ft). All standard joints should have equal length.

Shorter joints, "pup joints", shall be provided to ensure correct space-out of the riser string. Pup joints shall have the same connector as standard riser joints.

The standard riser joints (and pup joints) shall, when connected together, act as an extension of the production and annulus bores from the subsea tree or tubing hanger up to the surface. Their basic function shall be to contain wellbore fluids during completion or workover operations while providing vertical access to the production and annulus bores for wireline or coiled tubing operations.

The standard riser joints shall all have identical connectors, to enable connection to any number of speciality joints such as the BOP adapter joint, stress joint, tension joint, slick joint, and surface tree adapter joint.

A control umbilical(s) may be used to provide hydraulic supply and electrical signal/power to the subsea tree and tubing hanger functions. Suitable umbilical clamps shall be installed to attach the umbilical(s) to the riser joint at specified intervals.

Riser joints shall not comprise loose parts or parts which can break loose during running and retrieval.

Riser joints, connectors and all appurtenances shall be designed to prevent snagging during running and retrieval.

Riser joints shall be designed for racking in stands of two or more joints.

#### 5.4.15 Tension joint

The tension joint shall include, if possible, an adapter ring designed to interface with the vessel's marine riser tensioner ring.

On vessels not equipped with a marine riser tensioner ring, the tension joint shall be provided with padeyes, or similar, to enable attachment of tension wires from the vessel's tensioner system. A sufficient number of padeyes shall be used to allow for alignment with the vessel's tensioners and minimize torque in the riser system. Alternatively, the padeyes may be allowed to swivel freely on the tension joint by use of a swivel ring to enhance alignment with the vessel's tensioners.

For turret-moored and dynamically positioned vessels the swivel ring shall be equipped with low-friction bearings. The break-out and running torque of the swivel ring, under operating conditions, shall be sufficiently low to prevent unacceptable misalignment of the vessel's tensioners and torsional load on the riser.

The joint shall provide continuity of the production bore and annulus bore where applicable.

The upper end of the tension joint shall be connected to the slick joint or spacer joint (pup joint).

The bottom of the tension joint shall be connected to a standard riser joint.

The tension joint, including the adapter ring, padeyes and swivel ring, etc. shall be designed

- to support the total weight of the C/WO riser, including lower workover riser package, tree, over-pull and dynamic effects;
- to accommodate the asymmetric pull caused by malfunction of at least one tensioner;
- to accommodate skew loads due to misalignment of the vessel's tensioner wires;
- if applicable, to accommodate static and dynamic effects of the vessel's marine riser tensioner ring. Consideration shall also be given to the load effects due to intermittent or permanent penetration of the tensioner ring through the splash zone;
- if applicable, to accommodate torsional effects due to torsional resistance of the swivel ring or vessel's tensioner ring.

#### 5.4.16 Slick (cased wear) joint

The slick joint or cased wear joint, if installed, shall provide a protective sleeve that extends through the rotary table. Unless otherwise agreed, the sleeve shall be removable to enable inspection and maintenance of interior pipes. The length shall be sufficient to pass through the rotary table, diverter and ball/flex joint including extra length to allow for vessel motions relative to the riser string.

The outer protective sleeve profile shall be smooth to ensure the slick joint will not snag while rubbing inside the vessel's heaving rotary table. The bending stiffness introduced by the sleeves should be reduced to reduce the bending moments introduced in the connecting riser joints. Continuous or segmented sleeves may be applied.

The slick joint shall, unless otherwise specified, be equipped with standard riser connectors. The top end of the slick joint is connected to the surface tree adapter joint. The bottom end of the slick joint may be connected to the tension joint or a spacer joint (pup joint).

A control umbilical may run in parallel with the slick joint. In such cases, it shall either run inside the outer sleeve or be properly supported on the outside in a suitable groove or recess in the sleeve, in order to prevent damage to the umbilical as it passes through the rotary table, diverter and ball/flex joint.

Ease of handling and field installation shall be emphasized.



#### 5.4.17 Surface tree adapter joint

The top of the surface tree adapter joint connects to the bottom of the surface tree. This connection may be a flange, threaded or other proprietary connection as dictated by the surface tree design. The bottom of the surface tree adapter joint is connected to the slick joint using a matching riser connection. Alternatively, the surface tree adapter joint may be integral with the slick joint.

The adapter joint shall be made as short as possible.

#### 5.4.18 Surface tree

The surface tree shall provide the facility to shut-in production flow and kill the well.

The surface tree shall be a vertical through-bore design. Number of bores shall be compatible with the CWO riser design and operation.

The vertical bore(s) shall permit the clear passage of wireline/coiled tubing tool strings.

The surface tree valve arrangement shall consist of at least one valve in each vertical bore and one wing valve for each bore unless specified otherwise by the purchaser. All valves shall be remotely operated. Wing valves shall be remotely operated, fail-safe close with bi-directional sealing. Master and/or swab valves shall be remotely operated, fail-in position with bi-directional sealing.

Production wing valve closure time shall be compatible with the process shutdown requirements.

The design of the surface tree shall be in accordance with ISO 10423 or equivalent.

The surface tree shall be drifted in accordance with ISO 10423 requirements, or equivalent.

Wing and kill outlets should be arranged 90° down. Outlets shall have provisions for attachment of flexible pipes or swivel connections. Bending, tension and shear loads induced by the flexible jumpers, combined with internal pressure, shall be considered in the design of the outlets.

The surface tree shall include pressure monitoring of the vertical bore(s).

The surface tree shall be capable of lifting the entire CWO riser string, including the tubing hanger system or tree, and accommodate "overpull" requirements to verify that the subsea equipment has been properly landed and locked in place.

The top of the surface tree shall support the wireline/coiled tubing adapter. The wireline/coiled tubing adapter may be separate or an integral part of the tree.

Bending loads on the wireline/coiled tubing adapter shall be considered in the design of the surface tree.

Riser top tension shall typically be applied via one of the following:

- tensioning ring incorporated into the surface tree;
- surface tree tension frame attached to the surface tree or wireline/coiled tubing adapter;
- casing elevator attached to the wireline/coiled tubing adapter;
- padeyes attached to the surface tree block.

If a tensioning ring is incorporated into the surface tree design, consideration shall be given to number of tension points, ability of the ring to rotate and the possibility of side loading. Tension rings shall facilitate the use of elevator bails or heavy duty slings. Padeyes shall be adequately sized to support the required tensioning loads.



If included, the surface tree tension frame shall be properly designed to accommodate any realistic loading condition. The tension frame shall ensure that the loads and deformations of the equipment installed on top of the surface tree (e.g. coiled tubing BOP and injector head) are kept within acceptable limits.

Surface trees equipped with an integral wireline/coiled tubing adapter shall include a profile on the adapter to interface with a standard casing elevator. The outer diameter and load shoulder in such cases shall be consistent with standard casing collars of similar size.

Surface trees equipped with padeyes for the attachment of elevator bails or heavy-duty slings shall include padeyes adequately sized to support the required tensioning loads.

The design of the surface tree and its appurtenances shall allow for safe and efficient handling to and from the drill floor.

The surface tree shall be equipped with a protection frame to prevent damage during handling.

The surface tree shall be provided with a platform(s) to allow for safe working.

The bottom of the surface tree shall interface to the surface tree adapter joint.

#### **5.4.19 Wireline/coiled tubing adapters**

Wireline or coiled tubing adapters shall be used to connect wireline/coiled tubing BOPs and lubricators to the surface tree or directly to the riser.

The adapter may be integral or non-integral with the surface tree or riser.

The top of the adapter shall be provided with a threaded union, flange or speciality connector. For wireline operations threaded union connectors are preferred. For coiled tubing operations a flange or speciality connector is preferred. The connection shall be qualified for all relevant make/break loads, pressures, temperatures and external loads.

The adapter shall be provided with a profile to interface with a standard casing elevator. The outer diameter and load shoulder in such cases shall be consistent with standard casing collars of similar size. The adapter shall be capable of maintaining the pressure integrity/seal between the wireline/coiled tubing BOP and the adapter under all operational conditions.

#### **5.4.20 Surface tree tension frame**

The tension frame shall support the C/WO riser on the travelling block motion compensator.

The tension frame shall typically support the C/WO riser from either above or below the surface tree block.

The tension frame shall be capable of lifting the entire C/WO riser string, including the tubing hanger system or subsea tree, and accommodate "overpull" requirements to verify equipment has been properly landed and locked in place. In addition, axial capacity of the tension frame shall be not less than that of the C/WO riser joints.

The manufacturer shall determine (based on a global riser analysis) the required bending capacity of the tension frame. The global analysis shall include both dynamic and static effects.

The required fatigue design life of the tension frame shall be documented by a global analysis of the C/WO riser system.

The tension frame shall have sufficient height to allow for installation of the wireline/coiled tubing units. Provisions should be made for handling and make/brake of the bottomhole assembly in the frame.

The frame shall contain a work window in which the coiled tubing injector head, stripper and BOP can operate isolated from the motion of the vessel.

The design of the frame shall allow for relative rotation between the frame and the surface tree. Typically, 90° rotation about the vertical axis should be accommodated.

The frame shall be provided with a work platform(s) to access relevant working areas.

The frame shall have a system to guide and prevent horizontal movement of the coiled tubing injector head during operations.

The frame shall be supplied with a permanently mounted winch for installation of wireline/coiled tubing equipment and other hook-up equipment. The winch shall be remotely operated from the work platform on the tension frame and/or from the drill floor. The winch shall be capable of lifting with a speed that is greater than the heave motion of the vessel. The load capacity of the winch shall be as a minimum 30 % greater than the maximum weight to be lifted (i.e. coiled tubing injector head, heaviest bottomhole assembly, force required to release injector head quick connector, etc.).

The frame should have an integrated hydraulic man-rider winch that is remotely operated from the work platform on the tension frame and/or from the drill floor.

Provisions shall be made for anchoring personnel safety harnesses at suitable areas.

#### 5.4.21 Swivel

A pressure-containing swivel may be included in the C/WO riser string to allow for relative rotations between the riser and the workover vessel. The main purpose of the swivel shall be to maintain the same surface tree and surface tree tension frame orientation relative to the drill floor. Relative rotations normally occur during landing of the tubing hanger and due to heading variations on dynamically positioned vessels.

The swivel shall be located between the surface tree and the slick joint.

The pressure and temperature rating of the swivel shall be equal to or greater than that of the surface tree.

Redundant resilient or elastomeric seals (primary plus backup) shall be used to seal against produced and injected fluids.

Seal surfaces shall have corrosion-resistant inlay welding.

The swivel bearing housing shall be provided with a pressure relief device to vent pressure in case of leakage past the bore seals.

The swivel break-out torque and running torque shall allow for free rotation. When establishing the free rotational resistance of the swivel consideration shall be given to the riser string torsional stiffness, and torsional resistance of the tension joint swivel ring, marine riser tensioner ring, elevator and top drive swivel.

The swivel shall be designed to withstand loads due to handling of surface tree and slick joint assembly from pipe deck to drill floor.

The swivel shall be capable of withstanding the relevant design loads and load combinations as specified in Clause 6. Special consideration shall be given to fatigue loading when used in tree mode.

The swivel shall be qualified for the application, based on calculations in combination with qualification testing, see 6.6 and Annex I.

#### 5.4.22 Annulus circulation line

A flexible circulation line(s) may be used to provide annulus fluid access. The line(s) shall normally be used for C/WO riser circulation, tubing annulus circulation, tubing annulus pressurization and well kill. The circulation line(s) may be included in the workover control umbilical.

The size of the line(s) shall be selected to allow for well kill.

Pressure rating of the line(s) shall not be less than that of C/WO riser.

Test pressure and minimum burst pressure shall comply with the requirements for choke and kill lines specified in API Spec 16C.

The circulation line may have either an unbonded or a bonded structure.

Design, material selection, manufacture and testing shall be conducted according to API RP 17B for bonded structures and ISO 13628-2 for unbonded structures. The following qualification tests shall be conducted as a minimum:

- burst test;
- tensile test;
- crush test;
- cyclic hydrostatic pressure test;
- external hydrostatic collapse test;
- cyclic bend fatigue test;
- exposure test.

#### 5.4.23 Riser spider

Riser spiders shall sit either in the rotary table or on top of the master bushing. The spider shall support the C/WO riser system, plus all suspended weights of the tubing hanger system or subsea tree system while the riser connection is being made-up or broken-out.

Retractable dogs, bushings or slips shall provide support of the C/WO.

Spiders shall be equipped with suitable open/close mechanisms that are manually, hydraulically or pneumatically operated.

Manual spiders shall be designed considering the “human factor” to prevent fingers or hands from getting pinched or trapped.

During operation, all work on the spider should be possible by personnel, while they are standing on the drill floor.

For pneumatic or hydraulic spiders, locking devices to hold the spider in the open and closed positions shall be included to prevent any possibility for accidental operation of the spider.

Spiders which are required to provide torque transfer to the rotary table (required for threaded riser connectors) shall have pins which engage in the kelly drive pin holes, or similar.

Spiders, which have sliding surfaces, shall be designed to minimize the amount of dirt, trash, and drilling fluids, which could interfere with its operation.

Spider designs shall accommodate the relevant umbilicals/control lines when applicable.

The spider shall be designed to interface with the size and type of rotary table and rotary bushings specified by the purchaser.

Interface of all tools used during the completion and workover operations shall be considered, including tubing hanger running tool, tubing make-up tools, and stress joint, etc.

The design of the spider shall account for the following loading conditions:

- static load effects due to the weight of the tubing hanger, tubing, riser joints, subsea tree, lower riser package, tree running tools, stress joint, surface tree, and completion fluid;
- dynamic environmental load effects due to vessel motions and waves;
- static environmental load effects due to current and drilling riser ball joint angles;
- shock loads;
- torque transfer due to make-up and break-out of riser connectors;
- load rating, design factor, qualification testing and proof load testing of the spider shall be in accordance with ISO 14693.

To reduce static and fatigue loading in case of a hang-off in severe weather, a gimbaled spider may be advantageous. If a rigid spider is used during severe weather hang-off, it shall be demonstrated that static and dynamic loading in the riser is acceptable.

Gimbals shall be designed to accommodate maximum rotation about two perpendicular horizontal axes, with maximum suspended weight.

#### 5.4.24 Handling and test tools

Unless otherwise agreed, handling tools shall have an API Spec 7 tool joint at the top and a riser coupling facing down.

As agreed, handling tools may be designed to interface with the casing elevators if handling loads are beyond the safe working capacities of API Spec 7 tool joints.

The handling tool shall enable pressure testing of the riser. For jacketed integral risers, control-line couplings shall be provided to allow testing and operation of the tubing hanger control lines while running the riser.

The length of the handling tool shall be minimized, but have sufficient length to allow make-up and break-out of the drill pipe or casing elevator and adequate space for make-up of any control or test lines.

Handling tools shall support the full riser weight (static and dynamic), including suspended loads of the tubing hanger system and the subsea tree system.

The following loading conditions shall be considered when designing handling tools:

- horizontal and vertical riser joint handling;
- vertical suspended loads (i.e. riser joints, landing string, tubing hanger, tubing, subsea tree, lower workover riser package, weight of the completion fluid, overpull);
- effects of vessel motion, wave loading and current.

Load rating, design factor, qualification testing and proof load testing of handling tools shall be in accordance with ISO 13535.

#### 5.4.25 Umbilical clamps

Umbilical clamps may be permanently mounted to the C/WO riser or be loose appurtenances.

Umbilical clamps shall be designed to accommodate the following:

- operation in open sea and inside a marine drilling riser;
- provision of sufficient clamping force to support the weight of the filled umbilical(s) between clamps. The required clamping force shall account for umbilical outside diameter tolerances, operational friction coefficient of the umbilical outer sheath, outside diameter contraction due to clamping force and external hydrostatic pressure;
- reliable, quick and easy to operate with minimum wear/chaffing of the umbilical(s);
- provision for snag-free running and retrieval through the rotary table, riser spider and marine drilling riser;
- provision for protection of the umbilical during running and retrieval and operation within the marine drilling riser;
- provision for C/WO riser storm hang-off inside the marine drilling;
- elimination of loose parts that can fall into the marine drilling riser.

Qualification testing shall be conducted on unproven design of clamps. The testing should simulate expected working conditions or be more severe.

#### 5.4.26 Miscellaneous auxiliary components

Miscellaneous and ancillary special components include, but are not limited to, make-up tools, buoyancy modules, gimbals, and false rotaries.

Generally, these components shall be designed to interface with C/WO riser joints, with due consideration to the relevant type of riser connectors, type of riser and water depth.

Make-up tools (e.g. spanners, wrenches or hydraulic torque wrenches) shall be designed to be fit for purpose. Maximum riser coupling make-up or break-out forces shall be considered when designing these tools. Additionally, consideration shall be given to method and ease of handling on deck (i.e. lift points).

Buoyancy modules shall be rated to the maximum water depth of the riser and shall sustain normal handling and environmental loads. The type of attachment to the riser shall be reliable and easy to operate. The size of modules shall be manageable, and be agreed upon. Reaction rings on riser joints shall transfer the buoyancy loads. Strapping and bolting shall be corrosion-resistant.

False rotaries shall be designed to have a slot, which allows the false rotary to be put around the tubing string(s). On top of the false rotary, a slips bowl for tubing slips shall be provided. False rotaries shall sit squarely on the rotary table/bushing. False rotaries shall be designed to withstand the combined loading conditions due to the weight of the riser system, weight of the production tubing and vessel motions. Load rating, design factor, and proof load testing of the false rotary shall be in accordance with ISO 14693.

### 5.5 Workover control system

#### 5.5.1 General

The workover control system shall provide the means to remotely control all functions on the completion/workover equipment including tooling and subsea tree systems during the following phases and operations:

- installation, retrieval and testing of the tubing hanger and downhole completion system;
- installation, retrieval and testing of the subsea tree system and auxiliary support equipment;

- initial well completion operations and subsequent well workover during the life of the well;
- process shutdown;
- emergency shutdown;
- emergency quick-disconnect.

The workover control system shall facilitate normal and emergency shutdowns, normal and emergency disconnects in automatic sequences upon activation from the workover vessel.

The workover control system shall facilitate methanol injection.

### 5.5.2 Failure modes

The system shall be designed to ensure that no single failure will cause an unacceptable risk to personnel safety, the environment and to loss of financial assets.

An overall objective shall be to design the system to ensure that no single failure will cause a total system shutdown or prevent the ability to secure the well. Consideration shall be given in the design to early detection of failure or redundancy for critical components, which cannot be designed according to this principle.

The system shall be designed so that any failure in the system or damage to components affecting the system's ability to carry out operations or control functions shall result in the system moving automatically towards a safe position. This can apply to loss of electrical power, hydraulic power, pneumatic power or control or total failure of parts of the system.

### 5.5.3 Safety measures

When the workover vessel has assumed well control via the workover control system, the production installation shall not be able to influence the control possibilities for the intervened well. The production control system may be utilized for workover control, provided primary control is from the workover vessel.

The workover control system shall comply with regulatory requirements regarding safety aspects and redundancy.

The overall arrangement of the workover vessel with regard to area classification and total safety philosophy shall be taken into consideration in design, fabrication, installation and operation of the workover control system.

### 5.5.4 Securing measures

A reduction of the possibilities for and the consequences of operator error shall be emphasized in the design of the system. This may, for instance, apply to the securing of connecting system (e.g. subsea tree, tree running tool, subsea test tree and tubing hanger running tool connectors) functions during handling and reconnection situations, securing of valves in open position during wireline or coil tubing operations and securing of functions that can cause hazardous situations. Protection may be provided by positive locking of connectors, mechanical override of valves in open position, interlocks between functions, automatic time delay sequences between functions, overlay panels and protective covers on push buttons. In the case of interlocks, it shall be possible to override these at any time.

It shall be possible to operate the control system from independent panels located at designated sites. It shall not be possible to operate the equipment from more than one site at any one point in time. The system design shall ensure that critical emergency shutdown and disconnecting functions can be performed from all of the designated sites at any time.

### 5.5.5 Shutdown and disconnect functions

The workover control system shall include the necessary functions for automatic, sequential shutdown and disconnection of modules by activation from surface control panels. Typically two levels of shutdown (process and emergency shutdowns) and an emergency disconnect function shall be provided. The sequence and timing of each individual function included in these automatic operations shall ensure that hazardous situations do not occur.

A process shutdown shall provide isolation of the C/WO from the workover vessel process equipment. Typically, a process shutdown shall include closure of the surface tree wing valve(s).

An emergency shutdown shall consist of a sequential establishment of the barrier elements. The barrier element closing sequence shall consider the presence of coiled tubing and wireline and whether cutting results in falling or raising of the coiled tubing and wireline.

An emergency disconnect shall consist of a sequential establishment of the barrier elements followed by disconnection at a level above the top barrier (e.g. emergency disconnect package and subsea test tree latch).

The workover control system shall be designed to perform an emergency shutdown within an acceptable response time based on a total assessment of the possible emergency situations and the consequences of such situations.

The workover control system shall be designed so that emergency disconnection can be carried out within a time interval determined in relation to the development of unforeseen situations on the workover vessel (e.g. loss of station-keeping), after the barriers against blowout have been established.

In the case of an unplanned disconnection, all fail-safe functions shall move automatically towards a safe position.

Following disconnections, the system shall be designed to minimize ingress of ambient fluids (i.e. seawater and drilling riser contents) into the hydraulic control circuits of the disconnected modules (i.e. emergency disconnect package, lower workover riser package, subsea test tree, etc.).

### 5.5.6 General requirements

The workover control system shall typically be used to control the modules listed in Table 6.

**Table 6 — Typical modules controlled by the workover control system**

<b>Tubing hanger mode</b>	<b>Tree mode</b>
Surface flow tree	Surface flow tree
Lubricator valve	Lubricator valve
Retainer valve	Retainer valve
Subsea test tree	Emergency disconnect package
Tubing hanger running tool	WCT-BOP
Tubing hanger	Tree running tool
Tree cap running tool	Subsea tree
Internal tree cap	Internal tree cap
Subsea tree	Downhole monitoring and flow control functions
Downhole monitoring and flow control functions	SCSSV
SCSSV	—



The workover control system shall typically consist of the following modules:

- high-pressure unit;
- main control panel;
- remote-control panel;
- process shutdown panel;
- emergency shutdown panel;
- riser control module;
- workover control module;
- umbilical;
- umbilical winches.

Emergency shutdown and emergency disconnect function buttons shall be clearly identified and located on the master control panel, remote control panel and emergency shutdown panels.

The remote-control panel shall be located on the drill floor, preferably in the drill-floor control room.

Emergency shutdown panels shall be provided at main escape routes or bridge.

The process shutdown panel shall be located at the production test area.

In the case of common functions between workover and production control, the control fluids should be identical and should be subjected to the same requirements with regard to purity and properties.

An uninterruptible power supply shall be provided to maintain control during loss of main electrical power supply. The uninterruptible power supply shall ensure normal control for 30 min and successful emergency shutdown and emergency disconnect within 1 h from loss of power.

All electrical equipment shall be designed according to requirements for explosion zone 1, gas group IIB and temperature class T3 in accordance with IEC 60089-0.

A hydraulic/electrical response analysis shall be performed to ensure adequate sizing of components for service at the required range of water depths. The analysis shall ensure that the design provides the required response for the shutdown and emergency disconnect sequences.

All hydraulic piping, tubing and hose shall comply with ISO 13628-6:2000, 7.3.1.3.

Surface and subsea accumulators shall comply with ASME Boiler and pressure vessel code, Section VIII, Division 1 and BS 7201, Part 1, and ISO 10945.

Accuracy of pressure gauges and transmitters shall be  $\pm 1$  % full-scale or better.

Protective covers shall be provided for all external control panels, umbilical terminations and multi-quick connector plates to prevent damage and/or contamination of couplers during transportation and operation.

The workover control system shall be designed to meet the environmental conditions of an exposed deck of the specified workover vessel.

Equipment shall be shock/vibration-resistant to withstand normal transportation and vessel motions.



All units shall be skid-mounted and designed for offshore lifting, onshore handling either by forklift or crane.

All units to be lifted shall be supplied with padeyes and loose lifting gear certified for offshore lifting.

All units shall be designed with seafastening to withstand 45° listing.

All enclosed working areas/containers shall have two separate means of personnel exiting the area/container.

#### 5.5.7 High-pressure unit

The high-pressure unit shall include pumps, high- and low-pressure accumulators, supply and return tanks, flushing/filtering facilities and a high-pressure unit control/alarm panel.

The high-pressure unit shall be capable of supplying hydraulic power to operate all the required tool functions within the required response times.

The design shall allow to a maximum extent, components within the high-pressure unit to be isolated and serviced without interrupting normal operation.

Permanent pressure gauges shall be installed to measure upstream (header) and downstream (regulated) pressures.

The high-pressure unit should contain a high-pressure circuit for SCSSV and other high-pressure functions and a low-pressure circuit for valve and connector operation unless otherwise specified.

The same type of fittings shall be used for each pressure class throughout the system.

The high-pressure unit shall store and maintain the specified hydraulic control fluid to the required cleanliness. The fluid shall have the same standard as the fluid used in the production control system.

The hydraulic fluid tanks shall be equipped with visual level indicators, preferably also with audio-visual low and low-low level.

Hydraulic fluid tanks shall be made from stainless steel, equipped with circulating pump(s) and filters for flushing/filling of new fluid from barrels. Sample points shall be made at the lowest point of the reservoir and at the pump. Control fluids from the return lines shall be filtered and cleaned before re-entering the high-pressure unit supply system or dumped to a waste tank.

Redundant fluid filters shall be provided to achieve required fluid cleanliness. They shall be easily replaced with minimum contamination risk to the system. A clogged filter indicator shall be provided. In case of an oil-based system, water removal shall be included.

The pump system shall be capable of pressurizing the topside accumulators within 15 min, and maintain the system pressure during all operational modes.

Accumulators shall be provided for the high-pressure and low-pressure systems.

Accumulators for the high-pressure system shall have sufficient capacity to operate the SCSSV five times plus 50 % reserve before it reaches the minimum system working pressure without being recharged by the pump.

The accumulators for the low-pressure system shall have sufficient capacity to operate all functions with the system as specified below:

- a) lower workover riser package operations: Operate subsea valves and WCT-BOP valves (close-open-close + 25 % of close operation) before it reaches the minimum system working pressure;
- b) tubing hanger operations: Operate all subsea tree valves, subsea test tree, retainer valve and lubricator valve (close-open-close + 25 % of close operation) before it reaches the minimum system working pressure.

For last closing functions, there shall be sufficient pressure capacity to accomplish cutting coiled tubing containing logging cable (as specified by purchaser) and finally disconnect the riser.

If separate accumulators are located on the lower workover riser package or landing string, these may be included in the volume calculations.

The accumulators should have individual visual indication of low nitrogen pressure.

Maximum noise levels shall not exceed regulatory authority requirements.

#### **5.5.8 Master control panel**

The master control panel shall be designed to provide for the distribution of hydraulic supply from the high-pressure unit to the control umbilicals.

The master control panel shall include a mimic type display featuring the general layout of the system, equipment to be operated and all associated functions. All subsea tree, landing string and running tool functions shall be available together with signals for verification of output of each function.

Pressure indicators/gauges for monitoring of pressure outputs and control of function line pressures shall be provided for each function. All functions related to pressure testing shall be provided with isolation valves for isolation of external circuits and a pressure monitoring device to record the pressure test. The upstream side of the isolation valve shall be vented prior to the commencement of pressure testing.

Unintended operation of connectors during running shall not be possible. Critical functions such as opening of connectors and closing of shear rams shall be protected by interlocks or protective covers or isolation of the dedicated hydraulic lines.

All controls and indicators shall be properly labelled, and all components shall be suitable for the operating environment.

#### **5.5.9 Remote-control panel**

The remote-control panel shall be designed to operate process shutdown, emergency shutdown and emergency disconnect functions together with any other functions specified by purchaser.

The remote-control panel shall be electrically connected to the master control panel. The electrical cables shall have sufficient length for direct connection to the master control panel.

The remote-control panel shall operate as a slave to the master control panel. Panel activation shall be controlled by a selector switch on the main control panel. Active panel indicators shall be provided on both panels.

A cable monitoring system shall be included to notify the operator of cable failures. In case of remote-control panel cable failure, the master control panel shall automatically be activated.

#### **5.5.10 Emergency shutdown panel**

The emergency shutdown panel(s) shall be designed to operate process shutdown, emergency shutdown and emergency disconnect functions.

The emergency shutdown panel shall be electrically connected to the master control panel. The electrical cables shall have sufficient length for direct connection to the master control panel.

A cable monitoring system shall be included to notify the operator of cable failures.

Indicator lamps shall provide function activation status.

#### 5.5.11 Process shutdown panel

The process shutdown panel shall initiate a process shutdown.

The workover control system shall have a connection to the topside well testing emergency shutdown system to allow a process shutdown on receipt of a shutdown signal. Absence of a signal shall cause a shutdown.

The process shutdown panel shall be electrically connected either to the master control panel or remote-control panel. The electrical cables shall have sufficient length for direct connection.

A cable monitoring system shall be included to notify the operator of cable failures.

Indicator lamps shall provide function activation status.

#### 5.5.12 Riser control module

An electro-hydraulic system contained within a riser control module mounted on or internal with the C/WO riser may be used in tubing hanger mode to control the operation of the landing string and downhole functions.

The riser control module shall typically contain hydraulic couplers, electrical pin connectors, hydraulic control valves and electronics.

The riser control module shall be designed to be suitable for operation inside a drilling riser. Consideration shall be given to operating temperature, ambient external pressure, drilling riser fluids, shock, impact and vibration loads generated during transportation, handling on pipe deck and drill floor, drill floor function testing, racking in derrick, running and retrieval and during storm hang-off.

The riser control module shall be designed in accordance with 5.5.14.

#### 5.5.13 Workover control module

An electro-hydraulic system contained within a workover control module may be used in tree mode to control the operation of the lower workover riser package, tree and downhole functions.

The workover control module shall be mounted on to the emergency disconnect package or above the emergency disconnect package.

The workover control module shall typically contain hydraulic couplers, electrical pin connectors, hydraulic control valves and electronics.

The workover control module shall be designed to be suitable for tree mode operations. Consideration shall be given to operating temperature, ambient external pressure, shock, impact and vibration loads generated during transportation, handling on pipe deck and drill floor, drill floor function testing, running and retrieval through the splash zone and during storm hang-off.

The workover control module shall be designed in accordance with 5.5.14.

#### 5.5.14 Control module design

The riser control module and workover control module shall be designed in accordance with the following.

- a) The system shall be fail-safe on loss of hydraulic pressure.
- b) The system shall be designed to ensure that loss of electrical power and/or communication does not result in a total system shutdown or prevent the ability to secure the well. This may be achieved by the system being fail as-is on loss of electrical power and/or communication.

- c) The response of the control module shall be compatible with the required emergency shutdown and emergency disconnect response times.
- d) The control module shall have a communication rate with the top side system that is compatible with the required emergency shutdown and emergency disconnect response times.
- e) All active electronic circuits should be enclosed in nominal one atmosphere gas-filled enclosures designed for full external pressure conditions.
- f) Electrical elements of electro-hydraulic components shall be mounted in a dielectric fluid-filled and pressure compensated housing.
- g) Fully redundant electronics shall be included.
- h) All supply and function line control may be performed by hydraulically latched, electrically pulsed, solenoid valves.
- i) Each hydraulic supply and function line shall be internally monitored by pressure transducers.
- j) The control module shall be capable of providing feedback to topside system in order to verify correct operation.
- k) Leakage in the hydraulic section of the system shall not impact the integrity of the electric/electronic system.
- l) Return hydraulic fluid may be returned by dedicated return lines in the supply umbilical and/or expelled to environment by an internal check valve system.
- m) Direct hydraulic lines shall not have any associated control valves within the control module.
- n) Each hydraulic supply line shall have a filter.

#### 5.5.15 Umbilicals and jumpers

Umbilical hoses shall transmit the necessary control and monitoring functions from the surface controls to the subsea functions. Signals to be transmitted may be both hydraulic and electrical.

The control umbilical shall take the form of a composite construction and accommodate all the necessary control and monitoring lines required of the workover system during the specified modes of operation.

The umbilical hoses and jumpers shall be capable of withstanding specified hydraulic and electrical requirements.

The umbilical shall have sufficient mechanical strength such that internal hoses and electrical cables shall be capable of withstanding both the static and dynamic forces encountered during all specified modes of operation of the workover system.

Hose material selected shall be compatible with the specified control fluid.

The materials used in the umbilical shall not produce debilitating gases in the case of fire.

Hose sizes shall be dimensioned to allow for sufficient volume flow to achieve the minimum required operating times for valves and connector functions. Hose dimensions shall be verified by conducting a hydraulic response analysis.

A minimum of one spare line should be included in the umbilical, unless specified otherwise by purchaser.

Bend restrictors shall be fitted to umbilical end terminations and individual hose end terminations shall be protected from accidental damage.

Umbilical(s) may be clamped to the riser string or a separate tensioned guide wire.

The design, manufacturing and qualification of the umbilical shall comply with requirements given in ISO 13628-5.

#### 5.5.16 Multi-quick connector plates

Umbilicals and umbilical jumpers should be terminated in multi-quick connector plates.

Multi-quick connector plates shall be designed for easy make-up and break-out and provide guidance, alignment, orientation and flexibility to ensure correct coupler alignment and prevent coupler damage.

Multi-quick connector plates should be designed for make-up and break-out by hand.

A locking mechanism shall be provided, designed to withstand relevant separation forces. The locking mechanism shall include a securing mechanism to prevent accidental disconnection.

A lifting eye shall be provided to allow for lifting to the correct position for make-up.

#### 5.5.17 Umbilical winch

The umbilical winch shall be capable of handling the complete fluid-filled umbilical length plus a surplus length of 20 %.

The winch shall be either pneumatically powered from available workover vessel air supply or alternatively powered hydraulically from the workover control system high-pressure unit or electrically powered from available vessel supply.

The winch shall be designed to provide sufficient torque and speed for efficient running.

The winch should be equipped with a transverse reciprocating guidance system to evenly spool the umbilical on the drum during wind-in retrieval.

Components required for operation of the winch should be mounted on the winch.

The winch should be skid-mounted with a protective frame and equipped for top four-point lift and forklift handling.

The winch power unit should have controls for forward, reverse and centre for stop.

Sufficient filtering, lubrication and pressure regulation of the air/oil supply shall be provided on the reel to protect the air/hydraulic motor from excessive wear or damage.

The winch shall be equipped with a fail-safe brake system for stop and hold. It should also have an independent manually operated static brake. The brake shall have sufficient braking capacity to stop and hold the umbilical when subjected to maximum operating tension.

The winch should be equipped with a quick-disconnect junction plate for attachment of the umbilical jumper.

A safety interlock shall be provided on the winch to immobilize the motor drive to the reel when the umbilical jumper is connected.

The winch should be equipped with a hot-line connection or multi-quick connector plate, isolation valves and gauges to allow selected tool functions to be pressurized and isolated. All functions should be mounted in an isolating/monitoring panel on the winch.

The winch should be equipped with a mobile remote-operation control in addition to local control on the reel. The length of the remote-control cables should be 20 m (65,6 ft) as a minimum.

#### 5.5.18 Umbilical sheaves

The sheaves shall be provided to support the umbilical during installation, retrieval and operation.

The sheaves shall be designed to protect the umbilical from exceeding its minimum bending radius and shall allow for smooth movement of the umbilical.

Padeyes on sheaves and appurtenances for attachment of sheaves shall have a safe working load equal to, or greater than the tensile breaking strength of the umbilicals they support.

#### 5.5.19 Test and auxiliary equipment

The workover control system shall be delivered with all necessary test and auxiliary equipment, including electrical jumpers, water coolant hoses and nitrogen boost with filling hoses.

## 6 Design requirements

### 6.1 Purpose

This clause specifies requirements for design principles, loads, load effect analysis and design of components including pipes and connectors.

### 6.2 Design principles

#### 6.2.1 Purpose

In 6.2, the design principles and applicable design methods are given.

#### 6.2.2 Fundamental requirements

A C/WO riser system and its components shall be designed, manufactured, fabricated and maintained so that it is suited to its intended use. In particular the C/WO riser system shall be designed to

- a) sustain load effects likely to occur during its intended life;
- b) maintain acceptable safety for personnel and environment;
- c) have adequate resistance against deterioration for its intended life.

#### 6.2.3 General design considerations

The design of the C/WO riser system, its components and details shall, as far as possible, account for the following principles.

- a) Riser joints and components shall possess ductile resistance.
- b) Riser joints and components shall be designed such that an unintended event does not escalate into a catastrophic failure.
- c) Riser joints and components shall be designed with the aim to minimize stress concentration (overall cyclic stress range and cyclic damage accumulation), e.g. by means of a stress-flow related design of cross-section transitions and reduce complex stress-flow patterns.
- d) Riser joints and components shall be made such that fabrication can be accomplished in accordance with recognized techniques and practices.

- e) Design of structural details and use of materials shall be done with the objective to minimize corrosion, erosion and wear.
- f) Permit simple and reliable installation, retrieval and be robust with respect to use.
- g) Provide adequate access for inspection, maintenance, replacement and repair.
- h) Facilitate monitoring of its behaviour in terms of tension, stroke, stresses, angles, vibrations, etc.

Inspection philosophy should be an integral part of the design. Criticality of components and ease of inspection should be considered early to ensure that provisions are made for adequate inspection.

The designer should ensure that necessary inspection methods or replacement procedures are available and are scheduled and described in adequate detail as part of the operating and maintenance documentation for the C/WO riser system.

#### 6.2.4 Design methods

The C/WO riser system design shall be based on calculations supplemented by necessary testing.

NOTE 1 Calculation methods imply use of analytical-based equations or numerical analysis, e.g. finite element analysis or boundary element analysis.

NOTE 2 Where this part of ISO 13628 does not indicate an applicable calculation or testing method, it is the designer's responsibility to use widely recognized methods to justify the dimensions and materials selected.

The C/WO riser system and components shall be designed against all relevant failure modes.

NOTE 3 A failure mode is a condition beyond which the riser or component of the riser exceeds a specified design requirement. Examples of failure modes are loss of structural resistance (excessive yielding and buckling), fatigue failure, leakage, unstable fracture, motions that exceed the limitations of components, exceedance of minimum clearance, mechanical malfunction of a component.

The design shall incorporate appropriate design factors or safety factors using comprehensive methods that are known to result in adequate safety margins against all relevant failure modes in a consistent manner.

The general ultimate strength safety format in this part of ISO 13628 is expressed as Equation (1):

$$S_d \leq R_d = R_{uc} \times F_d \quad (1)$$

where

$S_d$  is the design load effect;

$R_d$  is the design capacity (resistance);

$R_{uc}$  is the ultimate capacity (resistance);

$F_d$  is the design factor.

This design format is named the working stress design method, which is a design method by which the safety is obtained by applying design factors to the resistance of the component. The design factor depends on failure mode and design conditions.

NOTE 4 The design factor(s) accounts for the integrated uncertainty and possible bias in load effects and resistance. The inverted design factor ( $< 1$ ) can be considered as a safety factor ( $> 1$ ). The design factor is also named "allowable stress factor" or "usage factor" in some working stress design codes and standards.



As an alternative to the working stress design method or as a supplement to analytical methods, determination of load effects and resistance may in some cases be based either on testing or on observation of structural performance of models or full-scale riser systems with valid methods. A probabilistic approach based on recognized structural reliability analysis may also be applied. Direct reliability analysis methods are mainly considered as applicable to special case design problems, to calibrate design factors to be used in the working stress method for failure modes not covered in this part of ISO 13628 and for conditions where limited experience exists. Load effect and resistance factor design method with calibrated load effect and resistance factors may also be applied.

The reference values or characteristic values of  $S_d$  and  $R_{uc}$  to be used in the design process are normally based on lower fractiles for resistance and upper fractiles for the load effect.

For the calculation of load effect:

- a) for environmental load effects:
  - for permanent operational conditions the most probable extreme combined load effect for a 100-year return period ( $10^{-2}$  annual exceedance probability) shall apply;
  - for temporary operational conditions the most probable extreme combined load effect for the following return period values shall apply:
    - a 100-year return period if duration (i.e. continuous operation) is in excess of 6 months,
    - a 10-year return period for the actual seasonal environmental condition if duration is in excess of 3 days but less than 6 months,
    - specified extreme load condition for duration less than 3 days or operations which can be terminated within 3 days;
- b) values for pressure and temperature unlikely to be exceeded during the life of the riser may be used for minimum/maximum design pressure and design temperatures;
- c) the self-weight and buoyancy may be calculated on the basis of nominal dimensions and mean unit mass;
- d) the nominal top tension may be applied for top tension;
- e) the limit values may be used as characteristic values for effects which are bounded;
- f) the maximum and minimum extreme values in a given period may be used for load effects caused by deformation, e.g. intended vessel offset or thermal effects;
- g) the accidental load effect values shall be individually specified.

NOTE 5 The characteristic values of pressure and temperature describe the pressure-temperature regime that envelopes those pressures and temperatures that are unlikely to be exceeded during the life of the riser.

For the calculation of characteristic resistance:

- a) the nominal values of the geometric data may be used with the exception of thickness for which the following applies:
  - the nominal value minus the corrosion allowance shall be used for combined loading,
  - the nominal value minus the fabrication tolerance and corrosion allowance shall be used for pressure design, e.g. see 6.5.2;



- b) the 2,3 % fractile for relevant experimental data (mean resistance minus two standard deviations) or the minimum specified values shall be used for strength data at the design temperature, i.e. yield and ultimate tensile strength;
- c) for other properties, e.g. modulus of elasticity, coefficient of linear thermal expansion, nominal or mean value may be used.

The safety format for fatigue design in this part of ISO 13628 is expressed as given in Equation (2):

$$\frac{L_F}{D_F} \geq L_S \quad (2)$$

where

$L_F$  is the calculated fatigue life;

$D_F$  is the design fatigue factor;

$L_S$  is the service life.

For the calculation of fatigue load effects, the expected load effect history shall be used.

For the calculation of fatigue resistance:

- a) the 2,3 % fractile shall be applied for relevant experimental data, i.e.:
  - the design S-N curve shall be based on the mean minus two standard deviations curves,
  - the design crack growth parameters shall be based on the mean plus two standard deviations data;
- b) the expected initial crack size after fabrication and NDT (50 % probability of detection) shall be used.

## 6.3 Loads and load effects

### 6.3.1 Purpose

In 6.3, the loads to be considered in the design of riser systems are defined and the requirements for global riser analysis are given.

### 6.3.2 Definition of load classes

#### 6.3.2.1 General

The loads shall be categorized as functional, environmental and accidental defined as follows:

- a) functional loads are loads arising from the physical existence and intended use of the C/WO riser system, without consideration of environmental or accidental loads;
- b) environmental loads are those caused directly or indirectly by the ocean environment on the C/WO riser system, and that are not classified as functional or accidental loads;
- c) accidental loads (or low probability of occurrence loads) are loads related to abnormal operations or technical failure.

Unless specific exceptions apply, the characteristic loads defined in 6.2.4 shall apply.

### 6.3.2.2 Design pressure and design temperature

The C/WO riser system should be designed to operate in one of the design pressures specified in Table 7. Valves, flanges, connectors, and other components should have design pressures (or pressure ratings) equal to or greater than the design pressure of the C/WO riser. The design pressure of the lowest rated component shall define the design pressure of the riser system.

For deep-water applications where differential pressures are controlled by water depth, segmented pressure ratings can be considered in order to avoid unnecessary conservatism and save mass.

**Table 7 — Internal design pressure,  $p_{\text{int,d}}$ , classes**

$p_{\text{int,d}}$ MPa (psi)
34,5 (5 000)
69,0 (10 000)
103,5 (15 000)
138,0 (20 000)

The internal design pressure or pressure rating at any point in the C/WO riser system shall be equal to or greater than the maximum working pressure. Pressures due to static head of the fluid shall be included in the steady-state pressures.

The maximum working pressure or internal design pressure is the internal pressure that is unlikely to be exceeded during the life of the riser. This means that the internal design pressure shall not be less than for flowing pressure, shut-in pressure including surge pressure, maximum accumulated pressure, relieving pressure (i.e. set pressure of the relief valve plus over-pressure) and pressure during well-kill, stimulation, or injection operations. Higher pressure ratings may be required where leakage from higher pressure sources (e.g. SCSSV control lines) can become trapped.

For the purpose of design, pressure shall be interpreted as the difference between internal pressure and external pressure acting on the component.

In deep-water applications, the differential pressure across pressure-containing bodies is substantially reduced by the effect from the external hydrostatic pressure. This effect may be taken into consideration when determining the actual working pressure for such components. Note that pressure tests under atmospheric conditions shall be modified accordingly. For examples, see ISO 13628-4:1999, 5.1.2.1.1.

The design pressure shall be specified at a reference level with corresponding temperature and fluid densities. The reference level may be the wellhead (seabed) or the top (surface) of the riser.

The pressure difference between internal and external pressure shall be used for design as the fluid hydrostatic pressures inside and outside the riser vary with depth. The local internal pressure,  $p_{\text{l,int}}$ , i.e. the local internal pressure at a specified point in the C/WO riser system relative to the internal pressure at a reference point,  $p_{\text{int}}$ , is given by Equation (3):

$$p_{\text{l,int}} = p_{\text{int}} + \rho_{\text{int}} \times g \times h \quad (3)$$

where

$h$  is the height difference between the actual location and the internal pressure reference point;

$g$  is the acceleration due to gravity;

$\rho_{\text{int}}$  is the density of the internal fluid.

Gas mixed with oil in the riser could reduce the hydrostatic pressure acting downstream of a closed valve. This factor shall be taken into account when calculating the maximum allowable shut-in pressure for the specific application.

The C/WO riser system should preferably be designed to operate in one or more of the temperature classes as specified in Table 8.

**Table 8 — Temperature design classes based on fluid temperature**

Temperature classification	Operating range °C (°F)	
	Minimum	Maximum
K	– 60 (– 75)	82 (180)
L	– 46 (– 50)	82 (180)
P	– 29 (– 20)	82 (180)
R	Room temperature	
S	– 18 (0)	66 (150)
T	– 18 (0)	82 (180)
U	– 18 (0)	121 (250)
V	2 (35)	121 (250)
X	– 18 (0)	180 (350)
Y	– 18 (0)	345 (650)

Various combinations of internal and external pressure in combination with coincident temperature shall be considered to determine the appropriate design cases. Intermediate pressure and temperature classes may be considered where appropriate.

The design maximum metal temperature shall not be less than the fluid temperature unless calculations, tests or service experience based on measurements, support the use of another temperature. Any heat transfer calculation shall be performed on the assumption that there is no heat loss due to wind. Heat loss due to seawater can be considered for submerged parts.

The minimum design metal temperature shall be determined by considering the lowest temperature to which the component will normally be exposed to in service, including controlled blowdown.

The fluid temperature range for the selected temperature class shall be considered when determining temperature-induced loads.

All components shall also be designed for net external pressure when applicable. Annual average seawater density and mean sea levels shall be used to establish the external hydrostatic pressure caused by the seawater.

Special consideration shall be given to external pressures that exceed the environmental (open sea or drilling riser) hydrostatic pressure.

**EXAMPLES** Annulus pressure for a concentric riser and BOP pressure (during setting of production packers, tubing hanger pressure testing, BOP pressure testing, annulus circulation to choke/kill lines, operation of landing string secondary functions, etc.) are examples of external pressure which need special consideration.

### 6.3.2.3 Environmental loads

#### 6.3.2.3.1 General

All relevant environmental phenomena for the particular location and operations, including storage and transportation, shall be taken into account in the calculation of loads on the riser.

**EXAMPLES** Hydrodynamic loads on the riser induced by direct action of waves and current are examples of environmental loads. Loads caused by environmentally induced vessel motions are also defined as environmental loads.

#### 6.3.2.3.2 Environmental conditions

Data for the joint occurrence of e.g. waves and current conditions should be applied.

**NOTE** The principal environmental parameters are waves, currents and vessel motions.

If sufficient data are not available for the geographic location in question, conservative estimates based on data from other relevant locations may be used.

Ice and earthquake load effects shall be considered in regions where relevant.

Statistical data shall be utilized to describe environmental parameters of a random nature (e.g. waves). The parameters shall be derived in a statistically valid manner using recognized methods. The statistical description shall describe the extreme conditions as well as the long- and short-term variations, e.g. parameters for describing maximum wave load effects, wave-induced fatigue load effects, and other effects, such as vortex shedding.

#### 6.3.2.3.3 Surface waves

The wave data shall include the following:

- a) sea-state characteristics in terms of significant wave height, spectral peak period (or average upcrossing period), spectral shape and directionality;
- b) long-term statistics of these characteristics in terms of seasonal wave scatter diagrams given as significant wave height and spectral peak period (or average upcrossing period) or wave heights and wave periods for single design waves.

**NOTE 1** Other wave parameters of interest, such as the maximum wave height and the associated wave period (design wave), can be derived from these data.

**NOTE 2** Wind-driven surface waves exert significant oscillating forces directly on the risers. Such waves are irregular in shape, can vary in length and height and can approach the riser from one or more directions simultaneously. Waves also induce steady and oscillatory forces on the vessel to which risers are attached.

If directional information on waves is not available, wind direction may be used for wave direction.

Combination of wind-driven waves and swell from different directions should be included if relevant.

**NOTE 3** This has particular relevance, e.g. for mono-hull vessels, where large roll motions can introduce high bending moments due to beam-sea swell in combination with wind-driven head sea.

#### 6.3.2.3.4 Current

The design current velocity, profile and direction shall be selected using recognized statistical methods. The resulting current velocities shall include contributions from all relevant phenomena including, but not limited to, tidal current, wind-induced current, storm surge current, density-induced current, global ocean current, eddies that spin off from a circulating current, solitons, internal waves and other effects due to differences in water density.

Special attention shall be given to provide associated current profiles with the specified limiting operating sea-states, especially for deep-water applications.

Various current profiles (current velocity vs. water depth) and wave combinations should be considered.

#### 6.3.2.3.5 Water depth and tide

The water depth at the location shall be defined. Effects from tide and storm surge shall be considered if the water depth is a significant parameter.

Mean water level may be used to determine seawater pressure.

#### 6.3.2.3.6 Temperature

The maximum, average, and minimum seasonal air and sea temperatures at the site shall be specified if these temperatures are likely to be relevant to riser design. This is of particular relevance to arctic regions. The most conservative ambient temperature should be applied for design and choice of materials.

Maximum and minimum storage and transportation temperatures shall be specified.

NOTE Temperature and humidity are important for storage, preservation, design of workover control system, etc.

#### 6.3.2.3.7 Vessel offset and motions

The effect of vessel offset and motions shall be included in the riser design. Vessel response data due to environmental loading that shall be specified are the following:

- a) static offset: mean offset due to wave, wind and current loads;
- b) wave frequency motions: first-order wave-induced motions;
- c) low-frequency motions: motions due to wind gust and second-order wave forces;
- d) set-down and draught variations: due to the combined effect of mooring line constraints and vessel offset.

NOTE 1 For guidance regarding calculation of representative vessel offset, reference is made to section A.6.2.2 in API RP 2SK:1997 [3].

Vessel offset and motions constitute a source of both static and dynamic loading on the riser. The low-frequency motions may be considered as static in the riser load effect analysis.

The vessel wave frequency motions shall be given in terms of RAOs and with a clear-cut definition of amplitudes and phase angles as well as wave directions. The RAOs shall be defined for all six degrees-of-freedom (surge, sway, heave, roll, pitch and yaw), and for a sufficient number of discrete wave frequencies, such that the RAOs are particularly well defined near any resonance peaks in the dynamic system. The vessel attached coordinate system used as reference system shall be documented in terms of origin, i.e. motion reference point, and directions of coordinate axis. The vessel RAOs shall be applicable for relevant vessel draughts. Dynamic positioning system performance, e.g. positioning tolerances, should be provided if applicable.

If applicable, vessel motion data for damaged conditions, e.g. mooring line failure, shall be specified.

NOTE 2 Vessel RAOs depend on vessel draught and thruster-assisted positioning.

#### 6.3.2.3.8 Determination of hydrodynamic loads

Hydrodynamic loads shall be determined by analysis; see 6.3.4. If theoretical predictions are subject to significant uncertainties, theoretical calculations shall be supported by model tests or full-scale measurements of existing C/WO risers or by a combination of such tests and full-scale measurements.

#### 6.3.2.4 Accidental loads

The C/WO riser system shall be designed for accidental loads. Accidental loads are defined as events with a probability less than  $10^{-2}$  and larger than  $10^{-4}$ .

Relevant accidental loads, both magnitude and frequency, for a specific C/WO riser and vessel may be defined by system review, risk analysis and relevant accumulated experience; see 4.6.

**EXAMPLES** Loads caused by vessel tensioner system failure or motion compensator system failure, e.g. loss of top tension or heave compensator lock-up, loss of dynamic positioning system (drive-off or drift-off) are examples of accidental loads. Loads caused by emergency operation, loss of buoyancy, change in intended pressure difference, unintended change in ballast distribution, fire, explosions, collision impact from infrequent vessel/riser interference, dropped objects and extreme environmental conditions are also accidental.

Safety joints or weak links may be used to ensure that unacceptable escalation does not occur for accidental loads; see 6.7.1.

Accidental loads for the C/WO shall also be considered for other affected systems/components. For example, if the C/WO riser failure inside the drilling riser is a result of an accidental load case, the internal pressure resulting from this failure shall be considered also for the drilling riser.

#### 6.3.3 Load combinations and conditions

Loads and load effects, which can cause or contribute to failure of the C/WO riser system during its intended use and other reasonably foreseeable operational conditions, shall be identified and accounted for in the design.

The C/WO riser system shall be shown to meet the design criteria in 6.4 to 6.7 under the load combinations given in 6.3.3.

When establishing ultimate strength design load effects, the most unfavourable combination of functional, environmental and accidental loads, which can be predicted to occur simultaneously, shall be considered.

The worst-case orientation of coiled tubing frame or bails with respect to worst-case loading conditions shall be established and shall in general be used in the global analysis.

To find the maximum and minimum load effects, different combinations of wave heights and periods, current profiles, minimum and maximum vessel offsets, fluid densities, temperatures, pressures, etc. shall be considered.

**NOTE 1** Load combinations with a probability of occurrence less than  $10^{-4}$  for the period under consideration can be ignored.

Unless they can be reasonably expected to occur together, it is not necessary to consider a combination of accidental loads in combination with extreme environmental loads.

**NOTE 2** Restricted operating or maximum operating condition typically includes specification of wave height including relevant wave period range in combination with associated current profile and vessel mean static offset range.

Environmental limits should be determined for all modes of operations (see Annex B) including but not limited to the following:

- a) racking of equipment, e.g. surface tree assembly;

- b) installation and retrieval of relevant equipment, e.g. subsea tree, tubing hanger and completion string;
- c) landing and latching;
- d) each mode of connected mode operation, e.g.:
  - testing, e.g. overpull to verify lockdown and system hydrostatic pressure test,
  - normal operation with well access or surface shut-in,
  - extreme operation with subsea shut-in and pressure bleed-off;
- e) unlatching:
  - normal disconnect,
  - emergency disconnect;
- f) overpull to retrieve stuck equipment, e.g. tubing, subsea tree;
- g) storm hang-off;
- h) accidental conditions, e.g. in connected mode:
  - motion compensator failure, e.g. loss of tension or compensator lock-up,
  - tensioner failure, e.g. loss of tension or tensioner lock-up,
  - loss of vessel station-keeping, e.g. dynamic positioning failure or anchor failure.

In the case of installation/retrieval, varying lengths of riser deployment shall be considered.

The combined environmental load effects for hang-off conditions shall be taken for a 10-year return period (or  $10^{-1}$  probability of exceedance in a period of one year) for the actual seasonal environmental conditions if nothing is specified by the purchaser.

Set-down masses prior to orientation of tubing hanger and prior to locking of connectors shall be established including maximum angle for entry of connectors. Values of overpull to verify lock-down, for normal operation, and for emergency disconnect shall be established/specified. Maximum allowable overpull to retrieve stuck tubing in combination with drilling riser ball/flex joint angles shall be established/specified; see Table 12.

For latching operations, e.g. of emergency disconnect package, lower riser package and subsea tree, the following may be considered: allowable latching angles, maximum relative landing velocity and set-down weight.

For unlatching operations, e.g. of emergency disconnect package, lower riser package and subsea tree, the following may be considered: allowable unlatching angles in combination with overpull and moment for both normal and emergency quick-disconnect.

Vessel drift-off/drive-off, emergency shut-down and emergency disconnect operating limits shall be established for dynamically positioned vessels in the case of vessel drift-off/drive-off. These limits shall be defined to ensure the establishment of well barrier elements and safe disconnection of the C/WO riser before any critical limit is exceeded; see 5.5.5. This assessment shall consider vessel drift-off/drive-off response (i.e. offset and velocity) and the establishment of critical limits, see 4.13.2. The total time to perform an emergency disconnect shall be established, including the time to recognize drift-off/drive-off, the time to initiate the emergency disconnect function and the time for performing the emergency disconnect. Vessel operating watch circle limits shall be established that ensure sufficient time to perform an emergency disconnect of the C/WO riser before any critical limit is exceeded.



An operation manual (see 11.9) shall define the riser operational limitations for the relevant modes of operating.

Normal or planned disconnection of a C/WO riser shall be performed if a critical value for the operating limits of the riser is about to be exceeded. After disconnection, the riser shall be brought into a safe position, i.e. hung-off or retrieved. C/WO riser system operational parameters shall be closely monitored at all times to ensure that the riser is being operated within prescribed limits. Reliable weather forecasts shall be used to monitor the environmental conditions.

### 6.3.4 Load effect analysis

#### 6.3.4.1 General

The global analyses shall be based on accepted principles for static and dynamic analysis, model discretization, strength of materials and environmental loading to reliably determine load effects on the riser system. The load effect analysis may be based on analytical calculations, numerical simulations, physical testing, or a combination of these methods.

Load effects, in terms of motions, displacements, or internal forces and stresses of the C/WO riser system, shall be determined with due regard for the following:

- a) the spatial and temporal nature including:
  - possible non-linearities of the load,
  - dynamic character of the response;
- b) the relevant failure modes for design check;
- c) the desired accuracy in the relevant phase.

Functional loads and certain accidental loads can generally be treated by static methods of analysis. Environmental (wave) loads and certain accidental loads (impacts) require dynamic analysis. In addition to the static and dynamic analysis, the global analysis for open-sea operations shall include natural period and mode shape analysis. General guidance on global load effect analysis of risers is given in Annex B.

NOTE 1 Inertia and damping forces are important when the periods of steady-state load are close to natural periods or when transient loads occur.

Load effect analysis of the riser shall be conducted for all relevant operating modes and design cases to check the relevant failure modes of the riser components, to determine operating limits and establish riser interface data.

The structural riser analysis should be carried out with linear elastic material behaviour. If plastic or elastic-plastic analysis are used for C/WO riser systems exposed to cyclic loading, e.g. wave loads, checks shall be carried out to verify that the riser system will shake down without excessive plastic deformations or fracture due to repeated yielding.

NOTE 2 In cases where global riser analysis is performed with linear elastic material properties and with design factors set down in this part of ISO 13628, shakedown can be assumed for pipe cross-sections without further checks.

Uncertainties in the analysis model should be included in the design factors. If uncertainties are particularly high, conservative assumptions shall be made.

If analytical models are particularly uncertain, the sensitivity of the models and the parameters utilized in the model shall be examined.

NOTE 3 The main purpose of sensitivity analysis is to quantify model uncertainties, support rational conservative assumptions and identify areas where a more thorough investigation is needed to achieve an acceptable modelling (e.g.



calibration of computer model against physical testing). Parameters to be considered include hydrodynamic parameters, wave period, current profile, top tension and tensioner spring stiffness characteristics, wellhead inclination angle and level, stack-up length, slick-joint stiffness, slick-joint contact level with drill floor, vessel offset, structural damping, submerged weight and internal fluid density.

Global riser analysis should be performed to optimize the top tension to improve the performance of the riser with respect to combined load effects.

NOTE 4 Coupled analysis can be considered for applications where the anchor lines and risers have a significant effect on the vessel motions.

### 6.3.4.2 Modelling

#### 6.3.4.2.1 Riser structural model

The global riser model shall include the complete riser system considering accurate modelling of stiffness, mass, damping and hydrodynamic load effects along the riser string in addition to top and bottom equipment and boundary conditions. In particular, appropriate drag and inertia coefficients for the selected method shall be applied.

NOTE Top-end equipment and boundary conditions typically include modelling of surface equipment, bails, tension frame, draw works, slick joint, drill floor (rotary/spider) contact, tensioners and vessel motion RAOs. Bottom-end equipment and boundary conditions typically include modelling of the stress joint, subsea equipment and wellhead system including wellhead/soil flexibility as required.

Top tensioned risers should be modelled with the appropriate tension acting on the tension ring at the tension joint and at the top of the riser (motion compensator) and with appropriate stiffness characteristics.

The riser shall be discretized with a sufficient number of elements to represent environmental loading and structural load effects and to resolve load effects in all critical areas.

Load effect calculations should be performed applying nominal cross-section properties and nominal physical properties.

#### 6.3.4.2.2 Hydrodynamic loads

The maximum operating conditions shall be analysed by appropriate combination of magnitude and directions of maximum waves, currents and vessel when determining the most probable maximum hydrodynamic load effects.

In cases where only a wave height is specified, the wave period range to be considered may be determined by the 90 % confidence interval from the wave scatter diagram.

Wave theory and kinematics shall be selected to recognized methods with due considerations of actual water depth and description of wave kinematics at the surface and the water column below.

When determining the hydrodynamic loads, the relative liquid particle velocities and accelerations used in the calculations shall be established, taking into account contributions from waves, current and riser motions.

NOTE 1 The hydrodynamic loading on slender structures like C/WO risers can be expressed by the Morison equation in terms of the relative fluid-structure velocities and accelerations.

NOTE 2 The selection of appropriate wave theory depends on the actual application and link to assumptions made to vessel motion RAOs. Normally, linear wave theory, e.g. Airy, combined with Wheeler stretching can be considered in addition to distributed kinematics, if relevant. For the part of the riser below the splash zone, linear wave theory is usually adequate in connection with irregular sea-states. Note, however, that distributed kinematics, e.g. for semi-submersible vessels, can effect the kinematics close to the vessel.

Time and/or frequency discretization shall be verified to ensure that desired accuracy is obtained.

Possible effects of adjacent structural parts shall be taken into account when determining the wave and current loads. The increased accelerations and flow velocities in the flow around a cylinder, e.g. columns, can lead to additional forces on the riser.

Possible loads from vortex shedding shall be considered. Concerning vortex shedding-induced transverse vibrations, the increase in drag coefficient shall be taken into account. The effect of VIV suppressing devices, if included as part of the riser system, shall be analysed.

#### 6.3.4.3 Extreme load effect analysis

Static analysis should be carried out using a full non-linear approach. One or combinations of the following methods should be applied in the subsequent dynamic analysis to establish hydrodynamic load effects:

- a) irregular wave analysis in the time domain (design storm);
- b) regular wave analysis in the time domain (design wave);
- c) irregular wave analysis in the frequency domain.

The irregular wave analysis refers to modelling of water particle kinematics and vessel motions. Extreme load effect analyses should preferably be carried out by use of time domain analyses. However, frequency domain analyses may be applied if the adequacies of such analyses are documented by validation against time domain analysis.

It shall be documented that the duration of irregular time domain analyses is sufficient to obtain load effect estimates with sufficient statistical confidence.

Any use of simplified modelling and/or analysis technique shall be validated by more advanced modelling and/or analysis, see Table 9. In particular, the validation as specified in 6.3.4.6 shall be considered for representative (critical) load cases.

**Table 9 — Validation analysis methods overview**

Applied method	Method for validation
Linearized time domain analysis	Non-linear time domain analysis
Frequency domain analysis	Time domain analysis
Regular wave analysis	Irregular wave analysis

Wave period variation shall be performed to identify the most unfavourable loading condition for both regular and irregular wave analyses to identify the most unfavourable loading condition. This is of special importance for regular wave analysis, which can be subjected to severe bias for dynamic sensitive systems. At least three different periods covering a realistic variation range (e.g. 90 % confidence interval from the wave scatter diagram) shall be analysed. The period variation shall be performed with due consideration of the following:

- a) statistical variation of wave period;
- b) natural frequencies of the riser system;
- c) peaks in vessel motion transfer function;
- d) wave peak periods from the wave scatter diagram.

**NOTE** Maximum wave load effects might not always be experienced during the passage of the design wave (maximum wave height). The maximum wave loads can be due to waves of a particular length, period or steepness.

#### 6.3.4.4 Fatigue load effect analysis

Fatigue analysis of the riser system shall consider all relevant cyclic load effects, including the following:

- a) first-order wave effects (direct wave loads and associated vessel motions);
- b) second-order vessel motions or vessel-induced motions (quasi-static offset motions);
- c) vortex-induced vibrations;
- d) thermal and pressure induced stress cycles.

The fatigue load effect due to first-order wave effects and second-order vessel motions may be calculated with the same methods as for extreme load effect calculation in 6.3.4.3. If frequency domain analysis or regular wave analysis is used, validation against irregular sea, time domain analysis should be performed. Cycle counting, e.g. rain flow cycle counting, should be used for irregular time domain fatigue analysis.

Variation in pipe wall or component wall thickness over the service life of the riser system shall be considered in the fatigue life calculations, i.e. running, operational and hang-off conditions. The global fatigue analysis may be based on nominal wall thickness while the fatigue stresses may be based on average representative wall thickness, i.e. the nominal wall thickness minus half the corrosion allowance.

Fatigue analysis should cover the sea-states lying within the operating limits of the various activities.

Stresses to be considered in the fatigue analysis are given in Table C.2, for further details, see Annex C.

**NOTE** First-order wave-induced fatigue under normal operation in open sea is normally the governing case; however, fatigue damage accumulated in disconnected or hang-off mode can be significant.

#### 6.3.4.5 Inside drilling riser mode

If the C/WO riser is operating within a drilling riser, the C/WO riser may be analysed using a non-linear quasi-static approach. The C/WO riser analysis shall include effects from top tension, fluids, tubing, tubing hanger and C/WO riser weight, fluids, pressure, temperature, C/WO and drilling riser contents, top and bottom flex/ball joint angles and drilling riser deflections.

The minimum top and bottom flex/ball joint angles may be calculated by a separate drilling riser analysis or the values in Table 12 may be applied.

Both extreme load effect and fatigue damage shall be determined at critical locations along the riser string.

#### 6.3.4.6 Model validation

The global analysis models shall be checked for errors. Emphasis shall be given on correct input of the vessel motion transfer functions for the actual computer programme.

Animation showing vessel motions, waves and riser deflections may be used for verification of vessel motions.

The following analytical checks shall be performed of the riser model:

- a) verification of static effective tension distribution including top and bottom tension;
- b) calculated natural periods and mode shapes.

**NOTE 1** Analytical calculation of static effective tension represents a verification of the riser mass, buoyancy and tensioner modelling of the system.

**NOTE 2** Natural periods and mode shapes of top tensioned risers can be verified by analytical calculations. Approximate solutions are given in terms of closed form expressions for tensioned beams; see Blevin<sup>[26]</sup>.

## 6.4 Component design criteria

### 6.4.1 Scope

General design requirements applicable to all components within the scope of this part of ISO 13628 including connectors and bolts are provided in 6.4. Design requirements for components that are governed by other applicable codes and standards (see Table 2) are outside the scope of this part of ISO 13628.

Specific component subclauses providing component-specific design requirements are included in this part of ISO 13628. In case of conflict between 6.4 and the component-specific subclause design requirements, the component-specific design requirements shall govern.

### 6.4.2 Failure modes

It shall be shown that the C/WO riser system has the required structural safety against all relevant failure modes. As a minimum, the riser components shall be designed against the following possible modes of failure, as appropriate:

- a) excessive yielding;
- b) buckling;
- c) fatigue;
- d) brittle fracture;
- e) excessive deflections;
- f) leak-tightness;
- g) corrosion and wear;
- h) sudden disengagement;
- i) mechanical function.

For design against corrosion and wear, see 6.4.4 and Clause 7.

The requirements given in 6.4 are valid for pipes having materials meeting the general requirements of Clause 7 and especially the tensile requirements of 7.2.9.

### 6.4.3 Material selection

Materials to be selected for C/WO riser systems shall be suitable for such application during the design life unless replacement is foreseen. Due consideration shall be given to external and internal fluids, loads, temperature and possible failure modes during all phases including operation, fabrication and testing. The selection of materials shall ensure compatibility of all components in the riser system.

Materials shall have appropriate properties for all fabrication steps, testing, operating and storage conditions, and shall have sufficient strength, ductility and toughness; see Table 15. Furthermore, the C/WO riser system shall be free from surface or internal defects, which might impair their usability.

Risk for sour service conditions shall be evaluated for all parts of the C/WO riser which during the lifetime can be exposed to reservoir fluids during operation; see 7.2.4.

#### 6.4.4 Corrosion allowance

Whenever the word “corrosion” is used in this part of ISO 13628 it shall be taken to mean corrosion, oxidation, scaling, abrasion, erosion, wear and all other forms of metal loss. The manufacturer shall consider the effect which corrosion (both internal and external) can have upon the useful life of the component; see 7.2.13. When in doubt, corrosion tests should be undertaken.

In all cases where a reduction in wall thickness is possible as a result of surface corrosion of either internal or external surfaces, provisions shall be made for such loss during the design or specified life (operation and storage) of the component by a suitable increase to the thickness of the base metal over that determined by the design formulas or stress analysis.

The evaluation to quantify a suitable increase in wall thickness (i.e. corrosion allowance) shall take into consideration material properties, internal and external environment, internal and external coatings, inspection intervals and routine preservation; see 7.2.13.

A minimum corrosion allowance shall be applied and shall be documented in design calculations or specified by purchaser.

**NOTE** This corrosion allowance does not ensure safety against the risk of deep corrosion or stress corrosion cracking. In these cases a change in material, cladding, etc. is the appropriate means.

#### 6.4.5 Thickness

Unless otherwise stated, all design calculations shall be made in the corroded condition with a consistent set of dimensions (thickness, diameter, etc.).

Possible beneficial strengthening effect of cladding or liner on a pipe shall not be taken into account in the design, unless the strengthening effect is documented.

#### 6.4.6 Design material strength and properties

The yield strength,  $\sigma_y$ , and ultimate tensile strength,  $\sigma_u$ , to be used in design shall be as follows:

$$\sigma_y = \phi_{A5} \times R_{t0,5/T} = \phi_{A5} \times Y_y \times R_{t0,5} \quad (4)$$

$$\sigma_u = \phi_{A5} \times R_{m/T} = \phi_{A5} \times Y_u \times R_m \quad (5)$$

where

$\phi_{A5}$  is the ductility reduction factor; see Equation (6);

$R_{t0,5/T}$  is the specified minimum yield strength for 0,5 % total elongation at a specific temperature;

$R_{t0,5}$  is the specified minimum yield strength for 0,5 % total elongation at room temperature;

$Y_y$  is the yield strength reduction factor at elevated temperature;

$R_{m/T}$  is the specified minimum ultimate tensile strength at a specific temperature;

$Y_u$  is the ultimate tensile strength reduction factor at elevated temperature;

$R_m$  is the specified minimum ultimate tensile strength at room temperature.

**NOTE 1** The total extension of 0,5 % used to define minimum specified yield strength is valid for yield strength up to 655 MPa (95 000 psi). A value of 0,6 % applies for minimum specified yield strength up to 758 MPa (110 000 psi).

The ductility reduction factor,  $\phi_{A5}$ , may be applied for materials not fulfilling the ductility requirement in Table 15. The ductility factor is 1,0 when the minimum elongation after fracture,  $A_5$ , is equal to or larger than 14 % and for  $A_5 < 14$  % the ductility factor is calculated as given in Equation (6):

$$\phi_{A5} = \frac{1,5}{2 - \sqrt{\frac{A_5}{56}}} \quad (6)$$

If  $\sigma_y$  is greater than  $0,92 \times \sigma_u$ , then use  $0,92 \times \sigma_u$  instead of  $\sigma_y$  in Equation (4); see Table 15.

For carbon manganese steels and low-alloy steels, the specified value at 20 °C (68 °F) may be used for temperatures less or equal to 50 °C (122 °F). For carbon manganese steels and low-alloy steels with a temperature above 50 °C (122 °F), de-rated material properties at design temperatures shall be established as input to the design. If no specific documentation of the material properties at elevated temperatures is available, the yield and tensile strength values at room temperature may be reduced in accordance with Table 10.

**Table 10 — Optional reduction factors for elevated temperatures of carbon manganese and low-alloy steels**

Temperature reduction factor	Temperature °C (°F)				
	Room temperature	66 (150)	82 (180)	121 (250)	180 (350)
$Y_y$	1,00	0,99	0,97	0,91	0,85
$Y_u$	1,00	1,00	1,00	1,00	1,00

For carbon and low-alloy steels at temperatures up to 120 °C (250 °F), the following values for physical properties may be used:

- a) modulus of elasticity:  $E = 205\,000$  MPa (29 730 ksi);
- b) Poisson's ratio:  $\nu = 0,3$ ;
- c) linear coefficient of thermal expansion:  $\alpha_L = 12 \times 10^{-6}$  m/m/°C ( $5,73 \times 10^{-6}$  in/in/°F).

For the ultimate tensile and the yield strength, the values shall be those which apply to the materials in the final fabricated condition. Any difference in strength- and temperature-de-rating effects for strength in tension and compression shall be accounted for. If the material or weld metal gives lower strength or toughness values after fabrication, these shall be used in design; see 7.2.14 and 7.2.16.

#### 6.4.7 Excessive yielding

Components for which excessive yielding is a possible mode of failure shall be investigated for yielding; see 6.2.4.

The design capacity for pressure-containing components, including bolts, shall be determined from the material properties as defined in 6.4.6 and the design factors as defined in Table 11. Excessive yielding capacities of components shall be achieved by one of the methods in Annex D.

For cyclic thermal loads associated with permanent loads, thermal ratcheting, i.e. a mechanism of incremental collapse, should be considered.

Special considerations may require lower design factors, e.g. risk of stress corrosion cracking, hydrogen-induced cracking.

Table 11 — Design factors,  $F_d$ 

Load condition	$F_d$	Failure mode calculation basis
Assembly (bolting-up or make-up) and disassembly (break-out)	0,90	Based on actual design values at assembly/disassembly temperature
Mill/FAT hydrostatic pressure test	0,90	Based on actual design values at test temperature, fluid (hydrostatic)
Normal operation	0,67	Based on corroded wall thickness at design metal temperature
Extreme operation	0,80	Based on corroded wall thickness at design metal temperature
System (in-service) pressure test	0,67	Based on corroded wall thickness at test temperature
Temporary operation	0,80	Based on corroded wall thickness at actual metal temperature
Accidental (survival)	1,00	Based on corroded wall thickness at actual metal temperature

#### 6.4.8 Buckling

The possibility of buckling shall be considered of members in compression or components with a compressive stress field.

**EXAMPLES** One or more of the following two buckling modes can be possible: local buckling of the pipe wall and buckling of the pipe as a bar in compression.

Buckling analysis shall be based on the most unfavourable buckling mode. Initial imperfections and residual stresses shall be accounted for. It shall be insured that there is conformity between the initial imperfections in the buckling resistance calculations and the tolerances in the fabrication.

Components may be designed according to provisions in recognized standards, e.g. API RP 2A-WSD [1]. In cases where plastic analyses are performed using large deformation theory, see D.2.4; where testing is performed, see D.2.5; the design factors given in 6.4.7 shall apply.

If beam-column buckling is unavoidable, it shall be documented that the riser or component will not suffer any failure in the post-buckled mode.

A negative effective tension can cause a riser to buckle as a beam column in compression. Special care should be taken when a small decrease in top tension could cause excessive bending moments. In these cases, a margin above the minimum tension causing excessive bending moments should be established. Members above the tension joint for top tensioned risers can be subjected to compressive forces for some riser configurations.

#### 6.4.9 Fatigue and fatigue inspections

In this part of ISO 13628, requirements are given in relation to fatigue analysis based on fatigue tests and fracture mechanics. Reference is made to Annex C for practical details with respect to fatigue design.

The aim of the fatigue design is to ensure that the C/WO riser has an adequate fatigue life. Calculated fatigue lives can form the basis for a fatigue crack inspection programme during fabrication and the service life of the C/WO riser.

All cyclic load effects imposed during the entire life that have magnitude and number large enough to induce significant fatigue damage effect shall be taken into account; see 6.3.4.4. All modes of operation, including open-sea mode and tubing hanger mode (inside marine riser) and temporary conditions like running and hang-off, should be considered. As a minimum, fatigue analysis shall be performed in connected conditions for open-sea mode and tubing hanger mode (operation inside marine riser) when appropriate.



C/WO risers should be designed so that vortex-induced resonant vibrations are prevented, whenever practical. Vortex suppression devices may be used as a method to minimize the strength of vortex-induced resonant vibrations; for further details, see API RP 2RD [2].

Fatigue-sensitive points shall be identified and a fatigue analysis shall be performed for each point. Emphasis should be on bolts, welds and details with stress concentrations, in addition to locations with high surface roughness and surface marks. If there is a significant risk of fatigue failure, the design should be reviewed to reduce the risk by considering changes to the configuration to lower peak stresses, e.g. by reducing girth weld eccentricities, the provision of smooth profiles, particularly at welds, and the use of less susceptible materials.

The fatigue life may be calculated by methods based on cumulative damage and/or crack growth analysis. Normally, the methods based on cumulative damage should be used during design for fatigue life assessment due to its simplicity and efficiency. Fatigue crack growth analysis may also be applied to specify detection limits for the NDT methods to be applied during fabrication and in-service inspection planning.

If the service life has not been specified by the purchaser, a minimum of 5 years shall be used. The required minimum calculated fatigue life shall be based on the intended service life and the inspection schedule. The calculated fatigue life shall be at least 3 times the service life for all components considered acceptable for inspection ( $D_F = 3$ ). For components that cannot be inspected, the calculated fatigue life shall be at least 10 times the service life ( $D_F = 10$ ). Unless the calculated fatigue life is at least 10 times the intended service life, riser components shall be inspected periodically for fatigue cracks. The inspection interval/replacement interval shall not be more than one-tenth the calculated fatigue life.

#### 6.4.10 Brittle fracture

Riser components shall have adequate resistance against initiation of brittle (unstable) fracture; see 7.2.10. The safety against brittle fracture is normally considered satisfactory if the materials, workmanship, and testing are in accordance with Clause 7 and 8.3.

#### 6.4.11 Excessive deflection

##### 6.4.11.1 General

Maximum riser deflections limits may include assessment of stroke, riser interference and flex/ball joints angles.

##### 6.4.11.2 Stroke

C/WO riser systems shall be designed to have sufficient stroke capability such that damage to riser components and equipment is avoided. Riser stroke limitations typically include consideration of the following:

- a) stroke range of draw-work motion compensator;
- b) stroke range of tensioner system;
- c) slick joint, "heave protection length", i.e. length of cased wear joint section;
- d) surface equipment down-stroke.

NOTE Slick joint "heave protection length" and surface equipment down-stroke normally are the governing parameters for operation limitations.

Current-induced stroke can be reduced by increased top tension. This is of special importance for deep-water applications where realistic current profiles and speeds should be applied.

The tension capacity of the motion compensator and tensioner shall be addressed.



The up- and down-stroke calculations shall include effects from environmental response, tension, pressure (end-cap effects), temperature, tide, storm surge, swell, riser space-out and stack-up tolerances, set-down/pull-down effects and vessel draught.

Environmental response includes static and dynamic stroke. The static stroke is due to current loading and set-down effect due to vessel mean offset. The vessel mean offset includes effects from static wind and mean wave drift. The wave loading introduces relative motions between the vessel and the riser, i.e. dynamic stroke.

Stroke requirements should be determined from the effects above multiplied by an appropriate safety factor.

A safety margin of 10 % on upstroke and downstroke may be applied.

#### 6.4.11.3 Interference

Interference shall be considered during all phases of the riser design life. The riser system design shall include evaluation of or analysis of potential interference with other risers, anchor lines, moon-pool, hull, seabed, the motion limits of the upper riser assembly so as not to interfere with other riser system equipment or contact the vessel (tension frame, surface tree or jumper hose), and with any other obstructions, including landing string clearance to bottom flex joint and subsea equipment clearance to seabed during hang-off. A feasible design approach may be categorized as follows:

- no collision allowed;
- collision allowed.

No collision allowed (no impact or interference) should be the aim due to potential damage to the riser or other part of the system if interference occurs. An appropriate safety margin on minimum clearance necessary to avoid collision should be considered.

If negative clearance (contact) is permitted, resulting impact loads should be determined to demonstrate that structural integrity is maintained. This requires an assessment of collision frequency, location, force impulse or relative riser velocity prior to impact. Separate local calculations/analysis are in general required for assessment of pipe or riser component stresses during impact.

#### 6.4.11.4 Drilling riser flex/ball joint angles

Unless otherwise agreed, the minimum values of the maximum drilling riser angle of deflection at the flex/ball joint for inside drilling riser operations shall be in accordance with Table 12.

**Table 12 — Drilling riser ball/flex joint angles**

Load condition	Minimum values of the maximum drilling riser angle ball/flex joint angle degrees
Running and retrieval <sup>a</sup>	± 1,0
Normal operation	± 3,0
Overpull to retrieve stuck tubing	± 2,0
<sup>a</sup> The angle shall allow for passage of tubing hanger, tubing hanger running tool and landing string.	

#### 6.4.11.5 Leak-tightness

A leak-tight component shall meet the following maximum allowable tightness test leakage rates for internal pressure:

- a) for a liquid tightness test: no visible leakage shall occur for the duration of the test;

- b) for a gas tightness test: no sustained bubbles shall occur for the duration of the test. If leakage is observed, the rate shall be less than  $1 \times 10^{-3} \text{ cm}^3/\text{s}$  ( $3,6 \text{ cm}^3/\text{h}$ ), measured at atmospheric pressure, for the duration of the test. The leak rate shall not have an increasing character.

The test medium for a liquid tightness test may be water, while nitrogen may be used for a gas tightness test. Minimum duration for tightness tests shall be 15 min. Unless specified otherwise, the test temperature is room temperature.

NOTE The leaked volume of  $0,9 \text{ cm}^3$  in a 15 min period corresponds to  $1 \times 10^{-3} \text{ cm}^3/\text{s}$ .

A component shall be gas-tight for extreme operating conditions and liquid leak-tight for accidental design conditions. The purchaser may specify more stringent requirements to leak-tightness, test temperature and test set-up for very hazardous products and high-temperature applications.

The internal pressure leak-tightness requirements may also be applicable for external pressure.

## 6.5 Pipe design criteria

### 6.5.1 General

In 6.5, the provisions are given for checking of the ultimate strength capacity (burst, yield, buckling) of straight pipes and straight pipes with small tapers in pipe wall (e.g. taper joints). The capacity check shall consider the following:

- a) pressure design:
- internal pressure,
  - external pressure;
- b) combined loading:
- net internal pressure, effective tension and bending moment,
  - net external pressure, effective tension and bending moment.

For other relevant pipe failure modes to be designed against, see 6.4. A pipe calculation example is included in Annex E. The background for internal pressure (burst) design and net internal pressure combined load design can be found in References [35] and [36].

Full utilization of the riser pipe capacities, calculated in accordance with the equations given in 6.5, requires that the riser connectors have a level of structural safety comparable to the pipe; see 6.6.

### 6.5.2 Pressure design

#### 6.5.2.1 General

In 6.5.2, the requirements are provided for design against internal and external pressure, i.e. determination of minimum required wall thickness to resist internal and external pressure.

Pressure design, i.e. minimum burst resistances and minimum hoop buckling (collapse) resistances, shall be calculated based on minimum wall thickness,  $t_1$ , as given in Equations (7) and (8):

- a) Mill/FAT pressure test:

$$t_1 = t_n - t_{fab} \quad (7)$$

where

$t_n$  is the nominal (specified) pipe wall thickness;

$t_{fab}$  is the absolute value of the negative tolerance taken from the material specification/standard.

b) Operating conditions and system pressure test:

$$t_1 = t_n - t_{fab} - t_{ca} \quad (8)$$

where  $t_{ca}$  is the corrosion/wear/erosion allowance and the other variables are the same as for Equation (7).

### 6.5.2.2 Internal pressure (burst) design

The minimum burst pressure of the pipe shall exceed the net internal pressure at all cross-sections along the riser string as given in Equation (9):

$$\frac{(p_{int,d} - p_{o,min})}{F_b \times p_{b,min}} \leq 1 \quad (9)$$

where

$p_{int,d}$  is the internal design pressure;

$p_{o,min}$  is the minimum external hydrostatic pressure;

$F_b$  is the pipe burst design factor obtained from Table 13;

$p_{b,min}$  is the minimum pipe burst pressure; see Equation (10).

The internal design pressures and design temperatures in Table 7 and Table 8, respectively, normally apply for internal pressure (burst) design. For hydrostatic pressure testing at room temperature, see more details in 8.3, adjustment of test pressure is not required to account of derated material properties. Test pressure will normally not govern wall thickness.

Minimum external hydrostatic pressure may be set to zero.

**Table 13 — Burst (pressure containment) design factors,  $F_b$**

Internal design pressure	Hydrostatic test pressure
0,60	0,90

The minimum pipe burst pressure,  $p_{b,min}$ , is determined by Equation (10):

$$p_{b,min} = 1,1 \times (\sigma_y + \sigma_u) \times \frac{t_1}{D_o - t_1} \quad (10)$$

where

$\sigma_y$  is the design yield strength; see 6.4.6;

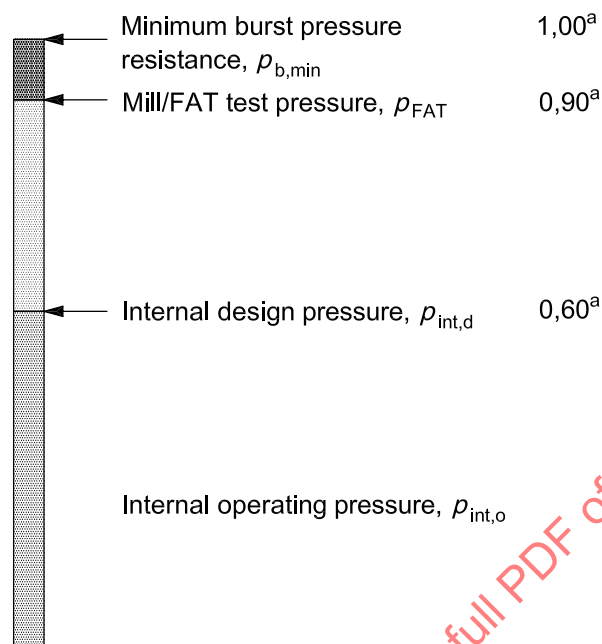
$\sigma_u$  is the design ultimate tensile strength; see 6.4.6;

$t_1$  is the minimum pipe wall thickness without allowances and fabrication tolerances as appropriate; see 6.5.2.1;

$D_o$  is the specified or nominal pipe outside diameter.

NOTE The failure mode covered is pipe wall ductile rupture due to net internal pressure, frequently referred to as "ductile pipe burst." The burst criterion is based on the burst resistance for pipes with closed (capped) ends.

The various pressure definitions and levels are illustrated in Figure 10.



Pressure	Description	Maximum fraction of $p_{b,min}$
$p_{b,min}$	Minimum burst pressure resistance	1,00
$p_{FAT}$	Mill/FAT pressure	0,90
$p_{int,d}$	Internal design pressure	0,60
$p_{int,o}$	Internal operating pressure	0,60
<sup>a</sup> Maximum fraction of $p_{b,min}$ .		

Figure 10 — Pressure level relations

### 6.5.2.3 External pressure (hoop buckling) design

The hoop buckling (collapse) pressure of the pipe shall exceed the net external pressure at all cross-sections along the riser string as follows:

$$\frac{(p_{od} - p_{int,min})}{F_{hb} \times p_{c,min}} \leq 1 \quad (11)$$

where

$p_{od}$  is the external design pressure;

$p_{int,min}$  is the minimum hydrostatic internal pressure;

$F_{hb}$  is the pipe hoop buckling (collapse) design factor, obtained from Table 14;

$p_{c,min}$  is the minimum pipe hoop buckling (collapse) pressure.

If the riser pipe is subjected to internal pressure, then the minimum internal pressure may be taken into account provided that it can be continuously sustained, otherwise zero or vacuum [– 0,1 MPa (– 1 bar)] internal pressure should be applied.

NOTE The C/WO riser can experience high external pressure when operating within a drilling riser; see 6.3.2.2.

External hydrostatic test pressure may be as given in I.7. Test pressure will normally not govern wall thickness.

**Table 14 — Hoop buckling (collapse) design factor,  $F_{hb}$**

Pipe manufacturing process	External design pressure	Hydrostatic test pressure
Seamless	0,67	0,80

The minimum hoop buckling (collapse) pressure,  $p_{c,min}$ , shall be calculated as given in Equation (12):

$$(p_{c,min} - p_{el,min}) \times (p_{c,min}^2 - p_{p,min}^2) = p_{c,min} \times p_{el,min} \times p_{p,min} \times 2 \times f_0 \times \frac{D_o}{t_1} \quad (12)$$

where

$p_{el,min}$  is the minimum elastic hoop buckling (collapse) pressure (instability) of pipe cross-section;

$p_{p,min}$  is the minimum plastic pressure at hoop buckling (collapse) of pipe cross-section;

$f_0$  is the initial ovality;

$D_o$  is the specified or nominal pipe outside diameter;

$t_1$  is the minimum pipe wall thickness without allowances and fabrication tolerances as appropriate, see 6.5.2.1.

and

$$p_{el,min} = \frac{2 \times E \times \left( \frac{t_1}{D_o - t_1} \right)^3}{1 - \nu^2} \quad (13)$$

where

$E$  is the modulus of elasticity;

$\nu$  is the Poisson's ratio;

$$p_{p,min} = 2 \times \sigma_y \times \frac{t_1}{D_o} \quad (14)$$

where the variables are the same as for Equations (12) and (13).

$$f_0 = \frac{D_{o,max} - D_{o,min}}{D_{o,max} + D_{o,min}} \quad (15)$$

where

$D_{o,max}$  is the maximum outside diameter at any cross-section;

$D_{o,min}$  is the minimum outside diameter at any cross-section.

The initial ovality,  $f_0$ , shall not be taken less than 0,002 5 (0,25 %). Maximum initial ovality should not be greater than 0,015 (1,5 %). Ovalization caused during manufacture and fabrication shall be included in the initial ovality. The solution of Equation (12) can be found in Annex E.

For deep-water applications, initial pipe ovality should generally not exceed 0,005 (0,5 %).

The external design pressure to be taken into account for calculation purposes shall be the maximum external pressure under operating conditions or test conditions, whichever is the greater.

The failure mode covered is hoop buckling (pipe cross-section collapse) under external hydrostatic pressure. The hoop buckling pressure predicted by these equations should be compared to the hydrostatic pressure due to water depth to ensure adequate wall thickness is chosen for the range of water depths to be encountered, external pressure for concentric pipes, etc. The design formula is based on hoop buckling resistance for pipes with open ends.

### 6.5.3 Combined load design

#### 6.5.3.1 General

The thickness for pipe used in combined load effect checks shall be the nominal thickness minus corrosion allowance given by Equation (16):

$$t_2 = t_n - t_{ca} \quad (16)$$

where

$t_2$  is the pipe wall thickness without allowances;

$t_n$  is the nominal (specified) pipe wall thickness;

$t_{ca}$  is the corrosion/wear/erosion allowance.

NOTE In case of design load effects based on global riser analysis models with linear elastic materials, combined with the resistance equations set down in this part of ISO 13628, shakedown can be assumed without further checks for the pipe strength criteria.

#### 6.5.3.2 Net internal overpressure

Pipe members subjected to effective tension, primary (load controlled) bending moment and net internal overpressure shall be designed to satisfy the following condition at all cross-sections as given in Equation (17):

$$\left( \frac{T_e}{F_d \times T_{pc}} \right)^2 + \frac{|M_{bm}|}{F_d \times M_{pc}} \times \sqrt{1 - \left( \frac{p_{int} - p_o}{F_d \times p_b} \right)^2} + \left( \frac{p_{int} - p_o}{F_d \times p_b} \right)^2 \leq 1 \quad p_{int} \geq p_o \quad (17)$$

where

$T_e$  is the effective tension in the pipe;

$T_{pc}$  is the plastic tension capacity of the pipe;

$F_d$  is the design factor as given in Table 11;

$M_{bm}$  is the bending moment in the pipe;

$M_{pc}$  is the plastic bending moment capacity of the pipe;

$p_{int}$  is the internal pressure in the pipe;

$p_o$  is the external pressure;

$p_b$  is the burst pressure of the pipe.

The pipe capacities are given in Equations (18), (19), and (20):

$$M_{pc} = \alpha_{bm} \times \sigma_y \times Z = \alpha_{bm} \times \sigma_y \times \frac{1}{6} \left[ D_o^3 - (D_o - 2 \times t_2)^3 \right] \quad (18)$$

where

$\alpha_{bm}$  is the pipe cross-section slenderness parameter;

$Z$  is the pipe plastic section modulus;

$D_o$  is the specified or nominal pipe outside diameter;

$t_2$  is the pipe wall thickness without allowances; see 6.5.3.1;

$$T_{pc} = \sigma_y \times A_c = \sigma_y \times \pi \times (D_o - t_2) \times t_2 \quad (19)$$

where

$A_c$  is the pipe cross-section area;

$\sigma_y$  is the design yield strength; see 6.4.6;

$$p_b = 1,1 \times (\sigma_y + \sigma_u) \times \frac{t_2}{D_o - t_2} \quad (20)$$

where  $\sigma_u$  is the design ultimate tensile strength; see 6.4.6.

The cross-section slenderness parameter,  $\alpha_{bm}$ , is given by Equations (21) to (23):

$$\alpha_{bm} = 1,00 \quad \text{for} \quad \frac{\sigma_y \times D_o}{E \times t_2} \leq 0,051 \, 7 \quad (21)$$

$$\alpha_{bm} = 1,13 - 2,58 \times \left( \frac{\sigma_y \times D_o}{E \times t_2} \right) \quad \text{for} \quad 0,051 \, 7 < \frac{\sigma_y \times D_o}{E \times t_2} \leq 0,103 \, 4 \quad (22)$$

$$\alpha_{bm} = 0,94 - 0,76 \times \left( \frac{\sigma_y \times D_o}{E \times t_2} \right) \quad \text{for} \quad 0,103 \, 4 < \frac{\sigma_y \times D_o}{E \times t_2} \leq 0,170 \quad (23)$$

The effective tension,  $T_e$ , is given by Equation (24) (tensile axial force is positive); see B.3.2.1:

$$T_e = T_w - p_{int} \times A_{int} + p_o \times A_o \quad (24)$$

where

$T_w$  is the true wall tension (i.e. axial stress resultant found by integrating axial stresses over the cross-section);

$A_{int}$  is the internal cross-section area of the pipe, might be occupied by fluid content;

$A_o$  is the external cross-section area of the pipe giving buoyancy if submerged.

NOTE 1 The failure modes controlled by this design equation include excessive yielding and local buckling of the compression side of the pipe (wrinkling) due to effective tension, bending moment and net internal overpressure.

NOTE 2 The design criterion is the von Mises criterion in terms of cross-sectional forces and plastic cross-sectional resistance.

NOTE 3 A conservative estimate is to assume the external pressure,  $p_o$ , equal to zero in these checks.

### 6.5.3.3 Net external overpressure

Pipe members subjected to combined effective tension, primary (load controlled) bending moment and net external overpressure shall be designed to satisfy the conditions given in Equation (25) at all cross-sections:

$$\left[ \left( \frac{T_e}{F_d \times T_{pc}} \right)^2 + \left( \frac{M_{bm}}{0,95 \times F_d \times M_{pc}} \right)^2 \right] + \left( \frac{p_o - p_{int}}{F_d \times p_c} \right)^2 \leq 1 \quad p_{int} < p_o \quad (25)$$

where

$T_e$  is the effective tension in the pipe;

$T_{pc}$  is the plastic tension capacity of the pipe; see Equation (19);

$F_d$  is the design factor as given in Table 11;

$M_{bm}$  is the bending moment in the pipe;

$M_{pc}$  is the plastic bending moment capacity of the pipe; see Equation (18);

$p_o$  is the external pressure;

$p_{int}$  is the internal pressure in the pipe;

$p_c$  is the pipe hoop buckling (collapse) pressure;

and

$$(p_c - p_{el}) \times (p_c^2 - p_p^2) = p_c \times p_{el} \times p_p \times 2 \times f_0 \times \frac{D_o}{t_2} \quad (26)$$

$$p_{el} = \frac{2 \times E \times \left( \frac{t_2}{D_o - t_2} \right)^3}{1 - \nu^2} \quad (27)$$

$$p_p = 2 \times \sigma_y \times \frac{t_2}{D_o} \quad (28)$$

where

$p_{el}$  is the elastic hoop buckling (collapse) pressure (instability) of pipe cross-section;

$p_p$  is the plastic pressure at hoop buckling (collapse) of the pipe cross-section;

$D_o$  is the specified or nominal pipe outside diameter;

$t_2$  is the pipe wall thickness without allowances, see 6.5.3.1;



$\nu$  is the Poisson's ratio;

$\sigma_y$  is the design yield strength, see 6.4.6.

The design factors are given in Table 11.

NOTE 1 A conservative estimate is to assume the internal pressure,  $p_{int}$ , equal to zero in these checks.

NOTE 2 The failure modes controlled by this semi-empirical design equation are excessive yielding and combined local buckling of the compression side of the pipe and hoop buckling of the cross-section due to combined bending moment, effective tension and net external pressure.

## 6.6 Connectors

### 6.6.1 Introduction

#### 6.6.1.1 Purpose

In 6.6, requirements and recommendations are given in relation to design of CWO riser connectors.

#### 6.6.1.2 Overall requirements

The aim of the design is to ensure that connectors have adequate structural resistance, leak-tightness, fatigue resistance and functionality for all relevant load cases. Resistance against accidental loads such as fire and impact shall be considered when applicable.

Riser connectors should preferably have a level of structural safety that is comparable to that of the connecting pipe or piping component.

Connectors shall be designed such that a smooth transfer of loads is made without high localized stresses or excessive deformation of the attached pipe.

Connector and component materials including seals and bolting shall conform to the requirements given in Clause 7.

Fatigue criteria are given in 6.4.9 and guidance on fatigue analysis and assessment is given in Annex C.

All CWO riser system connectors shall be qualified for the application, based on calculations in combination with qualification testing, see Annex I. Connectors of the same type, but of a different size may be qualified by calculation; see I.1.11.

The seal and the connector including any bolts, preload and friction forces shall be considered together as a system to determine capabilities of the connection.

#### 6.6.2 Loads and load conditions

As a minimum, the following loading parameters/conditions shall be considered and documented by the manufacturer when designing connectors:

- a) make-up and break-out loads (e.g. tension and torsion);
- b) internal and external pressure including test pressure;
- c) external loads (e.g. bending moments and effective tensions);
- d) cyclic (fatigue) loading;
- e) thermal load effects (trapped fluid/water, dissimilar metals) and thermal transients.

Pressure separation loads shall be based on worst-case sealing conditions (leakage to the largest redundant seal diameter shall be assumed).

For connectors which require connector or bolt preload, the following shall apply.

- Consideration shall be given to maximum and minimum assembly preload and possible loss of preload during operation due to the combination of minimum assembly load, pressure, external loads and thermal effects.
- Minimum assembly load shall be determined based on assessment of accuracy (scatter) of the preload method, short-term and long-term relaxation.

External pressure shall be considered for both inside drilling riser and open-sea operations in the design of connectors with respect to both strength and leakage.

The minimum mechanical preload shall be sufficient to seat seal rings/gaskets and ensure leak-tight operations. Corrosion effects shall be considered.

Design load effects should be based on global riser analysis of the riser system including environmental, functional, pressure load effects during all phases of use. Connectors can also provide support for auxiliary lines and buoyancy, which induces loads on the connectors. Temporary loads during handling or suspending the riser from the handling tool or spider should be accounted for including possible hang-off loads.

### 6.6.3 Failure modes

Riser connectors shall be designed against the following possible modes of failure, as appropriate:

- a) excessive yielding; see 6.4.7;
- b) leak-tightness; see 6.4.11.5;
- c) fracture; see 7.2.10;
- d) deformations and sudden disengagement, such as thread jump-out;
- e) fatigue failure; see 6.4.9;
- f) galling tendency between sliding elements;
- g) functionality, e.g. multiple make-up and break-outs, interchangeability, multiple latch/unlatch.

The relative radial displacement between mating threads resulting from the combination of pressure, thermal effects and external load effects shall not be greater than 10 % of the minimum thread overlap. The minimum overlap shall be determined considering the most unfavourable combination of tolerances.

Make-up/break-out tests are considered successful if no galling is observed or if repairable damage meeting the manufacturer's repair criteria is observed and repaired, and the connector performs without leakage. Only galling that can be repaired by the use of abrasive paper on contact or seal surfaces is acceptable.

Sufficient resistance against the relevant failure modes shall be demonstrated by applying calculations, see Annex D, supported by necessary qualification testing; see Annex I.

The sensitivity of the calculation model and the parameters utilized in the model shall be examined.

Calculations shall be performed using dimensions of the component in the corroded and the uncorroded condition, and the more severe case shall govern.

Strains developed under all relevant load conditions should be limited such that the sealability or mechanical functionality of the component is not adversely affected.

**NOTE** The main purpose of sensitivity analysis is to quantify model uncertainties, support rational conservative assumptions and identify areas where a more thorough investigation is needed to achieve an acceptable modelling. Parameters included in strength, leak-tightness and fatigue analysis typically are preload, machining tolerances and friction coefficients.

#### 6.6.4 Connector make-up and break-out

Connectors shall be made up and broken out in accordance with a written procedure that has been qualified by tests to achieve the specified minimum preload. Factors affecting the preload, such as friction and lubrication, shall be considered.

Connectors shall be made up and broken out by qualified personnel. The personnel shall be qualified by documenting their basic knowledge on how the connector and applied tools work, combined with conducting tests to demonstrate that they can apply the qualified procedure and achieve the specified minimum preload.

The applied tools used shall be calibrated against a reference with a calibration traceable to a recognized standard. It is important that the whole preload system, consisting of tools and measuring devices, is calibrated as one unit.

The manufacturer shall specify make-up/break-out procedures that shall include procedures for applying thread lubricants to ensure correct make-up without galling.

#### 6.6.5 Seals

Connectors shall provide a seal between the mating segments that is compatible with any fluid that will pass through the riser. The seal shall maintain its integrity under all external and internal loading conditions including both short-term and long-term conditions.

In cases where seal rings are used to guide the connectors during make-up/break-out, the seal rings shall be designed for guiding loads.

Seals shall be made from metallic materials or elastomers that are resistant to the internal and external fluid. Galvanic corrosion shall be avoided. Mechanical and physical properties shall be maintained at the anticipated pressure and temperatures.

The sealing faces of connectors shall have a surface finish and hardness suitable for the mating sealing surface on the connector or seal.

Connector designs where the seal acts as a primary load bearing member, e.g. API 6A type 6B flanges, shall not be utilized for applications exposed to cyclic loading, in order to maintain high reliability against leakage.

Seal rings wetted with internal fluid shall include the same internal corrosion allowance as the connecting pipe/equipment and be of compatible material. Alternatively, seals and seating surfaces shall be corrosion-resistant in the actual environment.

Further seal requirements are given in 5.4.2, 5.4.12 and Annex H.

#### 6.6.6 Threaded connections

Because of the many variables involved, and in order not to restrict innovative designs, detailed rules are kept to a minimum. The effects of the total load to be resisted, the number of threads, the thread form, the relative stiffness of mating parts and friction shall be considered in both static and fatigue analysis of threaded connections. Stresses can be minimized by providing generous undercuts (dummy threads not engaged) ahead of the first thread and providing flexibility in mating parts to promote equalization of the thread loads.

The designer shall identify the weakest area/section and the areas with highest stress concentrations of the threaded connection. This is generally the area of the root of the most highly loaded thread, which is usually the first or second thread. Calculation of stresses requires consideration of the actual thread load, SCF due to

thread form (in particular, the thread root radius or elliptical transition), thread bending stress, and the membrane and bending stress in the pipe at the thread.

In general, the threads do not carry the end load uniformly. The designer shall determine the thread load distribution.

Limits on torque for make-up shall be specified by the manufacturer.

Limits on angle of rotation for make-up should also be specified by the manufacturer.

#### 6.6.7 Flanged connections

All flanged connections used on the C/WO riser subjected to cyclic loads shall be of the seal ring type designed for face-to-face make-up for transfer of the bulk bolt loading through the flange faces. Flanged connections shall be designed to avoid bolt prying.

Self-energized and pressure-energized metal seal rings may be used to allow for the bulk bolt load to be transferred through the flange faces.

Prying may be avoided by an axial clearance outside the bolt circle diameter for at least one of the flanges in a connection that is large enough to avoid bolt prying, e.g. by a raised face or by an initial conical flange ring profile.

Flanges in ISO 10423 are applicable primarily for static load conditions and qualification should be considered for cyclic loading applications.

Examples of strength calculations of flanges can be found in EN 1591-1 [24] and ENV 1591-2 [25] with design factors given in 6.4. If not justified by tests or finite element analysis, the total bolt hole diameter shall be used instead of the effective bolt hole diameter to estimate the effective flange width for use in the flange capacity calculations (not for flexibility calculations) in EN 1591-1 [24]. Bolts shall be designed in accordance with 6.6.8. The stress limits for load bearing and shear stresses given in Annex D shall apply.

Examples of mechanical capacity charts for flanges in ISO 10423 can be found in API Bull 6AF [4], API Bull 6AF1 [5], and API Bull 6AF2 [6] for static loading conditions. These charts should be used with care, as the analysis models used do not fully address gasket seating or retaining forces in a realistic manner. The flange faces can begin to separate at the listed external loads, hence, flange face-to-face capacities have to be calculated separately. Flanged joints subjected to cyclic (dynamic) loading shall in general have face-to-face contact during operation to reduce the risk of bolt fatigue failure and leakage due to damage of the gasket.

#### 6.6.8 Bolts

In connectors, such as flanges and clamps, bolts are the primary means to transfer load across the assembled connector. Bolts shall normally be pre-tensioned to provide resistance against disengagement and reduce cyclic load effects in the bolt and connection.

Strength and fatigue criteria are given in 6.4.7 and 6.4.9.

Make-up preload should be sufficient to seat seals during assembly and to provide a leak-tight joint during operation without any bolt failure. Bolt preload methods are described in Annex G.

Cyclic stress shall include effects from axial and bending stress in the bolts due to cyclic external loads and possible thermal effects. For more details, see Annex C.

Finite element analysis may be used to evaluate bolt force fluctuation due to external loads, especially bending stress.

## 6.7 Design criteria for miscellaneous components

### 6.7.1 Safety joint or weak link

Measures should be taken to avoid damage to the C/WO in case of overloading due to accidental load effects. A weak link may be considered for accidental loads caused by excessive top tension (motion compensator lock-up) and excessive vessel offset (drive-off, drift-off, anchor line failure) to ensure that unacceptable escalation does not occur. This may be achieved by introducing controlled riser failure or a weak link above the subsea isolation valve.

A safety joint or weak link shall be designed to fail or break under specified loads.

The yield and ultimate tensile strength values applicable for weak-link assessment shall be the maximum specified values. The maximum strength values to be used shall be the mean strength plus two standard deviations or equivalent.

A safety margin of 10 % in the weak-link assessment may be applied.

All riser system components shall be capable to safely resist the same loads as generated in the pipe(s) of the riser string when subjected to accidental loads, except safety joints designed into the riser system to fail under specified loads.

Safety joints or system components where the ultimate (failure) resistance is not known shall be validated for fitness by either

- a) calculations with maximum specified values supported by testing;
- b) documented full-scale testing of the components or special assemblies; or
- c) a history of successful usage of these components or special assemblies produced by the same design method. Care should be exercised in any new application of existing design to ensure suitability for the intended service.

The calculation of riser load effects should take into account the fact that the riser moment-tension relationship can change before final failure, i.e. for ductile materials a bending dominated load condition can change to tension as a plastic hinge forms. As a minimum, the tension-pressure weak-link capacities for all components shall be established in the riser system.

### 6.7.2 Non-pressurized primary structural components

Non-pressurized structural components shall be designed in accordance with accepted industry practice and documented in accordance with Clause 11. A safety factor of 1,5 (design factor of 0,67) or more shall be used in the design calculations or industry codes, like API RP 2A-WSD<sup>[1]</sup>, which may be used. Alternatively, finite element analysis or load test may be used. In cases where a load test is performed to 1,5 times the design load, the component shall sustain the test load without any deformation to the extent that any other performance requirements are affected.

### 6.7.3 Design of padeyes and lifting devices

Padeyes and other lifting devices used for general handling of equipment shall be designed and qualified in accordance with ISO 13628-4:1999, 4.1.3.7, or equivalent.

## 7 Materials and fabrication

### 7.1 Introduction

Clause 7 includes requirements and guidelines for material selection, manufacture, testing, corrosion protection, fabrication and documentation. These requirements are applicable for all components assembled in equipment included in the scope of this part of ISO 13628 with exception of equipment that is governed by other applicable codes and standards; see Table 2.

### 7.2 General material requirements

#### 7.2.1 Selection

Materials shall be selected to

- be suitable for all operations, test conditions and storage;
- have the mechanical properties, such as strength, ductility and toughness, necessary to comply with the design requirements of Clause 6;
- have properties necessary to comply with the functional requirements of Clause 5;
- be suitable for the intended fabrication steps, including welding if applicable;
- be suitable for the internal fluid, external fluid and external environment during testing, running, operation and storage;
- avoid use of dissimilar metals in an assembly if this can create a risk of galvanic corrosion;
- have material performance due to ageing above the minimum requirements;
- have sufficient resistance to abrasion/wear or mechanical damage likely to occur during handling, running and operation.

Critical components in the C/WO riser shall not be manufactured from castings.

For components with high sliding contact stresses, e.g. threaded connections, special consideration shall be given to galling.

Non-metallic (polymer) material selection shall be based on evaluation of compatibility with service environment, functionality under service and the design lifetime. The following should be considered as appropriate to critical non-metallic seal requirements and evaluated when selecting the material:

- adequate physical and mechanical properties, such as hardness, tensile strength, elongation at break, modulus of elasticity, compression set, tear resistance, etc.;
- resistance to high-pressure extrusion or creep;
- resistance to thermal cycling and dynamic movement;
- resistance against rapid gas decompression;
- long-term behaviour and low-temperature flexibility.

#### 7.2.2 Specifications

All materials for riser pipe, components, welding consumables if relevant and coatings shall be manufactured and used in accordance with the requirements of the relevant product standard and of this part of ISO 13628.

Requirements of this part of ISO 13628 not included in the relevant product standard shall be specified and supplemented to the applicable standard.

Detailed specifications shall be prepared for materials if a relevant product standard is not available. The specifications shall define requirements for method and process of manufacture, chemical composition, heat treatment, physical and mechanical properties, weldability if appropriate, dimensions and tolerances, surface conditions, testing, inspection, marking, temporary coating and protection, certification and documentation.

The material specification may be a material data sheet referring to the relevant product standard including supplementary requirements by this part of ISO 13628, requirements subject to agreement, etc.

The fabrication of riser components shall be performed according to a specification giving the requirements for fabrication methods, procedures, testing, acceptance criteria and required documentation.

Manufacture and fabrication shall be performed in accordance with a manufacturing procedure specification. The manufacturing procedure specification shall demonstrate how the specified properties may be achieved and verified through the proposed manufacturing/fabrication steps. The manufacturing procedure specification shall address all factors, which influence the quality and reliability of the production or fabrication. All main manufacturing/fabrication steps from control of received material to shipment of finished product(s), including all examination and checkpoints shall be covered in detail. References to the procedures established for the execution of all steps shall be included.

### 7.2.3 Qualification of materials and manufacturers

The need for qualification of materials for the service condition should be considered. The consideration should be based on the internal and external fluids, loads, temperatures and the material selected. If qualification of materials is required, the extent of testing and investigations to be performed for a complete qualification shall be specified.

Requirements for the qualification of processes, tests, manufacturers and fabricators shall be considered in each case. The consideration shall take into account the complexity and criticality of the product to be supplied and available experience of the potential manufacturer and fabricator.

### 7.2.4 Materials for sour service

Risk for sour service conditions shall be evaluated for all parts of the C/WO riser, which during the lifetime can be exposed to reservoir fluids during operation, i.e. production testing and well circulation. Requirements for metallic materials in sour service shall comply with ISO 15156 (all parts) with amendments given in this part of ISO 13628.

Specifications for materials in sour service shall include requirements for performance testing to demonstrate resistance to sulphide stress cracking and hydrogen-induced cracking, if the suitability of the materials for sour service is not stated in other standards.

Requirements to prevent hydrogen-induced cracking can include reduction and/or shape control of non-metallic inclusions.

Qualification testing shall be in accordance with ISO 15156 (all parts) for carbon steel. The qualification shall include testing of sulfide stress cracking resistance of base material and welds, with a minimum threshold stress equal to 85 % of specified minimum yield strength, or higher if recommended by the applicable standard.

### 7.2.5 Consistency of requirements

Requirements shall be specified consistently for all pressure-containing and load-carrying components in the C/WO riser system.

**EXAMPLES** Chemical composition to ensure weldability; toughness to prevent brittle fracture.



### 7.2.6 Steel making

The steel shall be manufactured in a manner ensuring uniform composition, properties and soundness.

### 7.2.7 Chemical composition and analysis

The steel shall have a chemical composition, with specified manufacturing, fabrication and welding procedures, if applicable, that ensure sufficient strength, ductility, toughness and corrosion resistance.

Chemical composition shall be determined by analysis in accordance with recognized standards. All elements listed in the material specification shall be determined and reported. As a minimum, the following shall be reported by mass percent: carbon, manganese, silicon, phosphorus and sulfur. Any other intentionally added element (Ni, Cr, Mo, V, N, etc.) and trace elements of importance for mechanical and corrosion properties shall be reported.

Low-alloy steels, including AISI 4130 and AISI 4140 should be modified as follows: P: 0,025 % max. and S: 0,025 % max.

NOTE ISO/TR 9769:1991 <sup>[21]</sup> covers a list of standards providing chemical analysis methods, with information on the application and precision of the various methods.

### 7.2.8 Mechanical and corrosion testing

The extent and type of testing shall be specified considering the type, dimensions, processing, manufacturing, applications and intended service of materials for various components and shall be in accordance with relevant recognized product standards or specifications such as ISO, EN, ASTM or equivalent.

Testing shall be carried out in a laboratory that meets the requirements of ISO 17025, or an accepted equivalent and shall be performed according to the relevant standard or specification.

Selection of samples and preparation of mechanical test pieces shall be in accordance with the general conditions of ISO 377, as far as applicable. Samples shall be taken in accordance with the recognized standard or specification. Where thermal cutting has been used to remove samples, the full extent of the heat-affected region shall be removed during the preparation of the test pieces.

Test samples for pipes and components shall be taken from products or welded joints in their final delivery condition, which are suitable for subsequent extraction of mechanical test specimens. Test samples shall be sized to realistically represent the item at the critical cross-section after final forming and/or heat treatment.

Tensile testing shall be done in accordance with ISO 6892, ISO 783, or ISO 15579 as appropriate.

Samples for corrosion testing shall be taken such that the surface exposed to the corrosive medium will be tested.

### 7.2.9 General mechanical requirements

Requirements for mechanical properties of ferritic, ferritic/austenitic or martensitic stainless or carbon steels including welded joints (excluding bolts) of pressure-containing and/or load-carrying components are given in Table 15.

If high-strength materials are used, the designer should take necessary precautions to avoid possible failure mechanisms such as brittle fracture, stress corrosion cracking or hydrogen-induced cracking caused by cathodic protection systems. Special precautions should be taken when welding high-strength materials.



**Table 15 — Requirements for carbon and low-alloy steel**

Property	Requirement	
Minimum percentage elongation after fracture, $A_5$ for gauge length, $L_0 = 5,65\sqrt{A_{TTS}}$ or $5d_d$	Transverse or critical direction:	14 (16) <sup>a</sup>
	Longitudinal or less-critical direction:	16 (18) <sup>a</sup>
Minimum reduction in area for forgings or castings, %		35 %
Maximum yield strength to tensile strength ratio <sup>b</sup>		0,92
Impact test temperature <sup>c</sup>		Minimum design temperature
Minimum impact energy in transverse or critical direction, full-size Charpy V-notch specimens, average/individual, J (ft-lbs) <sup>c</sup>	$R_{t0,5} \leq 310 \text{ MPa (45 ksi)}$	27 (20) / 20 (15)
	$R_{t0,5} > 310 \text{ MPa (45 ksi)}$	40 (30) / 30 (22)
Maximum hardness Vickers, HV10 <sup>d</sup>	Non-sour service and cathodic protection	350 parent, weld and heat-affected zone
	Sour service	250 root area 275 cap area
<sup>a</sup> Values in brackets are for specimens with a gauge length/diameter ratio of 4. Higher safety factors or testing demonstrating ductile behaviour may be used to justify lower values; see 6.4.6. For conversion to other gauge lengths, the conversion tables in ISO 2566-1 apply for carbon and low-alloy steels. <sup>b</sup> See 6.4.6 for more details. <sup>c</sup> See 7.2.10 for more details. <sup>d</sup> See 7.2.11 for more details.		

## 7.2.10 Prevention of brittle fracture

### 7.2.10.1 General

Materials in the C/WO riser system shall be selected and applied in such a way that brittle fracture is prevented. One of the following methods shall be used to determine toughness requirements to avoid brittle fracture in metallic materials:

- application of the Charpy V-notch impact energy method;
- application of fracture mechanics testing and analysis.

The brittle fracture requirements shall be met in parent metal and for welded components, weld metal and heat-affected zones at minimum design temperature; see Table 15.

### 7.2.10.2 Charpy V-notch impact energy method — Code of practice

The impact energy requirements are given in Table 15. The requirements in Table 15 are for the V-notch transverse to the grain orientation and/or in the transverse direction to the highest applied tensile stress in the component. If geometry does not allow for transverse testing, longitudinal testing may be used instead. The minimum average and individual values when test pieces are taken in the longitudinal direction shall be 1,5 times the values stated for the transverse test pieces.

Full-size Charpy V-notch tests shall be carried out in accordance with ISO 148. Each set of impact tests shall consist of three adjacent test pieces. The alternative, tapered test pieces specified by ISO 3183 (all parts), ISO 11960, etc., may also be used. Charpy V-notch impact energy testing shall be performed for all items where test pieces with thickness of  $\geq 5 \text{ mm}$  (0,197 in) are obtainable. Where standard specimens cannot be made, subsize specimens may be used, i.e.  $10 \text{ mm} \times 7,5 \text{ mm}$  (0,394 in  $\times$  0,295 in) or  $10 \text{ mm} \times 5 \text{ mm}$  (0,394 in  $\times$  0,197 in). The required impact values shall then be reduced to respectively 0,80 and 0,70 of the value of the standard  $10 \text{ mm} \times 10 \text{ mm}$  (0,394 in  $\times$  0,394 in) test specimen.

Impact testing of welded components shall include test of base material, weld metal, fusion line, fusion line + 2 mm (0,079 in) and fusion line + 5 mm (0,197 in).

Fracture toughness testing and analysis shall be considered for materials and welded joints if the manufacturer cannot document satisfactory experience or testing from previous similar applications with Charpy V-notch impact energy requirements. Fracture toughness testing and analysis should be considered in each individual case for materials and PWHT weldments if the thickness exceeds 40 mm (1,57 in) for  $R_{t0,5} \leq [560 \text{ MPa (81 ksi)}]$  or for thickness exceeding 30 mm (1,18 in) for  $R_{t0,5} > [560 \text{ MPa (81 ksi)}]$ .

### 7.2.10.3 Fracture mechanics testing and analysis

Fracture mechanics testing and analysis may be used to determine the suitability of a particular component for the intended service, when agreed between the purchaser and the manufacturer, in the following cases:

- if materials are not currently covered by standard product codes;
- if the Charpy impact requirements in 7.2.10.2 cannot be adhered to;
- if defects detected by the required NDT are outside the specified acceptance criteria;
- if it is proposed to use a material thickness greater than permitted by the Charpy V-notch impact energy method in 7.2.10.2.

Fracture mechanics may also be used to establish inspection programmes.

For materials not covered by Charpy V-notch impact energy requirements, a similar level of tolerance to fracture can be obtained by specifying fracture toughness requirements, such as described in API RP 579 <sup>[10]</sup> and BS 7910 <sup>[16]</sup> with

- a reference defect size as agreed by the parties involved (e.g. a through-the-wall flaw of total length equal to 10 mm (0,39 in) or a quarter wall thickness surface flaw with length six times its depth); and
- using the calculated stresses or strains at the location of defect for design conditions, including residual stresses.

Fracture toughness properties should be obtained using full thickness single edge notched bend specimens, such as described in BS 7448-1 <sup>[14]</sup> and BS 7448-2 <sup>[15]</sup> or equivalent standards. As the resistance to fracture depends on the crack tip constraint, test specimens with reduced notch depth, e.g. equal to reference defect size, may be used for deriving fracture toughness values for sections predominantly subjected to membrane stress, e.g. pipe wall.

The fracture toughness values to be applied shall be representative for the coincident temperature and design load effects with associated relevant crack tip constraint (crack depth).

**NOTE** A minimum fracture toughness value of CTOD in the range of 0,15 mm to 0,20 mm (0,006 in to 0,008 in) at the actual operating temperature is appropriate.

If the NDT methods employed allow accurate sizing of defects, these flaw sizes, together with information on the stress state of the critical regions of the component, can be used with an appropriate fracture assessment procedure to specify more accurate Charpy V-notch impact energy requirements.

For materials which are covered by the Charpy V-notch impact energy method, but where the Charpy energy requirements cannot be met, a fitness-for-purpose assessment procedure, such as API RP 579 <sup>[10]</sup> or BS 7910 <sup>[16]</sup>, using representative fracture toughness data and inspection requirements may be employed to determine the integrity of the component for its intended use.

### 7.2.11 Hardness

Requirements applicable to maximum final hardness shall be specified dependent on the sensitivity of the steel material with regard to hydrogen-induced cracking and to whether the exposed fluids can cause stress corrosion cracking. The hardness shall meet the requirements in Table 15.

Hardness testing of welding procedure qualifications shall be performed using the Vickers method in accordance with ISO 6507-1 with a test force of 98,07 N (22,05 lbf), i.e. HV10.

Macro section test and hardness measurements shall be performed on a cross-section part of the weld during welding procedure qualification when specified in the purchase order, see 7.4.3. Indentations shall be made at maximum 1 mm intervals along a line across the fusion line from the weld metal into the base material or vice versa. Indentations shall be made along traverses, each  $1,5 \text{ mm} \pm 0,5 \text{ mm}$  below the surface at either side of the weld.

### 7.2.12 Retesting

If any test fails to meet the specified requirements, the manufacturer may, by agreement, carry out additional tests on two other items from the same heat/heat treatment batch.

If one of the additional tests or sets of tests still fail to meet the specified requirements, then all of the items from the heat/heat treatment batch shall be rejected. If both retests are acceptable, then the rest of the test lot, minus the one component that failed, is acceptable.

### 7.2.13 Corrosion

#### 7.2.13.1 General

All components of a riser system shall have adequate corrosion protection to avoid damage caused or initiated by corrosion, both externally and internally. Corrosion protection shall be provided by either or a combination of material selection, coating system, control of internal media, cathodic protection and routine preservation. Selection of the appropriate corrosion protection measures shall consider, as a minimum, the following: marine environmental conditions, drilling riser internal conditions, external fluids, internal fluids, corrosion properties of welds, crevice corrosion, dissimilar metals effects, cathodic protection effects, anodic-cathodic reactions inside a drilling riser and coatings.

For C/WO risers manufactured from carbon manganese steel, reduction in wall thickness due to corrosion during operation and storage shall be evaluated. An appropriate corrosion allowance shall be included in the design, see 6.4.4.

#### 7.2.13.2 Internal corrosion

The type of fluids being handled by the riser shall be considered and special allowances made for fluids that are particularly corrosive. Corrosion rates due to produced fluids and any treatment fluids shall be considered when determining wall thickness.

NOTE Care in selection of connectors can minimize corrosion in dead spaces.

Where necessary, internal corrosion may be mitigated by one or more of the following: flushing/scouring at regular intervals with inhibitors, bactericides, dehydrators, etc.; applying a temporary coating, such as grease, to minimize surface exposure; end capping; and applying a more permanent internal coating such as plastic or epoxy.

#### 7.2.13.3 External corrosion

The external surface shall be protected by a suitable coating system in addition to routine coating repair and preservation of damaged coating. Cathodic protection systems may also be considered.

Permanent external coating such as epoxy or thermally sprayed aluminium may be applied. Thermally sprayed aluminium may be used for elimination of coating maintenance. Wax coating may be considered for bolts, nuts, flanges, etc.

Where required, selection of external coating systems should include the following considerations:

- a) mechanical loading considerations, including thermal growth (or contraction), handling/installation loads, fatigue loads, damage due to make-up and break-out of riser connectors, and friction against riser connectors mating components;
- b) resistance to damage from temporary exposure to internal fluids during make-up or break-out of riser connectors;
- c) resistance to under-film migration;
- d) resistance to debonding, cold flow, embrittlement, chalking and cracking;
- e) easy repair and/or reapplication;
- f) assurance that metals are well coated to discourage galvanic corrosion. Specifically, cathodic materials should be well coated with respect to adjacent anodic materials (small cathode-large anode rule).

The design should ensure reliable electrical continuity to each individual element for the exposed period, if the external corrosion protection is based on cathodic protection.

If the riser is not equipped with own anodes, it is recommended that the cathodic protection systems of adjacent equipment are designed with sufficient capacity to include current drain to the riser.

#### 7.2.13.4 Corrosion testing

For certain material and fluid combinations where improper manufacture or fabrication can cause susceptibility to corrosion damage, the need for corrosion testing during qualification and/or production shall be assessed and agreed. Corrosion testing for carbon steels may include hydrogen-induced cracking and sulphide stress cracking; see 7.2.4.

#### 7.2.14 Weld strength

The mechanical properties of the weld metal shall, as a minimum, meet the requirements of the base material. Excessive overmatched yield and tensile strength shall be avoided. Consideration shall be given to obtain a balance between the requirements for toughness, ductility and overmatch for base material and welding consumables.

For girth welds, testing of batches of consumables used in production including possible wire/flux combinations shall be qualified by testing.

Sufficient overmatch can be achieved in two different ways.

- a) The weld metal should be selected with a guaranteed minimum yield strength at least 5 % higher than the actual tensile strength of the base material.
- b) The minimum yield strength of the weld metal should be above the maximum yield strength of the base material.

If weld overmatch cannot be guaranteed, special care shall be taken to ensure sufficient strength and toughness of the welded connection.

### 7.2.15 Properties at elevated temperatures

The mechanical and physical properties at the maximum design temperature of the materials for operations above 50 °C (122 °F) should be documented unless specified in the referenced product standard or complementary justification.

A material shall only be used within the range of temperatures for which the material properties required by Table 8 are defined in the product standard. If the product standard does not contain the specific material values required for the maximum design temperature, the values proposed in 6.4.6 may be applied.

For ferritic materials, where no values are available between 20 °C (68 °F) and 100 °C (212 °F), the yield strength for 20 °C (68 °F) may be used for temperatures up to and equal to 50 °C (122 °F).

### 7.2.16 Properties after forming and heat treatment

For materials subjected to heat treatment, hot or cold forming, welding or other processes that can affect the material properties, compliance with the specified requirements in the final condition shall be documented. Documentation shall 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 included in the specification.

### 7.2.17 Soundness

Visual examination and NDT shall be performed on all items to verify that they are free from defects that make the material/weld unsuitable for the intended use. Visual inspection and NDT shall be carried out by suitable qualified personnel.

The NDT shall be carried out using a combination of methods capable of detecting surface and internal imperfections. The applied NDT methods shall be in accordance with relevant specified procedures and acceptance criteria given in recognized standards.

### 7.2.18 Traceability

Traceability shall be verifiable during manufacture, with suitable identification at all stages of manufacture, fabrication and during subsequent handling and use. This shall be ensured with suitable marking, i.e. unique identification for each individual item, with references to material certificates. Care shall be exercised during storage and handling to preserve the identification of materials.

### 7.2.19 Marking

Materials and components shall be marked in accordance with the requirements of the applicable product standard or, if not specified, the requirements of MSS SP-25. All marking shall be such that it will be easily identifiable, retained during subsequent activities and at locations where the marking will not be harmful. Marking by die stamping shall be done in a manner resulting in minimum stress concentrations.

### 7.2.20 Inspection documents

The compliance with the requirements of the order shall be checked for products manufactured in accordance with this part of ISO 13628 by specific inspection and testing.

All materials shall be supplied with an inspection document in accordance with ISO 10474, which can be traced to the riser component. For materials for pressure-containing and load-carrying components including welding consumables if applicable, an inspection certificate type 3.1.B in accordance with ISO 10474 shall be supplied as a minimum. Non-metallic materials should be certified to a comparable standard.

### 7.2.21 Records

Specifications with agreed deviations, design dossier such as calculations and drawings, test and inspection results, and certifications shall be collected for retention during operations, in accordance with the design and fabrication résumé requirements in 11.8.

Records from the qualification of the manufacturer's procedure specification and complete statistics of chemical composition, mechanical properties and dimensions for the quantity delivered, shall be included in the final documentation.

### 7.2.22 Protection and handling

Items like riser pipe, components and riser joints shall be adequately protected from harmful deterioration from the time of manufacture and fabrication until taken into use and during use including storage.

All pipe/connector ends shall be fitted with suitable end caps/covers to seal the bore and to protect pipe ends/connector ends during handling and storage.

## 7.3 Products

### 7.3.1 General

If there are conflicting requirements between this part of ISO 13628 and the referenced standard or code used for manufacture of pipes and components, the requirements of this part of ISO 13628 shall have precedence.

### 7.3.2 Pipe

C/WO riser pressure-containing pipes shall be made of seamless pipes.

As a minimum, pressure-containing pipes shall be manufactured and tested in accordance with the requirements given in ISO 3183-3, ISO 11960, ISO 11961 or equivalent industry standards for metallic pipes.

Hardness tests shall be performed on all pipes in accordance with ISO 3183-3, ISO 11960 or equivalent.

### 7.3.3 Forging and extrusion

#### 7.3.3.1 General

Forgings shall be mechanically hot worked throughout section and length to reach a shape as close as possible to the final. The method of hot working shall be selected to give the most favourable grain flow and texture for the intended component and its application. Care shall be taken that no harmful segregation can appear on machined surfaces in the finished component. The reduction ratio shall be a minimum of three.

A range of chemical specifications may be considered suitable for forging, depending on the design requirements. Forgings shall meet the requirements of ISO 9327-1. Recognized specifications like ASTM A182 <sup>[11]</sup>, ASTM A694 <sup>[12]</sup> or ASTM A707 <sup>[13]</sup> may be used for forgings and extrusions.

#### 7.3.3.2 Manufacturing

The steel shall be fully killed and made according to a fine grain and inclusion control practice.

Heat treatment shall be in accordance with ISO 4885. The final heat treatment for mechanical properties shall be by quenching and tempering at a subcritical temperature after rough machining. The martensite content shall be controlled to minimum 90 % by hardness testing prior to tempering as outlined in ISO 11960:2001, 6.2.10. Carbon content shall relate to material where the hardness test has been conducted. The heat treatment shall be performed in accordance with a documented procedure.



A record (heat-treatment chart) shall be maintained of each treatment and shall be included in the inspection document. Heat treatment of materials exposed to well and injection fluids shall be according to ISO 15156 (all parts).

Quenching shall be arranged, wherever possible, from outside and inside. Quenching shall be conducted such that mechanical property variations through the cross-section are minimized. The manufacturer shall provide evidence that tempering practice will ensure that correct temperature has been achieved for all forgings.

Welding repair of forgings and extrusions shall not be performed without written approval of the purchaser.

### 7.3.3.3 Chemical composition and mechanical testing

The purchaser shall specify details of the post-weld heat-treatment cycle to be used during welding if applicable. The test requirements and acceptance criteria shall be by agreement.

A simulated heat treatment of the test piece shall be performed if welds between the component and other items are to be post-weld heat-treated.

A test unit shall consist of a prolongation, or sacrificial forging or extrusion.

The extent of testing to be performed during production shall be as stated in Table 16 for each heat. Locations of test pieces to be taken from a forging or extrusion shall be in accordance with ASTM A370,  $\frac{1}{4} t \times t$ , or as by agreement. The manufacturer shall prepare sketches for purchaser acceptance showing locations of the prolongations and the location of test specimens within the prolongations.

Specimen orientation is transverse relative to the direction of major working during forging or extrusion, as applicable.

Integral prolongations for test sampling shall be fitted onto the forging according to the provisions of ASTM A508. The prolongations shall have a size representative of the thicker sections of the forging they represent and shall normally include a thermal buffer. The size shall be sufficient to perform all tests and additionally allow for retesting.

The tensile, Charpy and hardness properties shall meet the requirements in Table 15. If nominal thickness exceeds 25 mm (0.984 in), tensile and Charpy samples shall be extracted and tested at 50 % thickness. The through-thickness ductility testing shall be carried out for every heat. Corrosion tests shall be performed by agreement; see 7.2.13.4. The hardness shall be measured at several locations along the length and the periphery of the rough machined units.

**Table 16 — Chemical analysis and mechanical testing of forgings**

Type of test	Number and frequency of testing
Chemical composition	1 per heat
Tensile	1 per melt and heat-treatment batch
Charpy V-notch	1 set per melt and heat-treatment batch
Through-thickness hardness	1 per heat for sour service
Surface hardness	By agreement
Metallography	1 per heat for sour service

All large forgings or extrusions shall be tested, i.e. for stress joints and tensioner joints. The extent of testing may be reduced for small forged items, i.e. forgings for mechanical connectors as follows: 100 % of the first 10 forgings of each size and type, thereafter 10 % of each size and type. If any test fails to meet the specified requirement in the first 10 forgings or during the 10 % testing, all forgings or extrusions of this size and similar type shall be 100 % tested.

#### 7.3.3.4 Visual inspection and NDT

Forgings shall be inspected by means of appropriate NDT methods to make sure that no significant internal or external defects are present.

Requirements for personnel, methods, equipment, procedures and acceptance criteria for NDT are given in 7.5.

Each forging or extrusion shall be subject to 100 % visual inspection of the external surface and accessible parts of internal surfaces under adequate illumination.

Forgings or extrusions shall be subject to 100 % MPI and 100 % UT.

MPI shall be performed on the entire surface (inner, outer and ends/end bevels to the extent possible) on all accessible surfaces after final heat treatment and machining. The end face shall be tested for detection of laminar imperfections in accordance with ISO 3183-3. Special attention shall be given to seal seating faces and regions with stress concentrations. If access limits the possibility for MPI at a bore, UT shall be performed on solid forgings before drilling of the bore, or before final machining of the bore. MPI shall be performed on all forged items.

UT shall be performed of the entire forging with angle and normal beam probes. UT shall be performed on all heavy forgings, i.e. forgings for stress joints and tensioner joints. Each end of the forging or extrusion shall be tested by UT for linear imperfections in accordance with ISO 3183-3. For smaller forgings, like forgings for mechanical connectors, all the first 10 forgings of each size and type ordered shall be tested. If no defects are found, the extent of UT may be reduced to random testing of 10 % of each size and type of the remaining items for each heat/heat treatment batch. If defects are found in the first 10 forgings or during testing of 10 % of the forgings, all forgings of this size and similar type shall be 100 % tested.

#### 7.3.4 Structural items

Structural items such as supports and protective structures that are not welded onto pressurized parts are considered as structural elements. The material requirements shall be relevant for the structural element category according to a recognized structural design code, e.g. API RP 2A-WSD [1].

Structural items that are welded directly to, or act as a pressure-containing part of the riser system shall meet the material requirements for the riser system where they are located.

#### 7.3.5 Bolting

Bolts, studs and nuts shall be tested according to recognized standards in addition to the requirements given in 7.3.5 and Table 15.

The general bolting material should be carbon or low-alloy steel selected in accordance with the standards listed in Table 17. Equivalent standards may be used, subject to agreement.

Hydrogen embrittlement, fatigue and relaxation properties shall be taken into account where appropriate.

If other bolting materials are required due to corrosion resistance or other reasons, the material shall be selected in accordance with the general requirements given in this part of ISO 13628. Of special importance are the requirements in Table 15.

The hardness of bolts in carbon steel and/or low-alloy material shall be less than 350 HV10.

Carbon steel and/or low-alloy bolting material shall be hot-dip galvanized, electrolytic galvanization or have similar corrosion protection. Hot-dip galvanizing shall be in accordance with ISO 1461. Hot-dip and electrolytic galvanization shall be followed by post-baking.



Table 17 — Bolting materials

Service	Bolt	Nut	Minimum design temperature
Subsea	ISO 898-1: Grade 8.8	ISO 898-2	$\geq 0\text{ }^{\circ}\text{C}$ (32 $^{\circ}\text{F}$ )
	ASTM A193: Grade B7	ASTM A194: Grade 2H	$\geq 0\text{ }^{\circ}\text{C}$ (32 $^{\circ}\text{F}$ )
	ASTM A320: Grade L7	ASTM A194: Grade 4/S3	$\geq -100\text{ }^{\circ}\text{C}$ (-148 $^{\circ}\text{F}$ )
	ASTM A320: Grade L43	ASTM A194: Grade 7	$\geq -100\text{ }^{\circ}\text{C}$ (-148 $^{\circ}\text{F}$ )
Sour service	ASTM A193: Grade B7M	ASTM A194: Grade 2H, Grade 2HM or Grade 7M	$\geq 0\text{ }^{\circ}\text{C}$ (32 $^{\circ}\text{F}$ )
	ASTM A320: Grade L7M	ASTM A194: Grade 2H, Grade 2HM or Grade 7M	$\geq -100\text{ }^{\circ}\text{C}$ (-148 $^{\circ}\text{F}$ )
ISO 15156 (all parts) SSC-resistant bolting (ASTM A193 L7M and ASTM A320 L7M) is not necessary for risers designed for ISO 15156 (all parts) sour service if the bolting is in an environment that would not allow $\text{H}_2\text{S}$ to concentrate. $\text{H}_2\text{S}$ can concentrate due to thermal insulation, flange protectors, or certain design features. Designers should note that bolting meeting ISO 15156 (all parts) requirements has derated tensile properties.			

For submerged applications, it should be verified that a possible dissolution of the zinc layer will not cause a significant loss of the bolt pretension.

### 7.3.6 Syntactic foam buoyancy

The type and quantity of materials to provide the required buoyant lift over the intended design life while accounting for the predicted degradation of buoyancy shall be selected.

Syntactic foam exhibits a progressive buoyancy loss resulting from water absorption over time. The rate of buoyancy loss (due to water absorption) is inversely proportional to the strength (and density) of the syntactic foam. Typically, heavier or stronger syntactic foam materials are required for service at greater depths and/or over longer periods in service.

Syntactic foam manufacturers maintain extensive data on the performance of specific materials in various densities at various depths, as well as extrapolation methods which permit the prediction of degradation of lift over extended time in service. Selection of particular syntactic foam should be based on test data.

## 7.4 Manufacture and fabrication

### 7.4.1 General

The manufacturer shall implement a system covering all aspects of quality control involving competent personnel with defined responsibilities.

The materials shall be identifiable during all stages of manufacturing and fabrication.

Dimensional tolerances and surface roughness assumed in the design analysis of the C/WO riser system shall be complied with during the manufacture and fabrication.

All defects and deficiencies shall be corrected before the structural components or equipment are painted, coated or made inaccessible.

The fabricator shall apply a weld numbering system for identification on all relevant drawings and as reference in all documentation.

All welded parts shall be post-weld heat-treated.

No welding is permitted in cold work areas.

#### 7.4.2 Welding procedure specifications

Welding procedure specifications shall be established in accordance with EN 288-2, ASME Boiler and pressure vessel code, Section IX or equivalent codes.

#### 7.4.3 Qualification of welding procedures

Welding procedures for steel shall be qualified in accordance with EN 288-3, EN 288-8, ASME Boiler and pressure vessel code, Section IX or equivalent codes.

Mechanical testing shall be performed as specified in ASME Boiler and pressure vessel code, Section IX, EN 288 (all parts) or equivalent codes and the additional requirements in this part of ISO 13628. The mechanical testing shall include the tensile properties, bend capacity, Charpy V-notch impact energy and hardness of the welded joints. Fracture mechanics testing should be considered if relevant, see 7.2.10.

The test weld shall be 100 % examined for both surface and volumetric defects with the relevant NDT methods. The soundness of the weld shall comply with the requirements given in Table 18.

#### 7.4.4 Qualification of welders and welding operators

Bracers, welders and welding operators shall be approved to ASME Boiler and pressure vessel code, Section IX, EN 287-1/ISO 9606-1, EN 1418 as applicable or equivalent codes.

#### 7.4.5 Welding consumables

Welding consumables shall 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 shall comply with a recognized standard. Welding consumable materials shall be selected such that the weld metal satisfies the specified mechanical properties as specified for the welding procedure specification.

Requirements should be stipulated for maximum hydrogen content of the weld metal. In the selection of welding consumables, consideration should be given also to corrosion properties and properties after post-weld heat treatment.

If sour service is specified, the chemical composition of welding consumables shall comply with ISO 15156 (all parts). Welding consumables for girth welds that produce a deposit containing more than 1 % Ni are acceptable after successful weld sulfide stress cracking qualification testing in accordance with ISO 15156-2:2003, Annex B.

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

#### 7.4.6 Forming of materials

Forming of plates, pipes, etc. shall be carried out according to a specification outlining the successive and controlling steps.

If cold forming is used during manufacturing or fabrication, the need for strain ageing testing shall be considered. Such testing shall always be performed if the total strain exceeds 5 %.

Hot forming shall be carried out within the minimum and maximum temperatures advised for post-weld heat treatment of the steel.

The specified mechanical properties shall be attained in the final worked condition.

#### 7.4.7 Material receipt, identification and tracking

All material shall be inspected for damage upon arrival. Quantities and identification of the material shall be verified. Damaged items shall be clearly marked and disposed properly.

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

A system that ensures correct installation of materials and traceability to the material certificates for all materials shall be established. The identification of material shall be preserved during handling, storage and all fabrication activities.

A riser joint tracking system shall be used to maintain records of weld numbers, NDT, pipe numbers, connector numbers, item numbers (if relevant), joint lengths and repair numbers. The system shall be capable of detecting duplicate records. The individual joints shall be marked in accordance with the established riser joint tracking system using a suitable marine paint.

#### 7.4.8 Cutting

Attention shall be paid to local effects on material properties and carbon contamination by thermal cutting. Preheating of the area to be cut may be required. Carbon contamination shall be removed by grinding off the affected material.

#### 7.4.9 Welding preparation and fit-up

Mill scale, rust, etc. shall be removed prior to welding, and the groove shall be dry and clean. The fit-up shall be checked before welding. The root gap and radial offset shall be as in the welding procedure specification.

Pipes and components should be fixed 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 shall be minimized, for example by rotating the pipe, until the best possible fit has been obtained.

Specifying tight dimensional requirements at pipe ends and tight fit-up tolerances should be considered for fatigue-sensitive locations.

Alignment of sections at edges to be butt-welded shall be such that the maximum offset does not exceed 10 % of the material thickness or maximum 3 mm (0,12 in). Larger misalignments may be accepted if the section ends are tapered by grinding or machining, with a slope not exceeding 1:4 provided the specified minimum wall thickness of the pipe is maintained.

The out-of-squareness shall be specified for connectors welded to pipes. Unless otherwise specified, the maximum allowable deviation from square shall be 1,5 mm (1/16 in) per 300 mm (12 in).

#### 7.4.10 Production tests

Production tests of weldments are subject to agreement. Each production weld test shall be carried out and documented as for the relevant welding procedure qualification test unless otherwise agreed.

#### 7.4.11 Welding performance

All welding operations shall be carried out in accordance with the appropriate welding procedure specification.

The weld reinforcement shall have a regular finish and shall merge smoothly into the base material without significant undercutting. All pipe butt welds shall be full penetration.

NOTE The quality of the root pass for single-sided welds significantly influences fatigue strength. One welding process that results in a good fatigue quality root is gas tungsten arc welding.

#### 7.4.12 Heat treatment after forming and welding

Heat treatment shall be performed in accordance with written procedures that describe the parameters critical for the heat-treatment process.

Equipment for the heat treatment, monitoring and recording of the thermal cycle shall be suitable for the heat treatment in question.

The temperature shall be measured on the thickness of the weld, unless otherwise defined in an approved procedure.

### 7.5 Visual inspection and non-destructive testing

#### 7.5.1 General

Methods of NDT shall be chosen with due regard to the conditions influencing the sensitivity of the methods. The method's ability to detect imperfections shall be considered for the material, joint 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 in order to ensure optimum probability of detection of harmful defects.

For detection of surface imperfections in ferromagnetic materials, MPI shall be preferred. For detection of surface imperfections in non-magnetic materials, either dye penetrant testing or eddy current testing is preferred. All MPI shall use the wet fluorescent method.

For detection of internal imperfections, either ultrasonic and/or radiographic testing shall be used. It may be necessary to supplement UT by radiographic testing or vice versa, in order to enhance the probability of detection or characterization/sizing of flaws.

UT is normally not applicable for thicknesses less than 10 mm (0,4 in). For such thicknesses, UT may be replaced with radiographic testing.

Radiographic testing is generally preferred for detection of volume imperfections. For thicknesses above 25 mm (0,984 in) radiographic testing should be supplemented by UT.

UT is preferred for detection of planar imperfections. Whenever determination of the imperfection height or length is necessary, e.g. as a result of fatigue or fracture assessment, UT is required.

Provided that forgings or extrusions have been subjected to 100 % examination by a method capable of detecting relevant internal imperfections, 100 % surface examination may only be necessary for final machined products like mechanical connectors.

Alternative methods or combinations of methods for detection of imperfections may be used, provided it is demonstrated that the methods are capable of detecting imperfections with an acceptable equivalence to the preferred methods.

The manufacturer shall present, for purchaser acceptance, detailed procedures including calibration for all visual examination and NDT. Visual examination and NDT of riser components and equipment shall be performed in accordance with and meeting the acceptance criteria of the code or standard used for design or manufacture of the item in question. Standard planar acceptance criteria used in common standards or codes should be evaluated prior to start of testing by using fracture mechanics and/or fatigue crack growth assessment and the criteria given in 7.5.4. Depending on design requirements, more severe acceptance criteria can be warranted.

Areas that are highly stressed in the thickness direction by the welding process shall be ultrasonically tested for laminar tearing.

UT may be carried out on raw materials prior to final machining.

All NDT shall be properly documented and identified in such a way that the tested areas can be easily retraced at a later stage.

### 7.5.2 Personnel qualifications

All visual inspection personnel shall be qualified and certified in accordance with recognized standards or have sufficient knowledge and experience.

Personnel responsible for all NDT activities shall be qualified according to ISO 9712 Level 3 or equivalent.

NDT operators shall be qualified according to ISO 9712 Level 2 or equivalent.

Operators holding Level 1 qualifications may carry out NDT under the direct supervision of Level 2 operators.

Operators simply producing radiographs, and not performing evaluation, do not require Level 2, but shall have sufficient training.

### 7.5.3 Visual examination and NDT of welds

Completed welds shall be subjected to visual inspection and NDT as manufacture and fabrication proceeds. The following shall be applicable to all welded joints.

- a) Welded joints shall be visually inspected before NDT is performed.
- b) Surface testing shall be performed on the outer surface.
- c) NDT of welds shall normally not be performed until 24 h 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 reduce harmful hydrogen content.
- d) If a welded joint is to be subsequently formed or heat-treated, the required NDT shall be carried out on the weld in the final condition.
- e) All welds shall be 100 % visually examined and 100 % examined for both surface and volumetric defects with the relevant NDT methods.
- f) Acceptance criteria for all NDT shall be in accordance with Table 18.
- g) All NDT and visual examination shall be documented such that the tested areas may be easily identified and such that the performed testing can be duplicated. The reports shall identify the defects present in the base weld area and state if the weld satisfies the acceptance criteria or not.

### 7.5.4 Weld surface imperfection acceptance criteria

The acceptance criteria given in Table 18 are applicable for weld surface imperfections in steels. Alternative evaluations ensuring an equivalent level of quality may be considered.

Special consideration shall be given to surface-breaking or near surface-breaking defects in the weld root area that can arise from lack of penetration or lack of side wall fusion of single-sided welds. These areas are inaccessible for visual examination or surface NDT inspection. UT from the outside diameter of the pipe should be considered to inspect the root of the completed weld for planar defects.

Table 18 — Acceptance criteria for weld surface imperfections

Type of defect	Acceptance criteria
Cracks	Not acceptable
Lack of fusion or incomplete penetration	Not acceptable
Undercut	Maximum depth 0,3 mm (0,012 in)
Surface porosity or exposed slag inclusion	Not acceptable
Weld reinforcement or internal protrusion	The height (crown) of reinforcement or internal protrusion of the weld shall not be below the surface of the pipe nor shall it be raised above the parent metal by more than 1,5 mm (1/16 in)
Roughness of weld	Weld surface shall be smooth, without sharp transitions
Misalignment	Maximum misalignment shall be 10 % of wall thickness or maximum 3 mm (1/8 in), whichever is smaller
Sharp edges	Maximum 2 mm (0,079 in) radius for coated items

## 7.6 Qualification of assembly (make-up) procedures and assemblers

Bolted flange connections shall be assembled by qualified bolted-connection assemblers.

Bolted connections shall be assembled and made-up in accordance with a written procedure, which has been qualified by test to achieve the specified minimum bolt preload without being overloaded. A general guideline on bolted flange joint assembly is given in ASME PCC 1-2000 [37].

Bolted-connection assemblers shall be qualified by test of a prototype assembly to demonstrate that they can apply the qualified procedure and achieve the specified minimum bolt preload without being overloaded.

## 8 Testing

### 8.1 General

Clause 8 establishes minimum requirements for testing the C/WO riser components and system.

### 8.2 Pretest requirements

Manufacturers and operations personnel shall review all test procedures. Procedures shall have a clear purpose/objective, prescribing a test method that will produce the desired output data and have clearly stated acceptance criteria. The test site shall have adequate room, facilities, calibrated equipment and safety arrangements.

### 8.3 Pressure testing

#### 8.3.1 General

Each pressure-containing item or component shall be subjected to a hydrostatic pressure test.

#### 8.3.2 Riser joints

Each assembled riser joint, including stress joints, slick joints, tension joints, etc. shall be subjected to hydrostatic pressure tests. Procedures for conducting these tests shall conform to the requirements for PSL 3 as described in ISO 10423, with the exception that riser joints may be painted or coated prior to testing.

The hydrostatic test pressure,  $p_{FAT}$ , shall in general be 1,5 times the design pressure. However, if capped ends are not applied during testing, i.e. the sealing against the end face of the pipe or joint is ensured by means of a ram, special considerations shall be made. In this case, the test pressure may be less than 1,5 times the design pressure in order to meet the requirement given in Table 13.

Pipes and pipe couplings manufactured in accordance with ISO 3183 (all parts), ISO 11960 and ISO 11961 might not require additional pressure testing provided that

- a) the mill pressure test was carried out with a pressure not less than 1,5 times the design pressure;
- b) pipes have not been subjected to any thermal or mechanical processing subsequent to the mill pressure test that reduces the pipe strength.

### 8.3.3 Components

Procedures for hydrostatic pressure testing of all pressure-containing components other than riser pipes, riser joints and riser joint connections shall conform to the requirements for PSL 2 or PSL 3 as described in ISO 10423, with the exception that parts may be painted prior to testing.

For all design pressure ratings, the hydrostatic test pressure shall be a minimum of 1,5 times the design pressure. The design factor shall be in accordance with Table 13.

Components having multiple bores or ports shall have each bore or port tested individually to verify that there is no intercommunication.

Gas testing is not a requirement. However, if specified by the purchaser, gas testing shall be performed in accordance with ISO 13628-4:1999, 5.4.6, or the manufacturer's written specification.

### 8.3.4 Workover control system and hydraulic equipment

Hydrostatic pressure testing of hydraulic control equipment, pressure monitoring lines, chemical injection lines, etc. shall be performed in accordance with ISO 13628-6:2000, 11.2.1.

## 8.4 Hydraulic cleanliness

The hydraulic fluid-wetted portions of the C/WO riser system components including the workover control system shall be prepared to a cleanliness level as defined in SAE AS4059. The selected level shall be clearly identified in the manufacturer's written component specifications and shall be demonstrated during testing of the system and components.

Typical cleanliness levels are SAE AS4059, Class 6B-F or SAE AS4059 Class 8B-F.

## 8.5 Qualification testing

The manufacturer shall complete qualification testing on any unproven component to be used in the C/WO riser system or provide suitable documented evidence of its performance from actual operational/field use.

Component qualification shall be carried out in accordance with the relevant standards and this part of ISO 13628 as listed in Table 2.

Qualification of components not covered by this part of ISO 13628 or other standards shall be verified against an agreed verification programme.

All qualifications shall demonstrate the following as applicable to the individual component:

- hydrostatic or gas pressure testing;
- pressure and temperature cycling tests;



- maximum (and combined) load testing;
- function testing;
- fatigue life testing;
- life cycle/endurance testing.

All testing should simulate expected working conditions or be more severe. Requirements for qualification of connectors are given in Annex I.

## 8.6 Riser equipment and FAT

The manufacturer shall complete a series of tests prior to supply of the C/WO riser system to confirm the correct functioning of each item as a unit and as part of the complete system. These tests shall have the following goals:

- ensure that all manufactured components meet the design specification;
- ensure that the individual components can be assembled into the final structure of components, in accordance with good and safe engineering practice;
- ensure that individual components of larger assemblies pass appropriate component testing and inspection requirements prior to assembly;
- ensure riser interchangeability, connection continuity and pressure integrity of each length of the C/WO riser assembled with a manufacture's standard end cap or connection fixture;
- ensure integrity and continuity of connections among assembled components;
- demonstrate that interfaces between assemblies can be made and broken without compromising integrity or safety.

Ensure that each pressure-containing item or component is subjected to a hydrostatic pressure test.

Drift testing of each riser component shall be conducted using a specified drift, see 5.3. Drift testing shall also be carried out on the combined made-up series of two or more components.

## 8.7 Workover control system and FAT

Functional testing of the workover control system shall be included in a FAT. The testing shall demonstrate the actions required to start-up and operate the functions of the workover control system. The following shall, as a minimum, be demonstrated:

- start-up of the system;
- air supply systems;
- power-up of electronics;
- hydraulic systems;
- accumulator systems;
- emergency shutdown systems;
- flow measurements;
- running tool and connector make-up;



- systems operational test;
- backup systems;
- hydrostatic pressure testing.

## 8.8 System integration tests

System integration testing should demonstrate the correct fit and operation of the overall equipment system.

The testing may be subject to the availability of a subsea tree, wellhead, BOP and tubing hanger equipment. If this equipment is not available, then the tests may be conducted using a suitable test jig that mimics the actual interface and can be used to confirm pressure integrity/operation of the interface.

All functions (e.g. valves, connectors) shall be operated via the workover control system.

Additionally, overhead space can limit stack-up height, such that the site integration test may have to be done in stages, e.g. the lower workover riser package and subsea tree, the riser stress joint and the emergency disconnect package. If space is available, a complete system stack-up including the stress joint and tree shall be conducted.

Pressure testing during integration testing shall be performed to verify sealing integrity between mating components. The test pressure shall be the design pressure of the system.

As a minimum, the following tests shall be carried out on the C/WO riser system after completion of satisfactory component testing and the FAT. Optionally, these tests may be included in the FAT:

### a) Lower workover riser package interface with subsea tree:

- 1) The lower workover riser package assembly shall be landed on the subsea tree to verify form, fit and function.
- 2) With the lower workover riser package connected to the subsea tree, a pressure test to verify pressure continuity of the bore shall be performed.
- 3) Relevant functional tests of all subsea tree and lower workover riser package functions shall be carried out.
- 4) With the lower workover riser package connected to the subsea tree, the production and annulus bores shall be drifted with the specified drift; see 5.3. Additionally, if plugs are used, they also shall be run through the lower workover riser package and subsea tree to assure proper function.

### b) Riser stress joint interface with lower workover riser package:

- 1) The stress joint with the emergency disconnect package connector shall be landed on the WCT-BOP to verify form, fit and function.
- 2) With the stress joint connected to the emergency disconnect package, a pressure test to verify pressure continuity of the bore shall be performed.
- 3) With the emergency disconnect package and stress joint connected to the WCT-BOP, the bores shall be drifted with the specified drift; see 5.3.
- 4) Connect and disconnect angles shall be simulated to verify proper function of the emergency disconnect package under riser load conditions. Interface shall be pressure tested before and after a disconnection.
- 5) The seals and sealing surfaces shall be thoroughly inspected after disconnection of the emergency disconnect package.

c) Landing string interface with wellhead or subsea tree:

- 1) With the landing string connected to the tubing hanger, a pressure test to verify pressure continuity of the bore shall be performed.
- 2) Relevant functional tests of all landing string functions shall be carried out.
- 3) Verification of any orientation system used shall be demonstrated.
- 4) With the landing string connected to the tubing hanger, the bores shall be drifted with the specified drift; see 5.3.

Verification of the workover control system shall be carried out in conjunction with the equipment to be operated and shall demonstrate

- that all control line interconnections are correctly routed;
- that any control logic (e.g. shutdown sequence) is operating in accordance with the requirements specified.

## 8.9 System pressure test

A system or field pressure test shall be performed on the riser system before the start of operations to ensure a fluid leak-tight riser. The test pressure shall be as a minimum the design pressure for the riser system.

## 9 Marking, storage and shipping

### 9.1 Riser joints

#### 9.1.1 General

The requirements given in Clause 9 are applicable for the following typical components: riser joints, slick joint, tension joint, stress joint, landing string, etc.

#### 9.1.2 Preservation

All joints shall be cleaned, dried and preserved in accordance with the manufacturer's written specification after pressure testing, prior to storage or shipment.

All end connectors shall be fitted with protection caps.

Damaged coatings shall be repaired prior to storage and shipment in accordance with the manufacturer's written specification.

#### 9.1.3 Loose seals and ring gaskets

Loose seals, stab subs and ring gaskets shall be individually boxed or wrapped for shipping and storage.

#### 9.1.4 Elastomers age control

The manufacturer shall document instructions concerning the proper storage environment, age control procedures, and protection of elastomers.

### 9.1.5 Hydraulic systems

All hydraulic ports and lines either assembled with, or integral with, the riser joints shall be flushed and filled in accordance with the manufacturer's written specification. Exposed hydraulic end fittings shall be capped.

### 9.1.6 Electrical systems

The manufacturer shall document instructions concerning the proper storage of all electrical cables and connectors.

### 9.1.7 Racking

All riser joints shall be stored and shipped in either baskets, containers or shipping racks.

The design or selection of baskets, containers and racks shall take into account the following.

- a) Riser joints shall be adequately supported and secured.
- b) Removal of riser joint protection caps shall be possible to allow for inspection.
- c) Maximum weight inclusive riser joints shall not exceed the lifting capacity of deck handling cranes on the vessel.
- d) Baskets, containers and racks shall be certified for offshore lifting in compliance with local legislation.
- e) Dedicated lifting slings shall be supplied, certified for offshore lifting in compliance with local legislation.
- f) Padeyes for sea fastening shall be provided. These padeyes shall be clearly marked with "SEA FASTENING ONLY".

### 9.1.8 Marking

Riser joints that meet the requirements of this part of ISO 13628 shall be marked with "ISO 13628-7".

Riser joints shall be supplied with permanent marking that includes the following:

- a) manufacturer's name or trademark;
- b) manufacturer's part number;
- c) manufacturer's serial number;
- d) date of manufacture;
- e) design pressure;
- f) design temperature;
- g) service condition [ISO 15156 (all parts) or non-ISO 15156 (all parts)].

In addition, riser joints shall be marked with a consecutive joint number or serial number to enable monitoring of joints during their lifetime. This marking shall be easily identifiable by vessel personnel, typically visual or electronic tagging.

## 9.2 Components

Shipping and storage requirements for equipment and components other than workover control system and riser pipes, riser joints, stress joints, slick joint, landing strings, etc. shall conform to the requirements in ISO 13628-4:1999, 5.6.

Where applicable, marking shall conform to the requirements in ISO 13628-4:1999, 5.5.

## 9.3 Workover control system and hydraulic equipment

Shipping and storage requirements for the workover control system and associated equipment shall conform to the requirements in ISO 13628-6:2000, Clause 12.

Where applicable, marking shall conform to the requirements in ISO 13628-6:2000, 12.1.

## 10 Inspection, maintenance, reassessment and monitoring

### 10.1 General

Riser shall be operated, maintained and inspected to maintain an acceptable safety level throughout the design life of the riser.

### 10.2 Inspection and maintenance

#### 10.2.1 General

Routine inspections shall be performed on the riser and control systems.

Inspections relating to areas such as the following may be necessary for risers and riser components:

- a) overloaded/permanently deformed riser string components;
- b) fatigue cracking (e.g. girth welds, connectors, anode attachment welds);
- c) leaks (loosening of mechanical connectors, seal ring damage);
- d) damage, e.g. dents, scratches, loosened or heavily distorted coating;
- e) internal and external wear;
- f) internal and external corrosion damage (e.g. girth welds, sealing faces);
- g) anti-corrosion/abrasion coatings;
- h) cathodic protection;
- i) marine growth.

The manufacturer shall establish type and frequency of inspections.

Parts that are damaged, repaired or particularly exposed and where failure will incur serious consequences shall be subject to particular attention in the planning of in-service inspection and maintenance.

### 10.2.2 Guidelines for inspection intervals

The following factors should be taken into account when determining inspection intervals:

- a) failure consequences;
- b) parts that are damaged, repaired or particularly exposed;
- c) specific intervals based on criteria discussed elsewhere in 10.2.2;
- d) present condition and service history, e.g. age, results of previous inspections, changes in design, operating or loading conditions or prior damage and repairs;
- e) redundancy;
- f) riser type and location, e.g. deep water or new design with few long-term operating examples.

The intervals given in Table 19 should not be exceeded unless experience or engineering analysis justifies longer intervals. In such cases, justification for changing guideline inspection intervals, based on the factors listed in 10.2.2, should be documented and retained by the operator.

Risers should be inspected for fatigue cracks in accordance with the principles given in 6.4.9.

**Table 19 — Guideline for inspection intervals**

Component	Inspection type	Interval
Areas of known or suspected damage	As appropriate	After exposure to design event
Components retrieved to surface	As recommended by manufacturer	After disconnect

Equipment consumables such as seals, lubrication, periodically disconnected components and paint should generally be inspected or replaced on a scheduled basis. Moreover, the equipment should be designed to facilitate these maintenance operations. Manufacturer-supplied data should include recommended maintenance operations and intervals.

### 10.3 Reassessment of risers

An existing riser shall undergo an integrity assessment to demonstrate fitness for purpose if one or more of the following conditions exists:

- a) extension of planned design life beyond the original design life;
- b) damage or deterioration to a riser component;
- c) change of use that violates the original design or previous integrity assessment basis;
- d) departure from the original basis of design, e.g. by
  - change in environmental data or relocation;
  - change in support vessel;
  - change in internal fluid;
  - change in top tension.

Assessment of existing risers should be based on the most recent information of the riser.

## 10.4 Monitoring

A detailed log or fatigue monitoring programme should be maintained that records the time duration and sea-state for each mode of operation of the riser. This information combined with fatigue or fracture mechanics analysis should be used to determine the need for riser joint inspections.

The riser's internal and external operating condition should be monitored to reveal whether design conditions have been exceeded. This monitoring should include the recording of riser response and tension as well as the composition, pressure and temperature of the riser contents.

A C/WO riser monitoring system is not mandatory within the scope of this part of ISO 13628, but it is useful for setting and maintaining precise tension, for monitoring riser dynamics and for design verification. The riser monitoring system may also be used to estimate riser accumulated fatigue damage, optimum vessel positioning and time-to-go estimates.

## 11 Documentation

### 11.1 Purpose

Clause 11 specifies the requirements for documentation that the manufacturer shall have available for the purchaser.

### 11.2 General

Sufficient documentation shall be available to demonstrate that the riser system including equipment and components complies with the requirements of this part of ISO 13628.

Documentation for all work performed shall, as far as practical, be concise, clear, reproducible, retrievable, non-voluminous, and should include all relevant information for all relevant phases of the lifetime of the C/WO riser system (i.e. design, manufacturing, fabrication, operation, storage); see also 4.16.

Design documentation shall include methods, assumptions, calculations and design requirements. Design requirements shall include, but not be limited to, those criteria for size, load and load combinations including preload, manufacturing tolerances, surface roughness of sealing surfaces, material, environment and other pertinent requirements upon which the design shall be based.

The manufacturer shall have available for the purchaser the following documents at the specified times:

- |                                   |                                   |
|-----------------------------------|-----------------------------------|
| a) design basis:                  | prior to riser design;            |
| b) design analysis:               | prior to manufacture;             |
| c) manufacturing and fabrication: | prior to manufacture/fabrication; |
| d) as-built documentation:        | with delivery;                    |
| e) design and fabrication résumé: | with delivery;                    |
| f) user and operation manual:     | prior to delivery.                |

In addition, the user/operator shall maintain a condition résumé during operation.

### 11.3 Design basis

A design basis document shall be established in the initial stages of the design process to document the basis requirements and criteria to be applied in the design of the C/WO riser system. It shall reflect the requirements in this part of ISO 13628, the purchaser's specification (see also Annex F) and the manufacturer's own

requirements. A summary of those items normally to be included in the design basis document is included below:

- a) overall riser system description;
- b) general design requirements;
- c) applicable codes, standards and regulations;
- d) functional requirements and operational requirements;
- e) internal fluid data including design pressure, design temperature and fluid density;
- f) external environmental data;
- g) vessel data;
- h) interface requirements;
- i) equipment/component performance data (e.g. tension capacity at design pressure);
- j) material selection including corrosion protection;
- k) inspection and maintenance philosophy;
- l) design load case definitions for all relevant temporary and operating design conditions;
- m) design criteria for relevant failure modes;
- n) analysis procedures for design analysis including main analysis parameters;
- o) description of safety joints (weak links) including reasons why using safety joints (weak links).

## 11.4 Design analysis

### 11.4.1 Pipe sizing including pipe and girth weld performance data

The following data shall, as a minimum, be provided for pipes and girth welds:

- a) explanation of notations;
- b) applicable codes, standards and regulations;
- c) calculation input data including
  - material details including yield strength, tensile strength and elongation after rupture,
  - design pressure and design temperature,
  - burst design factors,
  - drift diameter and drift clearance,
  - pipe ovality and wall thickness tolerances,
  - pipe/pipe or pipe/connector girth weld eccentricity,
  - weld root bead height,
  - corrosion or other allowances where applicable;

- d) calculation of minimum inside diameter;
- e) calculation of burst minimum thickness;
- f) selection of pipe wall thickness and outside diameter;
- g) the pipe structural capacity for single loads and limiting load envelopes; see 11.5.1;
- h) the girth weld SCF at inside and outside diameter.

#### 11.4.2 Global analysis

The global design analysis documentation should include the following items:

- a) summary including concise table with design check key results and illustrations in figures;
- b) explanation of notations;
- c) applicable codes, standards and regulations;
- d) introduction including the objective of the document and a brief description of the riser system and each component including drawings;
- e) design basis if not included in a separate document, see 11.3;
- f) calculation input data, including material details, assumptions for calculations and details of the computer programme;
- g) reference number of the standard/guideline/textbook including the reference number for the equations;
- h) full traceability of the calculations performed;
- i) analysis model validation (effective tension distribution, vessel motion RAOs and mode shape/eigenvalues);
- j) riser space-out calculations;
- k) riser stick-up calculations;
- l) graphs for the geometric model, including boundary conditions;
- m) results presented in a clear and concise manner, especially key results, and an evaluation of the results in the light of the failure modes and assumptions made in the analysis procedure/methods. Utilization ratios along the riser for the component for the relevant failure modes with number on figures should be provided;
- n) operating envelopes for normal, extreme, testing and accidental conditions;
- o) if relevant, component and interface design loads, e.g. loads on subsea tree and wellhead by the CWO riser, with careful documentation of sources and assumptions made;
- p) assumptions made with respect to handling, inspection and maintenance of the riser system in service.

#### 11.4.3 Drawings

Drawings shall be provided for the fabrication and construction of the riser system, including but not limited to

- a) vessel layout drawings with risers;
- b) riser fabrication drawings.



## 11.5 Connector documentation

### 11.5.1 Performance data summary report

A performance data summary report for each connector in the CWO riser system shall be prepared. It shall include the following information, as applicable:

- a) a description of how the connector works listing the design features and benefits of the threads, seals, shoulder and body configuration including connection axial and bending load transmission and locking systems. Examples of locking systems can include threads, friction, grip, forged, balls/forged, flanged or machined;
- b) design criteria with reference to applicable codes, standards and regulations for
  - strength and leak-tightness for normal, extreme, testing, accidental load conditions based on minimum specified strength/preload values,
  - safe break joints (weak links) based on maximum specified strength values, and
  - maximum cyclic peak stress ranges, i.e. SCFs/stress distributions for fatigue assessment;
- c) geometry of connector, including tolerances, roughness and treatment(s) of sealing surfaces, mass, material properties and the product designation for the connection including references to drawings and material specifications;
- d) a representative cross-section diagram of the connection identifying the weak (limiting) sections (planes) or components for tension, compression, internal pressure, external pressure, bending, torsion and shear, where applicable, in addition to localization of regions with maximum cyclic peak stress ranges;
- e) connection structural capacity, separation limits of preloaded surface and sealing (leak-tightness) integrity for single loads only, i.e. tension, compression, internal pressure, external pressure, bending, torsion and shear;
- f) load envelopes or resistance charts defining the various combinations of loads, temperatures and preloads which define the sealing (leak-tightness) integrity and structural capacity limits for normal, extreme, testing and accidental conditions, in addition to weak link load envelopes and separation limits of preloaded surfaces;
- g) documentation of the actual failure loads causing loss of sealing integrity or a structural failure (axial separation, rupture or hoop buckling) whenever data are available and compared to code allowable loads;
- h) SCFs referred to connecting pipe size for pipe-to-connector weld and the locations of the highest stress range in the connector (bolt cyclic stress including bending axial). If the SCF varies with load or preload, this variation shall be documented. SCFs introduced by the connector in the connecting pipe girth weld location (both inside and outside diameter) without any eccentricity shall also be documented;
- i) complete make-up/break-out parameters listing the thread compound type, coverage and application method, along with make-up speed, required shoulder torque values and minimum and maximum final torque values and make-up loss. The maximum allowable misalignment for connection make-up;
- j) moment-tension-release angle capabilities of emergency disconnect package connector and tree running tool connectors;
- k) references to design calculations and tests performed.

A connector resistance for combined loading may be established using one of the following methods:

- a resistance (load envelope) chart;
- a resistance ellipse based on equivalent tension and net internal/external pressure;
- a von Mises equivalent stress envelope.

Resistance charts or load envelopes shall be given for the relevant design factors and are the preferred method for presenting capacities. It should be noted that the latter two methods for establishing the connector resistance are normally conservative for the bending moment resistance and should be avoided in order to perform consistent assessments with the pipe resistance.

Figure 11 illustrates a linear resistance chart. As an alternative to the resistance chart, the connector resistance may be given by effective tension-moment-pressure ( $T_e$ - $M_{bm}$ ) interaction equations in the format of Equation (29):

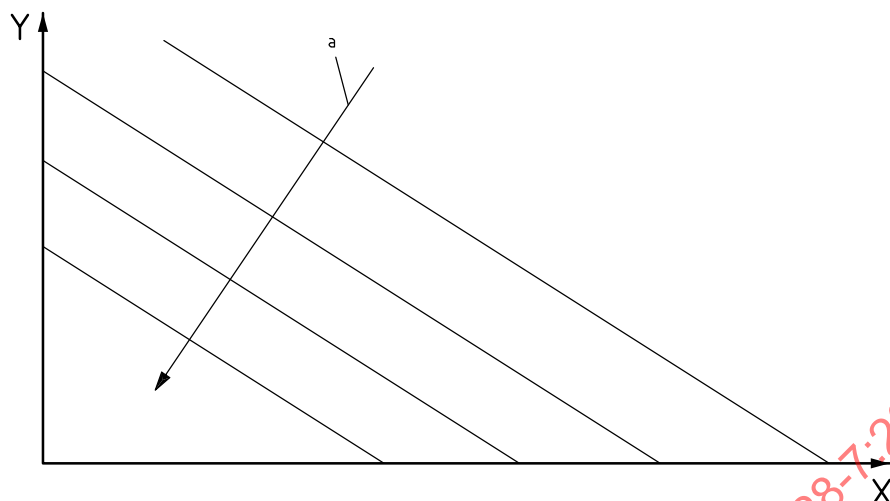
$$\left( \frac{T_e}{T_c} + \frac{M_{bm}}{M_c} + \frac{p_{int} - p_o}{p_{ec}} \right) \times \frac{1}{F_d} \leq 1 \quad (29)$$

where

- $T_e$  is the effective tension;
- $T_c$  is the single load ultimate tension capacity;
- $M_{bm}$  is the bending moment;
- $M_c$  is the single load ultimate bending capacity;
- $p_{int}$  is the internal pressure;
- $p_o$  is the external pressure;
- $p_{ec}$  is the single load ultimate pressure capacity due to end cap effect;
- $F_d$  is the design factor; see Table 11.

Several interaction equations may be provided for one connector in case a simple linear relation as suggested above may not be possible due to limited validity ranges of resistance parameters applied.

NOTE Examples of resistance (capacity) charts can be found in API Bull 6AF<sup>[4]</sup>, API Bull 6AF1<sup>[5]</sup> and API Bull 6AF2<sup>[6]</sup>; for static loading conditions, see 6.6.7.

**Key**

X effective tension,  $T_e$   
 Y bending moment,  $M_{bm}$

a Increasing pressure.

**Figure 11 — Component resistance chart**

## 11.5.2 Operating and maintenance manuals

### 11.5.2.1 General

The manufacturer shall provide operation and maintenance manuals that shall include, as a minimum, the information listed in 11.5.2.

### 11.5.2.2 Equipment description

A written description, drawings and applicable schematics shall be provided for the riser connector and interfacing equipment as follows:

- the riser connector including all parts;
- riser handling tools;
- all make-up, break-out and preload tools;
- riser connector protectors.

### 11.5.2.3 Guideline for connector use

The following information shall be addressed:

- use of the handling tool and its interface with the connector;
- connector make-up and break-out including, if applicable, detailed procedure for correctly applying preload.

#### 11.5.2.4 Maintenance instructions

The following information shall be provided:

- graphic chronological schedule of routine maintenance tasks;
- sample maintenance forms or check lists as necessary;
- log sheets for recording cumulative use of each riser connector;
- storage instructions and replacement schedule for rubber goods, elastomers and other consumables;
- specified lubricators, corrosion inhibitors, etc.;
- procedure and schedule for fatigue crack inspections. Manufacturers shall identify highly stressed areas to be inspected.

#### 11.6 Manufacture and fabrication

The following information shall be prepared prior to start of or during manufacture of pipes, components, equipment, structural and other fabricated items:

- a) material and manufacturing specifications;
- b) manufacturing procedure specification;
- c) quality plans;
- d) welding procedure specifications/qualification records if relevant;
- e) NDT procedures;
- f) manufacturing/fabrication procedures;
- g) manufacturer's/fabricator's quality system manual.

#### 11.7 As-built documentation

The as-built documentation shall include, as a minimum, the following:

- a) purchase order reference number;
- b) equipment descriptions;
- c) references to design specifications and drawing;
- d) material certificates;
- e) dimension control measurements;
- f) FAT results;
- g) all non-conformances identified during manufacture, and repairs performed;
- h) welding procedure specifications and qualifications;
- i) welder qualification records;
- j) weld map;

- k) NDT operator qualifications and NDT test records;
- l) heat treatment records.

### 11.8 Design and fabrication résumé

A design and fabrication résumé shall be prepared to provide information for operation of the C/WO riser system and for plans for periodic inspections. The design and fabrication résumé shall be considered as a condensed summary document for efficient retrieval of essential information from design, fabrication and testing phases. The résumé shall reflect the as-built status.

The design and fabrication résumé shall

- a) offer a general description of the C/WO riser system;
- b) provide a summary of all design and fabrication including responsibility, requirements, verification activities, deviations, detail design, design basis, and critical areas, with references to underlying detailed documentation;
- c) provide recommendations, requirements and sufficient information for the operation, in-service inspection, storage, integrity evaluation and maintenance activities throughout the lifetime of the C/WO riser system. Of special importance is identification of components with low-fatigue lives and components with high structural strength utilization ratios.

### 11.9 Installation and operation manual(s)

Installation and operational requirements shall be documented in a riser installation and operation manual(s). The manual(s), which should be prepared jointly by the designer and the operator, defines how to safely install, operate and maintain the riser and its component systems.

The manual(s) shall contain, as a minimum, the following information:

- a) step-by-step procedure for handling, transportation, running/retrieving, operating, preservation and storage of the riser system;
- b) step-by-step procedures for riser disconnects and hang-offs;
- c) operating limits for each mode of operation. Operating limitations shall be specified by the manufacturer for each of the riser operating modes. Limitations should be presented in tabular and/or graphical form or as a riser management programme;
- d) inspection and maintenance procedures for each component;
- e) manufacturer's drawings of the riser system components outlining critical dimensions, masses and part numbers of various components;
- f) recommended spare parts list.

The following information shall be prepared prior to start of installation/operation:

- FMECA and HAZOP studies by the operator;
- installation and testing specifications and drawings;
- riser installation and operation manual(s);
- contingency procedures; and
- contractor's quality system manual.

### 11.10 Condition résumé

Any changes to the C/WO riser system after fabrication will be a part of operation history and shall be reflected in a condition résumé. A condition résumé shall be prepared on regular basis, i.e. annually.

Necessary data shall be logged during the life cycle for documenting and analysis of fatigue status of the C/WO riser and summarized in the résumé. The log should typically include running sequence of joints, riser configuration, field data (water depth, pressure, density, etc.), vessel data including top tension and the length of time and sea-state for each mode of operation. This log should be reviewed regularly to assess the need for fatigue crack inspections.

It is the user's responsibility to establish and maintain the condition résumé.

### 11.11 Filing of documentation

Maintenance of complete files of all relevant documentation during the life of the riser system is the responsibility of the purchaser/user.

The engineering and as-built files shall, as a minimum, comprise the documentation from design, fabrication, installation and commissioning.

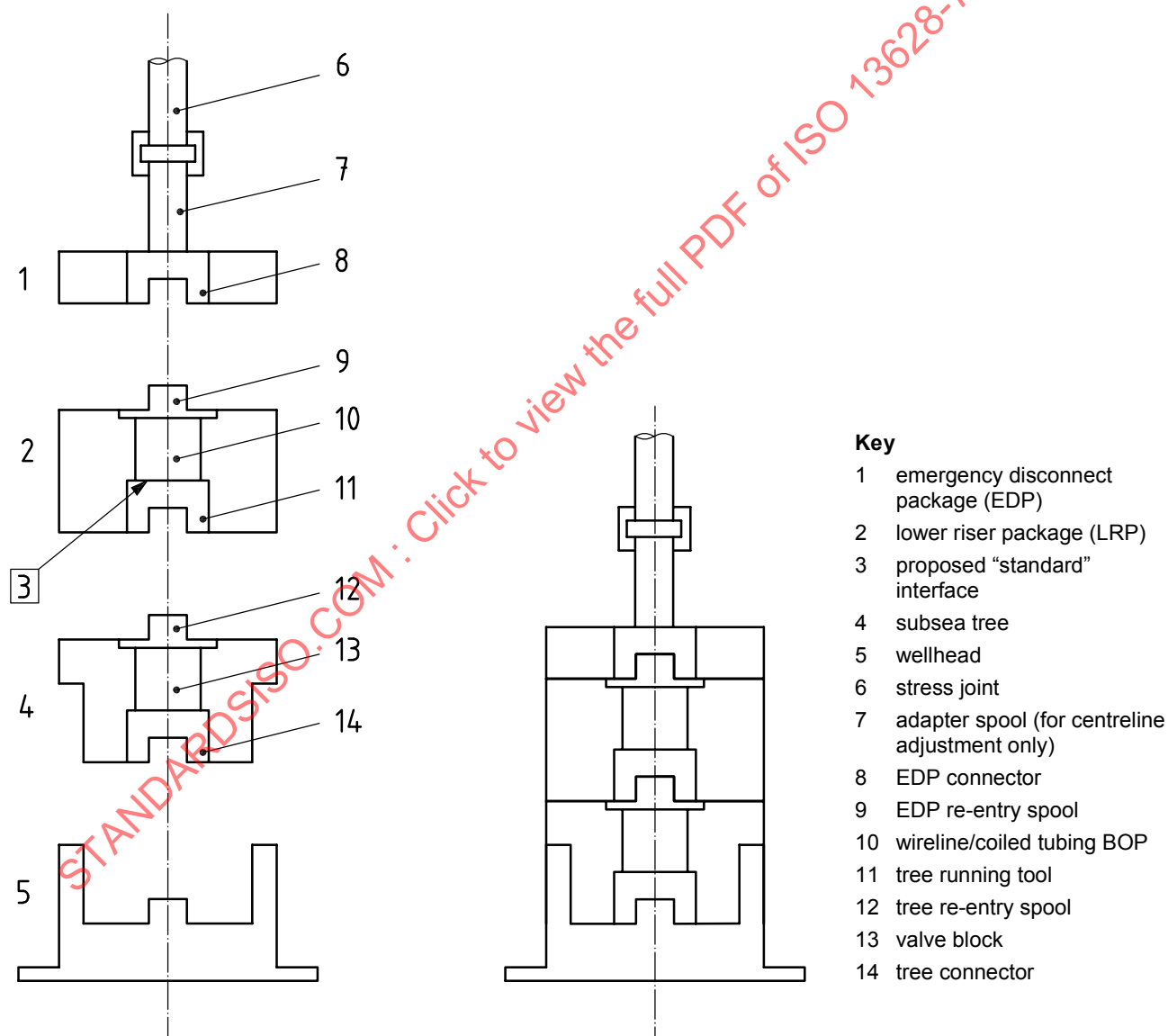
The engineering documentation shall be filed by the purchaser/user or by the engineering contractor for a minimum of 15 years. Design basis and key data for the riser system shall be filed for the lifetime of the system. This includes documentation from design to start-up and documentation from possible major repair or reconstruction of the riser system.

Files to be kept from the operational and maintenance phases of the riser system shall, as a minimum, include final in-service inspection reports from start-up, periodical and special inspections, condition monitoring records, and final reports of maintenance and repair.

## Annex A (informative)

### Standardization of the C/WO riser interface (vertical tree)

The industry has recognized the importance of sharing or renting of C/WO riser systems and, consequently, has proposed standardizing a common interface that allows risers to be used with several different tree systems. The proposed interface is between the top of the tree running tool and the bottom of the WCT-BOP; see Figure A.1.



**Figure A.1 — Location of proposed standard C/WO riser interface**

A 346 mm (13 5/8 in), 69,0 MPa (10 000 psi) flange in accordance with ISO 10423 is proposed as the interface connection. The seal mechanism is proposed to be a stab sub/pocket using a primary metal-to-metal seal with an elastomeric back-up. An environmental seal should be provided to isolate the stab subs. This environmental seal is proposed to be a BX seal ring/groove. The BX seal ring size is provided in Table A.1.

**Table A.1 — Centre distances of bores for vertical riser/tree running tool interface**

Valve bore sizes mm × mm (MPa) [in × in (psi)]	Bore centre to bore centre <sup>a</sup> mm (in)	Large bore centre to flange centre <sup>b</sup> mm (in)	Small bore centre to flange centre <sup>c</sup> mm (in)	Flange and BX ring size mm (MPa) [in (psi)]
103 × 52 (34,5; 69,0) [4 1/16 × 2 1/16 (5k; 10k)]	127,0 (5,000)	41,28 (1,625)	85,72 (3,375)	346 (69,0), BX-158 <sup>d</sup> [13 5/8 (10k)], BX-158 <sup>d</sup>
130 × 52 (34,5; 69,0) [5 1/8 × 2 1/16 (5k; 10k)]	136,52 (5,375)	47,62 (1,875)	88,9 (3,500)	346 (69,0), BX-159 [13 5/8 (10k)], BX-159
<sup>a</sup> See "A", Figure A.2. <sup>b</sup> See "B", Figure A.2. <sup>c</sup> See "C", Figure A.2. <sup>d</sup> A BX-158 ring is used to minimize separation load.				

At this time, two riser sizes have been proposed to incorporate the standard interface: a 127 mm × 50,8 mm (5 in × 2 in), 69,0 MPa (10 000 psi) system, and a 101,6 mm × 50,8 mm (4 in × 2 in), 69,0 MPa (10 000 psi) system. The proposed bore centres and offset dimensions are shown in Figure A.2 and Table A.1.

A transition or adapter spool may be required to allow riser usage with different tree manufacturers since stab sub designs are generally proprietary.

Other bore centres and offsets can be used. However, it is recommended that specifications for any new C/WO riser system be reviewed with the manufacturer for dimensional confirmation with any industry interface standards that are in existence or evolution.

Use of the proposed standard interface is only recommended if

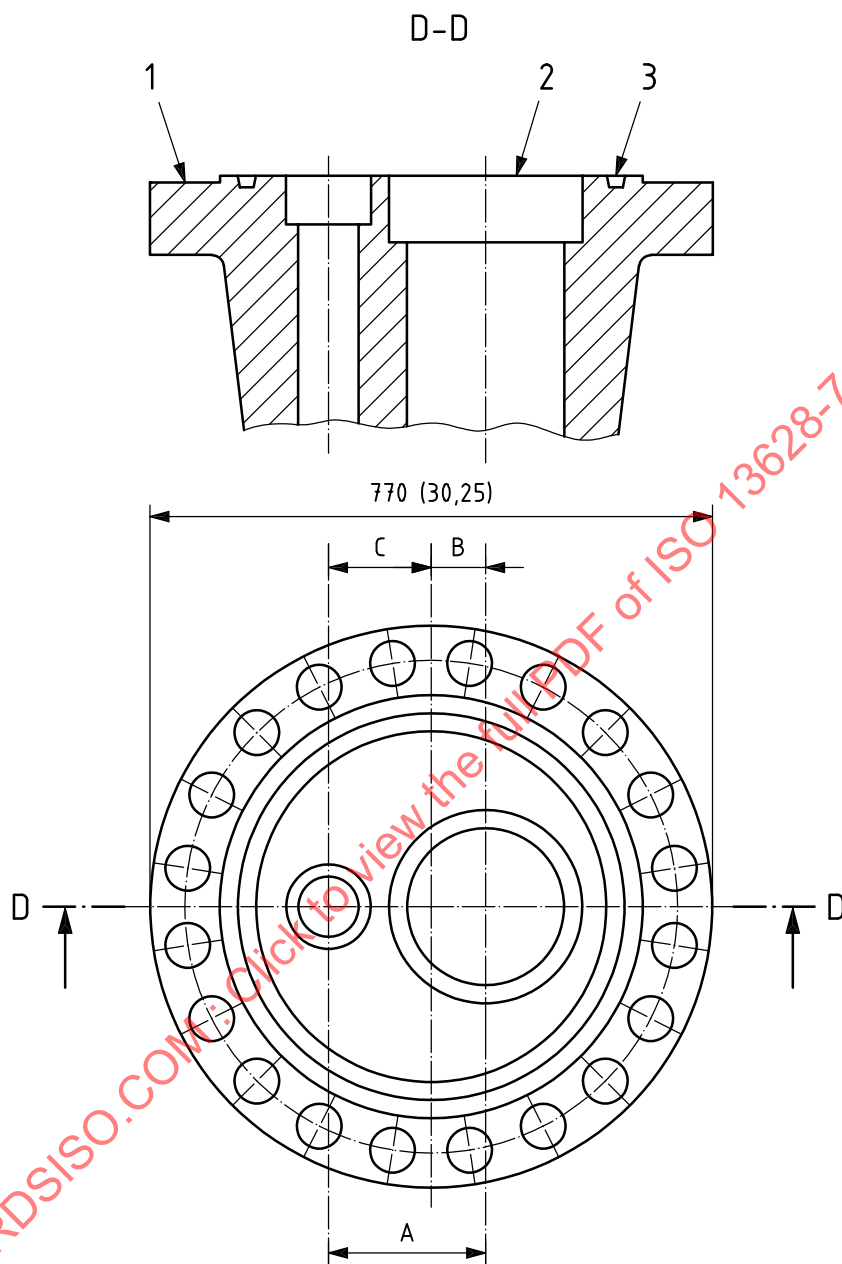
- the combined load effects for the applicable load combinations defined in 6.3.3 do not exceed the capacity (see 11.5.1) of the proposed flange;
- design, manufacture and make-up of the proposed flange ensures face-to-face contact up to normal operating loading conditions; see 6.6.7.

**NOTE** The BX-158 seal ring used for the 101,6 mm × 50,8 mm (4 in × 2 in) interface is smaller than normally used for a 346 mm (13 5/8 in), 69,0 MPa (10 000 psi) flange. The smaller ring reduces the separation load, which is critical in the deeper water riser applications where bending loads are already significant. In the case of the 127 mm × 50,8 mm (5 in × 2 in) riser interface, the BX-159 ring is the smallest ring possible.

Risers having bore diameters larger than the tree bores may be used in conjunction with the smaller tree bores as long as the mating bores are arranged so as to allow passage of all downhole tools that are used in conjunction with the riser system [i.e. a 101,6 mm × 50,8 mm (4 in × 2 in), 69,0 MPa (10 000 psi) riser could be used with a 76,2 mm × 50,8 mm (3 in × 2 in) tree having the same bore centres as the 101,6 mm × 50,8 mm (4 in × 2 in), 69,0 MPa (10 000 psi) riser interface].



Dimensions in millimetres  
(Dimensions in inches)



#### Key

- 1 346 mm - 69,0 MPa (13 5/8" - 10 000 psi) flange
- 2 seal pocket dimensions to be specified by manufacturer
- 3 BX-groove as required
- A, B, C see Table A.1

**Figure A.2 — Proposed standard interface detail 364 mm (13 5/8 in) - 69,0 MPa (10 000 psi) 6BX**

## **Annex B** (informative)

### **Operational modes and global riser system analysis**

#### **B.1 Introduction**

Annex B provides guidelines for handling and use of the C/WO riser system in addition to guidance on global riser system analysis by finite element based computer codes.

Typical data needed for global C/WO riser analysis are addressed in Annex F. General description of global riser analysis can be found in API RP 2RD [2].

#### **B.2 Operation modes**

##### **B.2.1 Tree mode**

###### **B.2.1.1 Racking**

During racking and handling of riser joints and surface tree tension frames, consideration should be given to structural strength. The manufacturer should determine the allowable sea-states and vessel motions, when these operations can be safely conducted. Detailed procedures should also be provided giving details of external support equipment required for the operation (i.e. tuggers' wire locations and minimum tugger tensions, derrick manipulator arms, lifting slings, etc.).

###### **B.2.1.2 Running and retrieval**

Running and retrieval typically covers the following sequences of operation:

- running through the splash zone;
- intermediate phases during running;
- landing on wellhead.

Running of the emergency disconnect package, lower riser package and tree suspended on the riser through the splash zone and at intermediate water depths can be considered as a special case of riser hang-off. The areas of concern are usually impact with the vessel (i.e. moonpool or pontoon bracing) and allowable loads in the riser. Consideration should be given to running the emergency disconnect package, lower riser package and tree stack as quickly as possible by running two or more previously made-up riser joints. Moonpool pendulum motions can also be limited by running the stack on a moon-pool cursor system. Operating limitations for these phases of operation should normally be specified in terms of allowable wave height, wave period and current profile.

During running and prior to landing of the riser string, it is normal practice for the workover vessel to be offset from the target area as a precaution in case of loss of the riser string. Offset upstream of the dominant current direction minimizes the landing angle of the riser. Typical operating limitations in terms of the following parameters should be specified:

- maximum landing speed;
- maximum vessel offsets;

- maximum current return period;
- maximum sea-state;
- maximum set-down weights (i.e. minimum tension or maximum compression in riser end);
- maximum landing and connection angles.

Following landing and connection, the riser tension should be increased to the specified operating tension as soon as possible.

#### **B.2.1.3 Connected conditions**

For connected conditions in the tree mode (normal operation and shut-in modes), it is current practice to present operating limitations in terms of operating envelopes, which are a function of vessel offset and wave height. The operating envelopes should be determined for realistic combinations of current, metocean and riser bore fluid conditions. Factors that can influence the operating envelopes are the following:

- allowable load levels for the mode of operation;
- internal fluid conditions, pressure, mass of internal fluid or tool strings;
- riser tension;
- clearance to vessel structures (moon-pool, pontoon bracing, etc.);
- current profile;
- water depth;
- wellhead inclination;
- vessel heading and motions.

#### **B.2.1.4 Disconnect**

Riser disconnect can either be a planned or an emergency disconnect. For planned disconnects, consideration should be given to

- minimizing riser tension to prevent riser recoil and damage to the riser and vessel;
- vessel offset such that riser angle prior to disconnect is minimized and, following the disconnect, the direction of motion of the riser is away from adjacent structures;
- following disconnect, the riser string should be raised to prevent impact with subsea structures and seabed.

Operating limitations for planned disconnect are typically the same as for landing of the riser.

For an emergency disconnect, the following workover control system emergency shutdown and emergency quick-disconnect sequence should be performed:

- a complete shutdown of all process equipment;
- closure of all subsea and riser valves;
- disconnection of the emergency disconnect package connector.

The moment-tension-release angle capabilities of the emergency disconnect package connector can limit disconnection operations. Following an emergency disconnect, the riser should be fully inspected. The manufacturer should specify type and scope of the inspection.

#### B.2.1.5 Hang-off

When the riser is in hang-off mode, vessel offset is generally not a governing parameter. Allowable loads and impact with the vessel are of concern. Operating limitations for hang-off conditions are typically presented in the form of operating envelopes, which are a function of wave height and wave period. When determining allowable sea-state conditions, consideration should be given to the following:

- length of suspended riser;
- method of hang-off (i.e. free hanging from a rotary spider or restrained to rotate by elevator bails of surface tree tension frame);
- vessel heading and motions;
- slack or tensioned guidelines or guideline-less.

#### B.2.1.6 Operating envelope

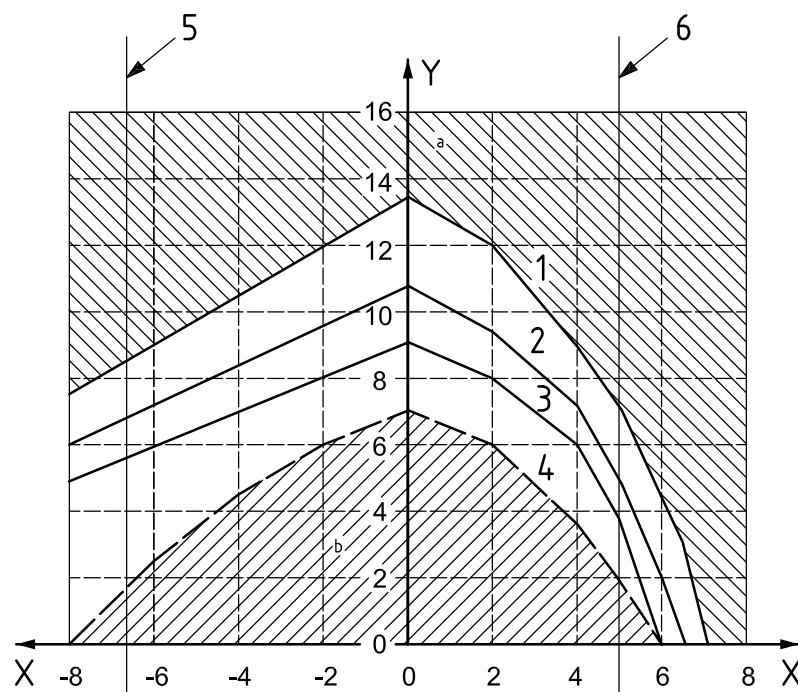
A useful form of the riser analysis results is the operational limits (operating window) which should be referred and used by personnel to maintain the C/WO riser within its parameters while in offshore use. The riser operating limits should be determined by the designer and may be presented as graphs of significant wave height against mean vessel offset from wellhead extension. A typical diagram for a connected C/WO riser is shown in Figure B.1, which shows the range of acceptable vessel offsets for a set of operating conditions. Values below the curve represent safe operation; i.e. the failure modes are met. Outside the curve, the load effect acting on the riser may exceed limits on strength and stroke clearance and consideration of remedial or disconnect operation is necessary. The curve provides a range of significant wave heights, spectral peak periods and vessel offset conditions, which can easily be monitored. A unique curve is generated for a unique set of vessel, water depth, current profile, top tension, internal fluid density and surface design pressure.

The parameters used for the setting of operating shown in Figure B.1 are functional and environmental. To ensure for safe operation these parameters should be monitored. These parameters may be monitored directly or indirectly. The method of monitoring and accuracy of measurement of these parameters should be accounted for in the setting of operating limits. Operating limits based on direct monitoring of environmental parameters (e.g. wave height, current and offset) is less restrictive than indirect monitoring (e.g. vessel heave, pitch, roll, etc.).

Riser operating limits in connected mode are affected by limiting factors such as strength, riser stroke, riser clearance, maximum allowable emergency disconnect package angle for disconnect and vessel drift considerations. Operating limits should be defined for each of these factors. The overall riser operating window, shown in Figure B.1, is the result of considering the combined effect of all limiting factors. In the example shown in Figure B.1, the critical limiting factors are the top drive motion compensator stroke limit and EDP disconnect angle.

Installation analysis often includes evaluation of strength limits and riser/moonpool clearance as well as requirements for vessel positioning when stabbing at the seabed. Different elevations should be checked. All conditions during installation should be considered, e.g. connector make-up during running with the riser suspended at the drill floor and lowering of the riser (modelled with a lateral constraint at the drill floor but free to rotate).

During storm conditions, or following emergency disconnect, the emergency disconnect package may be pulled clear of the subsea assembly and the vessel moved off position. During hang-off, the riser may be held rotationally fixed at the drill floor or be able to rotate (i.e. gimballed spider or special hang-off structure).



Location: Field .....

Vessel: Vessel name .....

Riser: Designation .....

Mode: Tree mode .....

Top configuration: Tension frame.

Top tension:

    Motion compensator: ..... kN (lbf)

    Tension ring: ..... kN (lbf)

Bottom tension:

    Bottom of EDP: ..... kN (lbf)

Pressure: ..... MPa (psi)

Fluid density: ..... s.g.

Wave direction: Head .....

$T_p$  range: 90 % confidence interval

Current: ..... year return period

Current direction: Head .....

Wellhead inclination: ..... °

#### Key

- X vessel static offset,  $L_{SO}$ , from wellhead extension, measured as percentage of water depth, positive in direction of current
- Y significant wave height,  $H_s$
- 1 strength limit: accidental
- 2 strength limit: extreme
- 3 strength limit: normal
- 4 stroke limit: motion compensator
- 5 EDP angle limit: upstream
- 6 EDP angle limit: downstream
- a Unsafe operating area.
- b Safe operating area.

Figure B.1 — Typical operating envelope (window) — Tree mode

### B.2.2 Tubing hanger mode

#### B.2.2.1 Running/retrieval and landing

Consideration should be given to the running/retrieval and landing of the following assemblies:

a) vertical tree:

- for a killed well, tubing, tubing hanger, tubing hanger running tool, BOP adapter joint, completion riser,
- for a live well, tubing, tubing hanger, tubing hanger running tool, BOP adapter joint/subsea test tree, retainer valve, completion riser;

b) horizontal tree:

- tubing, tubing hanger, tubing hanger running tool, subsea test tree, retainer valve, completion riser.

To prevent damaging the landing string components, it is normal practice:

- to space out the riser string such that the tubing hanger is above the drilling riser lower flex joint while making up the last assembly (i.e. slick joint and surface tree);
- to land out the tubing hanger in the BOP in a single operation.

To comply with these requirements, there needs to be sufficient lifting height in the derrick. It can be seen from Figure B.2 that the required lifting height is a function of the BOP height, required stick-up after landing, in addition to the other factors listed in Table B.1.

Operating limitations should be determined for running of each assembly. Operating limitations are usually specified in terms of allowable top and bottom drilling riser ball/flex joint angles. Passage of components in the stack with the highest bending stiffness is usually the most critical.

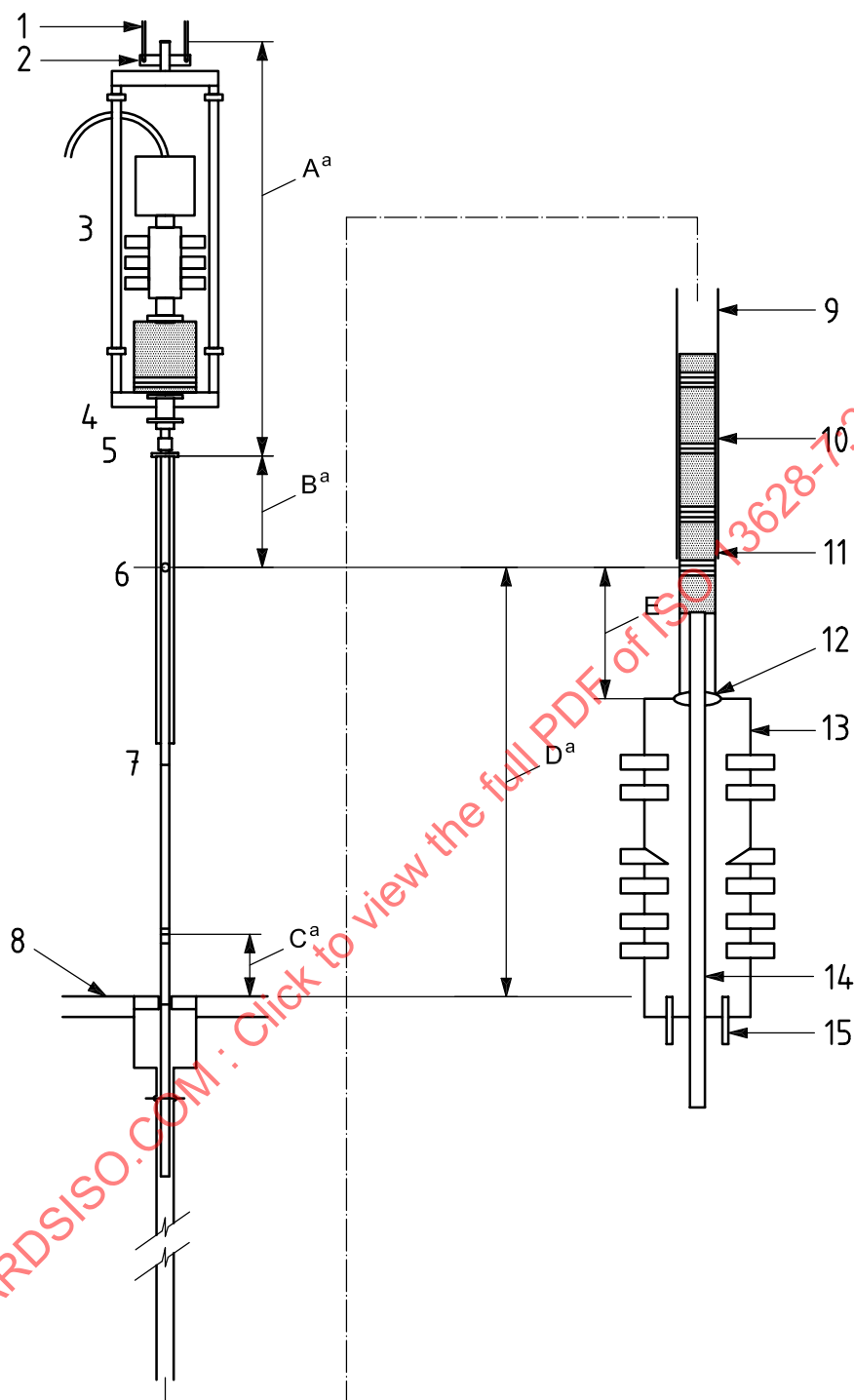
Relative stiffness between the completion riser components and the drilling riser should be considered during passage through the lower ball/flex joint. Operator guidance should be given in terms of expected ball/flex joint angles prior to entry and during passage of the stiffest elements through the lower ball/flex joint. In addition, the consequences and requirements for inspection following exceedance of the allowable angles should be given in the operating manual.

When determining allowable ball/flex joint angles, consideration should be given to the following:

- relative bending stiffness between the completion riser and the drilling riser;
- internal clearance between the completion riser components and drilling risers, including all appurtenances attached to the completion riser (i.e. umbilical clamps, annulus pipe clamps, slick casings, etc.);
- elevation of lower ball/flex joint above wellhead datum;
- elevation of top ball/flex joint below drill floor.

Limitations should typically be specified in terms of the following:

- a) allowable top and bottom ball/flex joint angles;
- b) landing speed;
- c) minimum and maximum tension including overpull.

**Key**

1	bails	6	slick joint	11	tubing hanger
2	elevator	7	pup joint	12	lower flex joint
3	tension frame	8	drill floor	13	BOP
4	adapter	9	drilling riser	14	production tubing
5	swivel	10	landing string	15	wellhead

<sup>a</sup> See Table B.1.

**Figure B.2 — Lifting height and landing stroke parameters**

**Table B.1 — Lifting height and landing stroke parameters** (see Figure B.2)

Parameter	Dimension
Surface tree and surface tree tension frame or bails assembly height	A
Nominal stick-up after landing	B
Riser joint hang-off height	C
Landing stroke (distance from tubing hanger wellhead landing shoulder to underneath of the suspended tubing hanger)	D
Clearance between tubing hanger and flex joint to account for vessel heave and uncertainty of position	E
Minimum required lifting height in derrick	A + B + D + handling clearance

**B.2.2.2 Connected**

For connected conditions in the tubing hanger mode operating limitations are normally presented in terms of allowable drilling riser top and bottom ball/flex joint angles. Limitations in terms of vessel offset and wave height are normally outside the scope of the C/WO riser manufacturer. Factors, which may influence allowable top and bottom ball/flex joint angles, are the following:

- allowable load levels for the mode of operation;
- internal fluid conditions, pressure, mass of internal fluid or tool strings;
- riser tension.

When determining allowable ball/flex joint angles consideration should be given to the following:

- a) relative bending stiffness between the completion riser and the drilling riser;
- b) internal clearance between the completion and drilling risers, including all appurtenances attached to the completion riser (i.e. umbilical clamps, annulus pipe clamps, slick casings, etc.);
- c) elevation of lower ball/flex joint above wellhead datum;
- d) elevation of top ball/flex joint below drill floor.

When determining allowable ball/flex joint angles it is important to consider the drilling riser/BOP and C/WO riser as a system. Allowable angles for one configuration do not necessarily apply to another.

**B.2.2.3 Overpull to retrieve tubing**

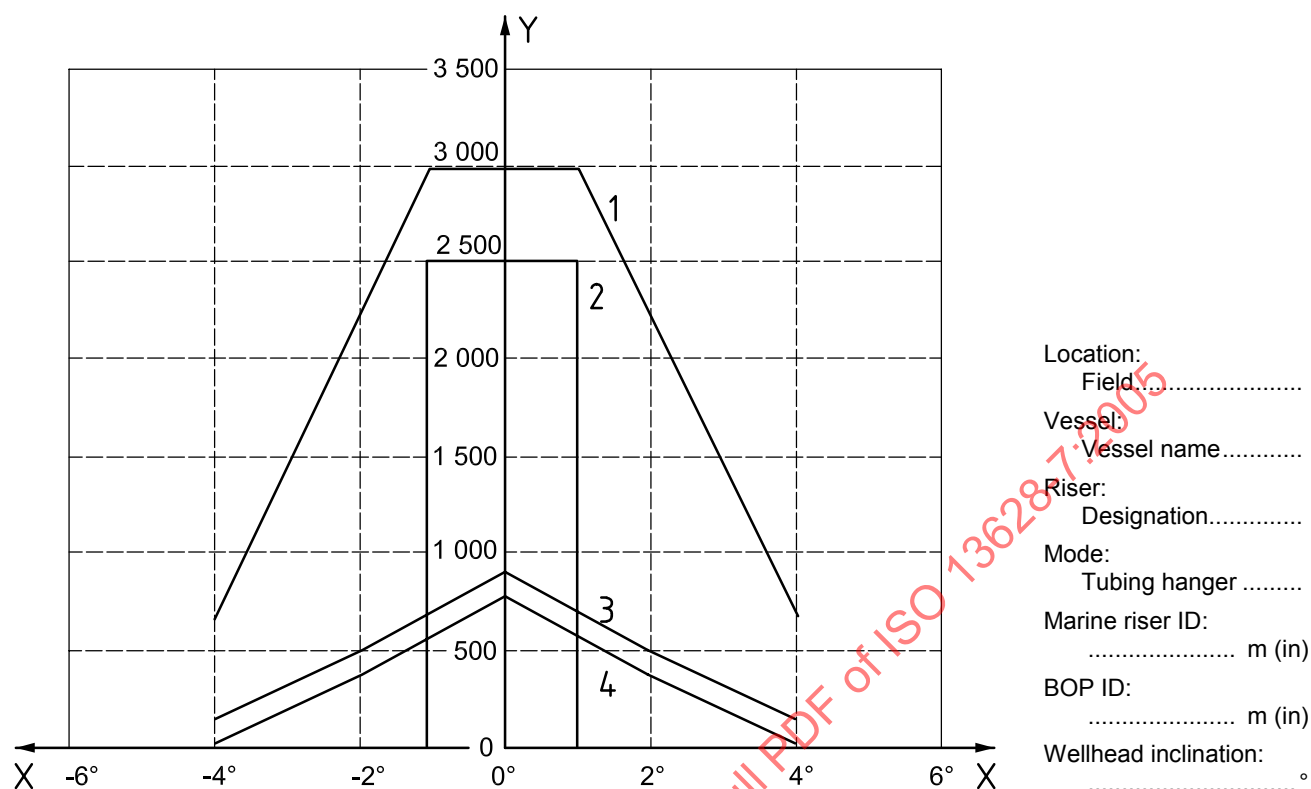
Limitations in terms of allowable ball/joint flex joint angle should be determined as a minimum. The minimum overpull at the tubing hanger should be equal to the tubing weight and additional force to account for friction. Increased tension normally results in reduced allowable angles.

**B.2.2.4 Operating limitations**

The operating limitations for tubing hanger mode can be affected by the same factors as for open sea. Analysis may be performed to define the limiting flex-joint rotations for in-place, overpull scenarios and running (clearance).

Limitations given in Figure B.3 are local to the C/WO system only.

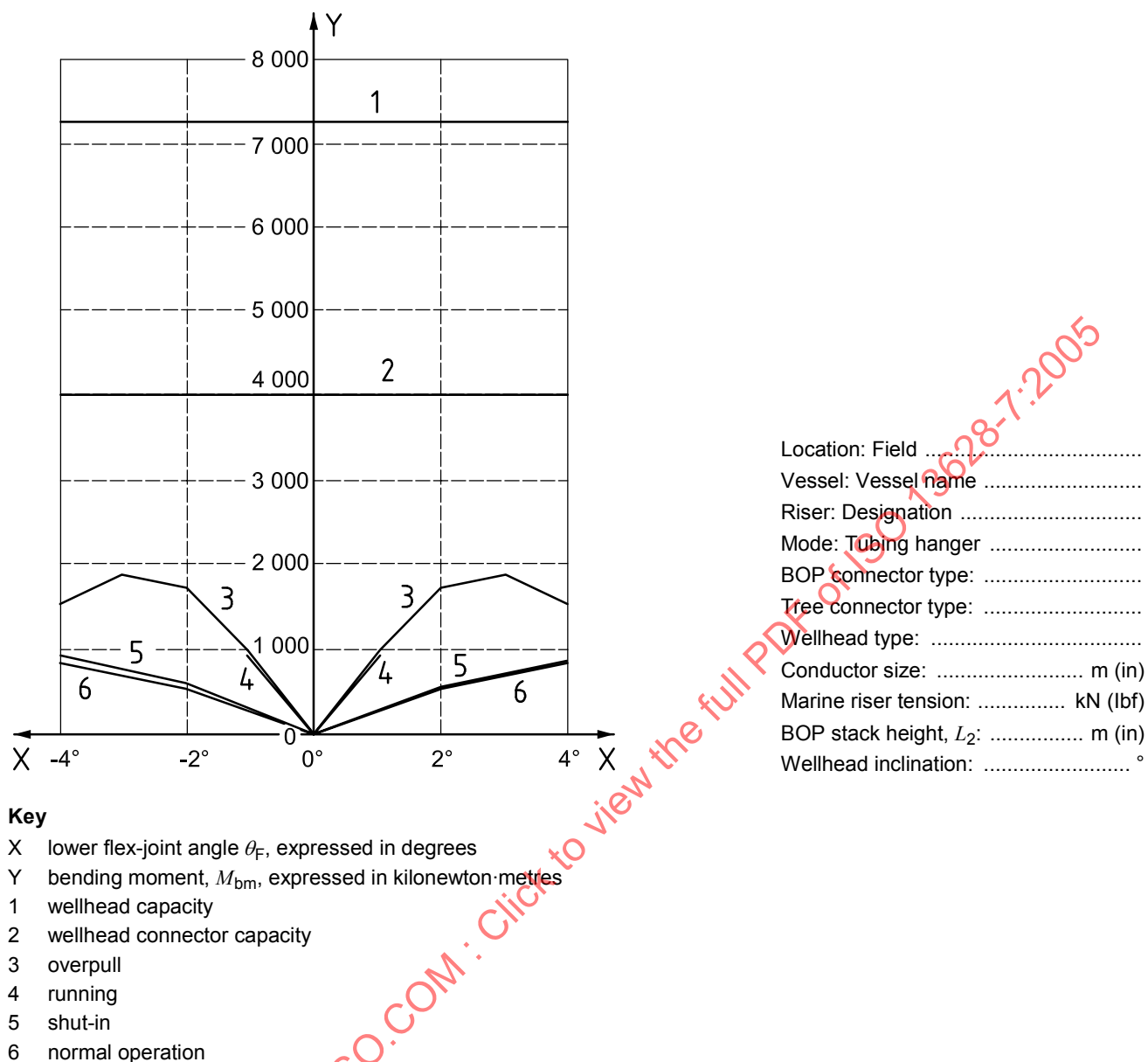


**Key**

- X lower flex joint angle  $\theta_F$ , expressed in degrees
- Y C/WO riser effective tension,  $T_e$ , relative to tubing hanger, expressed in kilonewtons
- 1 overpull to release stuck tubing
- 2 running/retrieval
- 3 subsea shut-in
- 4 normal operation

**Figure B.3 — Typical C/WO riser operating limitations — Tubing hanger mode**

The local C/WO riser operating limitations combined with the marine riser operating conditions result in the global operating limitations where account can be taken of the BOP, wellhead, subsea tree and conductor capacities. It is important to note that the capacities of some of these components are influenced by end-cap effects. A combination of the above results in a global limitation check, as shown in Figure B.4. In this example, the global loading based on the C/WO riser operations does not exceed the global capacities.



**Figure B.4 — Typical global limitations check — Tubing hanger mode**

The global bending moment acting below the marine lower flex joint,  $M_G$ , resulting from the C/WO riser and marine riser, can be determined according to Equation (B.1). In this example, the global bending moment is determined at the wellhead connector.

$$M_G = (V_{sh} \times L_2) + (w_{BOP} \times \delta_2) - (T_v \times \delta_1) + [(\theta_G - \theta_{dev}) \times K_F] + M_f \quad (B.1)$$

where

$$V_{sh} = T_{e,tot} \times \sin(\theta_G) + V_{se} \quad (B.2)$$

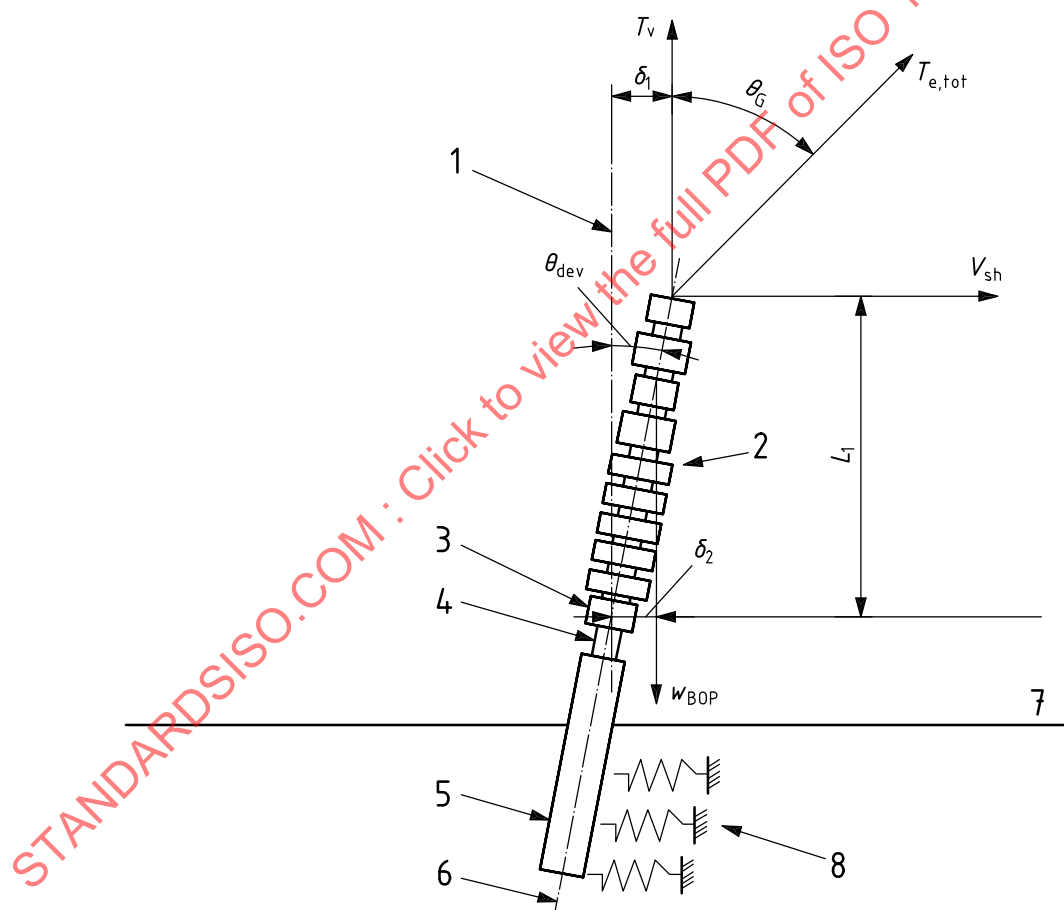
where

$V_{sh}$  is the total shear force acting at the flex-joint;

$L_2$  is the elevation from the DATUM, top of wellhead to flex-joint axis; see Figure F.2;

$w_{BOP}$  is the submerged weight of the BOP and LMRP, including bore contents;

- $g$  is the acceleration due to gravity;  
 $\delta_2$  is the horizontal distance from the BOP centre of gravity to the point of interest;  
 $T_v$  is the vertical tension component of  $T_{e,tot}$ ;  
 $\delta_1$  is the horizontal distance between the flex-joint and point of interest;  
 $\theta_G$  is the global flex-joint angle relative to the global vertical axis; see Figure B.5;  
 $\theta_{dev}$  is the deviation angle of the BOP and high pressure wellhead housing vertical axis, relative to the global vertical axis, see Figure B.5;  
 $K_F$  is the rotational stiffness of the flex-joint;  
 $T_{e,tot}$  is the total effective tension from the marine riser and C/WO riser acting at the flex-joint;  
 $M_f$  is the bending moment required to bend the C/WO riser;  
 $V_{se}$  is the shear force acting at the flex-joint due to environmental loading on the marine riser and BOP.



#### Key

- 1 vertical global line through wellhead connector
- 2 BOP
- 3 wellhead connector
- 4 high pressure wellhead housing
- 5 conductor
- 6 deviated vertical axis of the BOP and high pressure wellhead housing
- 7 seabed
- 8 lateral soil stiffness

**Figure B.5 — Global wellhead bending moment capacity check — Tubing hanger mode**

## B.3 Global riser analysis

### B.3.1 Riser analysis considerations

The global riser analysis is generally used to predict global riser behaviour under the design conditions, and to determine top tension requirements and extreme (operating limitations) and fatigue load effects on riser components.

The global analyses are intended to verify the detailed design, determine operating limitations, estimate fatigue lives and determine extreme/fatigue interface design loads. Some activities typically included in global analysis are as follows:

- analysis of individual pipes and checking with relevant failure modes;
- establishment of individual component design loads (extreme and fatigue); components include couplings, stress joint, tension joint, slick (cased wear) joint, etc.;
- optimize applied tension to achieve acceptable load effects; evaluate the need for buoyancy;
- evaluate riser clearances, e.g. riser-vessel, riser-seabed, surface equipment-deck/spider;
- evaluate displacements and rotations, e.g. riser top stroke, flex/ball joint angles;
- assess vortex-induced vibrations and evaluate need for monitoring and inspection if the riser is susceptible to vortex-induced vibrations, which can be detrimental during the operations. The need for increased top tension and/or for suppression devices should be evaluated.

Some principal design and analysis parameters for C/WO riser systems are shown in Figure B.6.

Riser operating procedures should be prepared for all phases of riser operations. Limiting conditions identified by riser analysis and component limitations should be included.

### B.3.2 Riser tension

#### B.3.2.1 Effective tension

Loading due to external and internal pressure acting on a pipe section is normally treated in terms of the effective tension/weight concept:

$$\begin{aligned}
 T_e &= (T_w - p_{\text{int}} \times A_{\text{int}}) - (-p_o \times A_o) \\
 &= T_w - p_{\text{int}} \times A_{\text{int}} + p_o \times A_o \\
 &= T_w - \frac{\pi}{4} \times \left[ p_{\text{int}} \times (D_o - 2 \times t)^2 - p_o \times D_o^2 \right]
 \end{aligned} \tag{B.3}$$

$$\begin{aligned}
 w_e &= w_p + A_{\text{int}} \times \rho_{\text{int}} \times g - A_o \times \rho_o \times g \\
 &= w_p + \frac{\pi}{4} \times g \times \left[ \rho_{\text{int}} \times (D_o - 2 \times t)^2 - \rho_o \times D_o^2 \right]
 \end{aligned} \tag{B.4}$$

where

- $T_e$  is the effective tension in the pipe;
- $T_w$  is the true wall tension;
- $p_{\text{int}}$  is the internal pressure at a reference point;

- $A_{\text{int}}$  is the internal cross-section area of the pipe;
- $p_o$  is the external pressure at a reference point;
- $A_o$  is the external cross-section area of the pipe giving buoyancy if submerged;
- $D_o$  is the specified or nominal pipe outside diameter;
- $t$  is the pipe wall thickness;
- $w_e$  is the effective (apparent) weight;
- $w_p$  is the weight of the pipe in air (dry);
- $g$  is the acceleration due to gravity;
- $\rho_{\text{int}}$  is the density of the internal fluid;
- $\rho_o$  is the density of seawater.

The effective tension is the axial force (axial stress times pipe cross-section area) adjusted for the contribution from internal and external fluid pressure.

The physical significance of the effective tension can be summarized as follows:

- geometric stiffness, which is governed by the effective tension. This means that the effective tension is the overall governing stiffness parameter for the vast majority of slender structures;
- global stability (column buckling) of the riser, which is governed by the effective tension.

The effective tension is the axial tension, which is calculated at any point along the riser by considering only the top tension and the apparent weight of the riser and its contents. The effective tension may also be considered as the tension in the pipe ignoring the influence of pressure effects.

### B.3.2.2 Top tension

A minimum tension setting is normally required to avoid global buckling of the riser. The tension setting should normally be sufficiently high so that the effective tension is positive in all parts of the riser even if a tensioner should fail. In most cases, the minimum effective tension is encountered at the bottom of the riser. The connector at bottom of stress joint is used as the reference here.

The initial minimum total top tension may be determined by the requirements given in API RP 16Q [8]. Low or even negative effective tension over a portion of the riser does not imply the riser is unstable, nor does it cause the riser to instantaneously experience Euler buckling. The direct consequence of low or negative effective tension is low lateral stiffness, the result of which is adequately estimated by the standard global riser analysis if changes in effective tension are accounted for. An effective compression that occurs should be shown tolerable for the riser pipe and components; see Clause 6.

The draw works tension should normally balance out the weight above the tension ring with a minor margin, i.e. almost zero effective tension above the tension ring. However, in some riser systems an improvement in performance can be achieved by optimizing the split in tension between the riser tensioner and the draw works. It is important to note that this implies an increase in the draw works tension above the minimum given above.

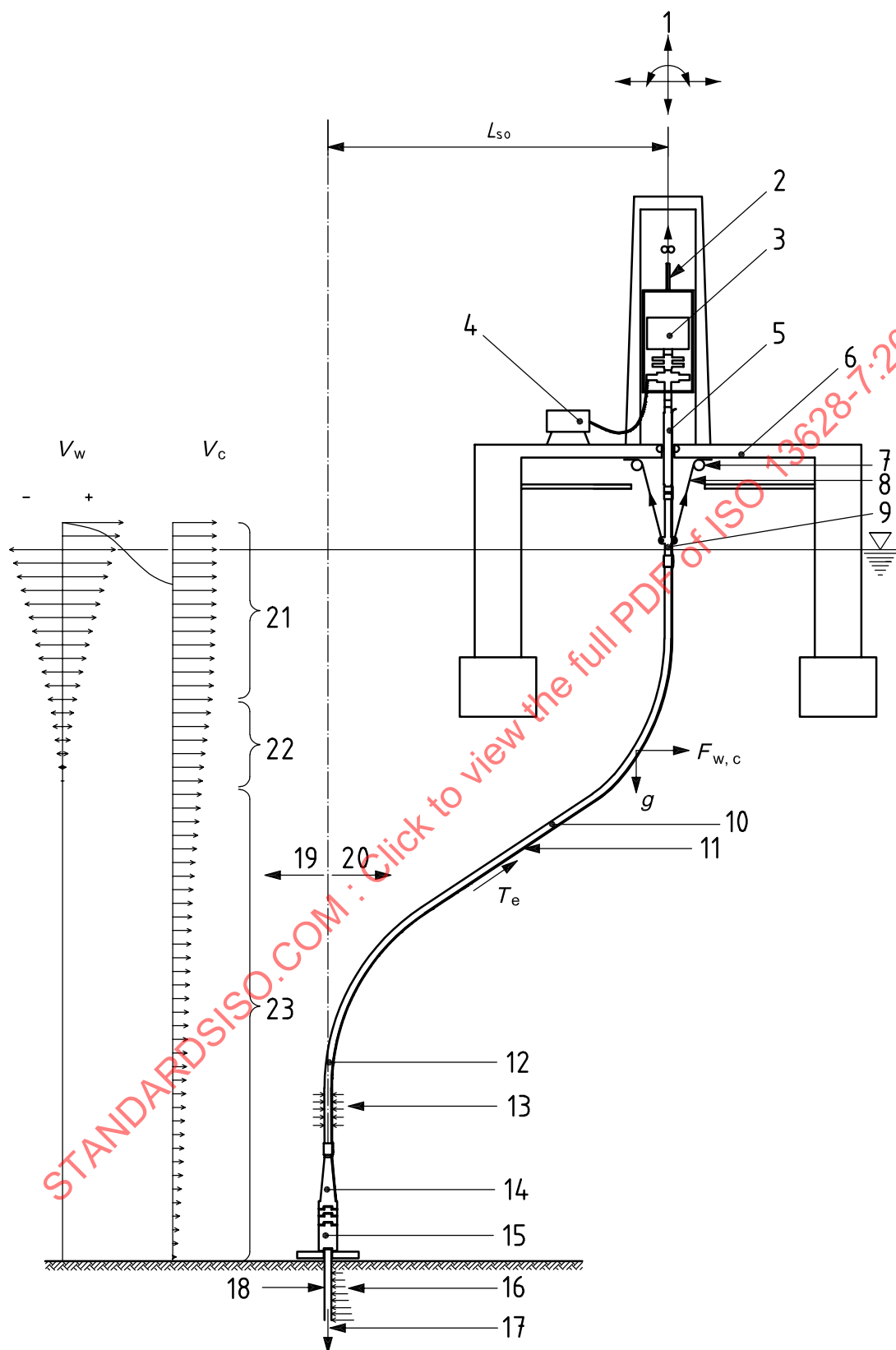


Figure B.6 — Principal parameters involved in the design and analysis of C/WO riser systems

**Key**

1	rig motions due to first-order wave motions	13	external pressure	$F_{w,c}$	wave and current forces
2	draw works tension and stroke	14	stress joint	$g$	gravitational force
3	surface equipment	15	subsea equipment	$T_e$	effective tension
4	surface pressure (choke or mud-pump)	16	soil restraint	$V_w$	wave velocity
5	slick joint	17	tool	$V_c$	current velocity
6	drill floor	18	conductor bending stiffness	$L_{so}$	vessel offset (+)
7	tensioner sheaves	19	upstream		
8	tensioner tension and stroke	20	downstream		
9	tensioner joint	21	excitation zone		
10	outside diameter	22	shear zone		
11	riser joints	23	damping zone		
12	bending stiffness				

**Figure B.6 — Principal parameters involved in the design and analysis of C/WO riser systems**  
(continued)

### B.3.3 Structural model examples

#### B.3.3.1 Open-sea operations

Typical C/WO riser system analysis models for open-sea operations are illustrated in Figure B.7.

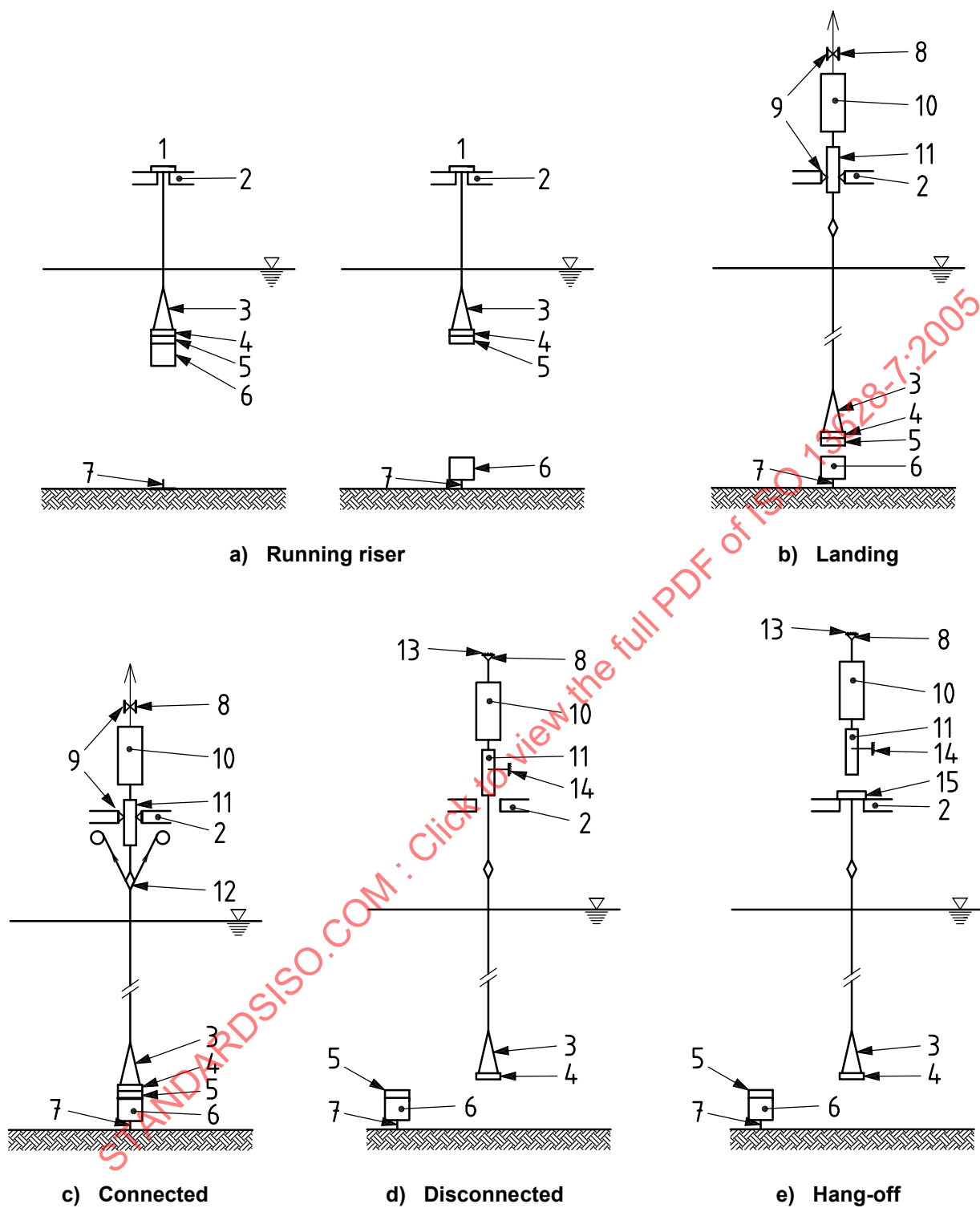
During running, the riser will be held alternatively in the derrick, in the slips/gimbals at the drill floor or in the spider on landing blocks. The top tension in the draw works will increase as the deployed length goes up. The slips can be modelled as rigid, see Figure B.7. If the riser is hung off from gimbals, a pinned support may be assumed. Running analysis should consider various lengths of the submerged riser.

Riser landing involves considerations of landing speed and maximum connection angle criteria. A minimum set-down weight is required to perform latching. This local negative effective tension will reduce the stability of the riser.

In the connected model, the riser model is constrained in all degrees of freedom at the seabed (rigid wellhead and soil) in this example. The vessel motions are typically induced to the riser system at the top draw blocks, the drill floor (rotary table) and the tension wire terminations (sheaves).

During unlatching of the riser, the applied tension is reduced to meet the connector maximum overpull criteria. In addition, the unlatching angle of the connector should not exceed maximum angle criteria.

The disconnected riser may be hung off from the hook, the spider or a specially designed beam structure. For storm hang-off condition, special hang-off systems may be used which provide axial and lateral support, see Figure B.7.



**Key**

- |                                |                            |                      |
|--------------------------------|----------------------------|----------------------|
| 1 slips/spider                 | 6 subsea tree              | 11 slick joint       |
| 2 drill floor                  | 7 wellhead                 | 12 tension joint     |
| 3 stress joint                 | 8 top drive                | 13 pinned connection |
| 4 emergency disconnect package | 9 lateral support          | 14 fixed support     |
| 5 lower riser package          | 10 tension frame equipment | 15 hang-off bushing  |

**Figure B.7 — Typical C/WO riser finite element analysis models — Open-sea operations**



### B.3.3.2 Inside drilling riser operations

Typical C/WO riser system analysis models for inside drilling riser operations are illustrated in Figure B.8. When the riser is operating within the drilling riser, the riser may be analysed using a quasi-static approach including drilling riser flex-joint and ball-joint angles in addition to effective tension and pressure load effects in the C/WO riser. The drilling riser flex-joint/ball-joint prescribed angles may introduce bending moments in the C/WO riser due to contact forces.

Both temporary and connected conditions should be modelled. In all cases, the analysis can be described as displacement controlled bending moment, where the degree of displacement is a function of the ball/flex-joint angle, clearances between the riser (including umbilical clamps, etc.) and marine riser/BOP and riser constraints. It is important that the effects of geometric stiffness on the bending moment response are included in the models. Axial and bending stiffness should be based on nominal dimensions.

### B.3.4 Load modelling

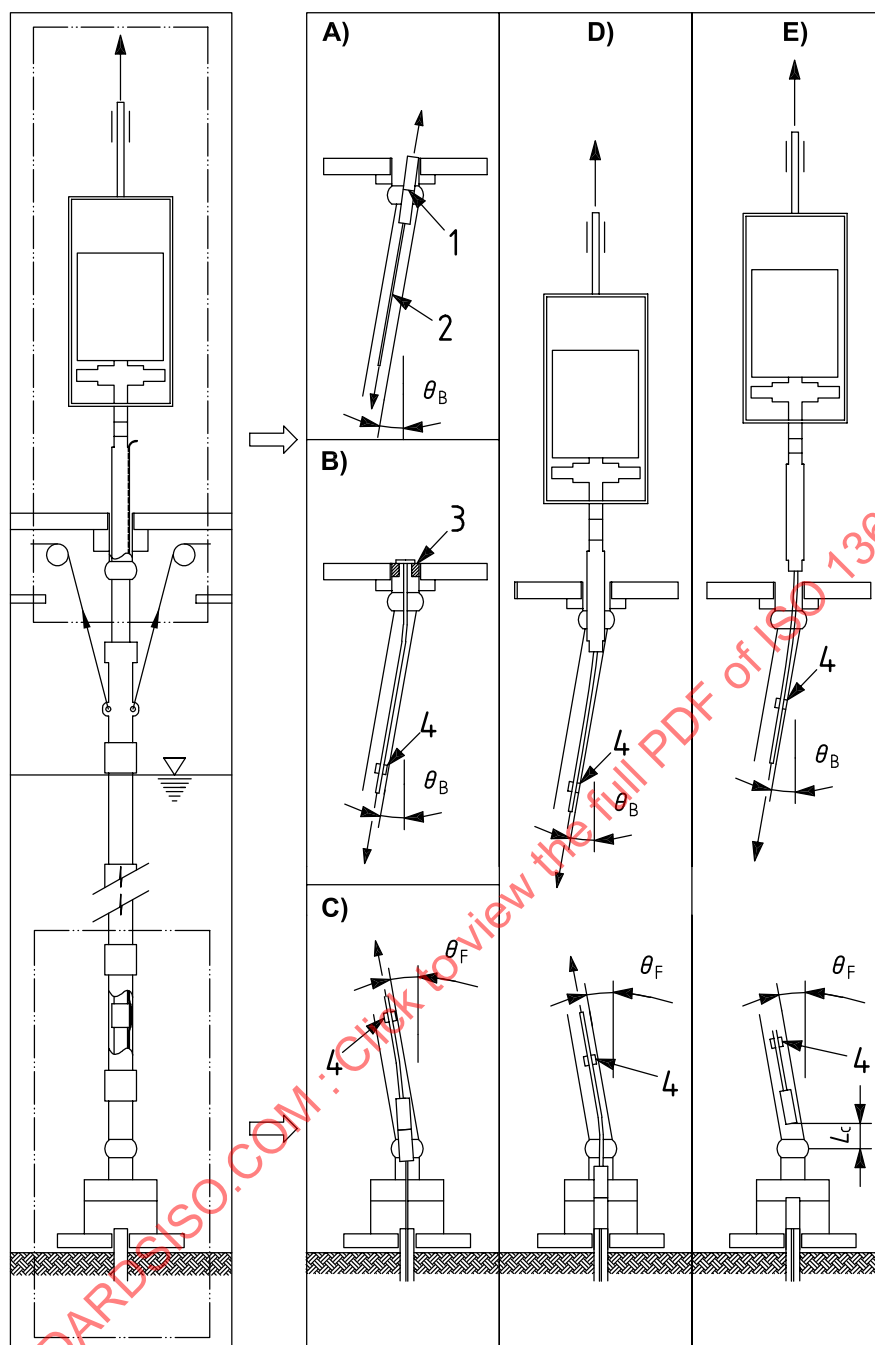
While pressure and functional loads generally can be treated by static methods of analysis, environmental (wave and vessel motions) loads require dynamic analysis. Inertia and damping forces are important when the frequencies of steady-state loads are close to natural frequencies or when transient loads occur (disconnection). Risers typically have natural frequencies below and above wave frequency loads. It should be noted that external and internal pressures in pipe members will normally be handled by the effective tension concept (see B.3.2) in the analyses and are normally included in the post-processing of the load effects.

The hydrodynamic load model gives the force exerted on the riser from the relative velocity and acceleration of seawater particles passing the riser. The hydrodynamic loading on slender structures can be expressed by the Morison formula in terms of the relative fluid-structure velocities and accelerations.

The drag and inertia coefficients incorporated into Morison's formulation are empirical coefficients which may be derived by experiments or numerical simulations. The hydrodynamic coefficients are dependent on a number of parameters, e.g. body shape, Reynolds number, Keulegan Carpenter number, relative roughness ratio, etc. and strictly should be considered as varying along the member with time. In practice, this renders hydrodynamic computations impractical and a constant value is invariably used in the riser analysis. This introduces a considerable source of uncertainty in the accuracy of the results.

In C/WO riser analysis, the inertia coefficient is usually taken to be 2,0, while the drag coefficient varies between 0,8 and 1,0. The drag coefficients above refer to the drag diameter, which is the maximum projected maximum (pitch) diameter. The inertia coefficient refers to embraced volume of the riser structure. Note that pipe bundles and attached external lines have different drag and buoyancy diameters as drag forces are linearly dependent on drag diameter whilst inertia forces depend on the squared buoyancy diameter. It is recommended that sensitivity studies be performed to investigate the effect on global analysis results of the selected coefficients. Consideration should also be given to the potential effect of vortex-induced vibrations on hydrodynamic coefficients, i.e. increased drag coefficients from vortex-induced vibrations.

**NOTE** The use of Morison's formulation to establish hydrodynamic loads reflects present practice, however, new analytical methods are not excluded.



**Key**

- A running: landing string through ball joint
- B running: hang-off of riser during make-up
- C running: landing string through flex joint
- D connected
- E disconnected
- 1 landing string
- 2 tubing
- 3 slips/spider
- 4 umbilical clamp
- $L_c$  clearance

**Figure B.8 — Typical C/WO riser FEM model — Inside drilling riser operations**

### B.3.5 Dynamic analysis methods

An overview of commonly used dynamic finite element analysis methods that may be used is given in Table B.2. Treatment of non-linearities is the distinguishing feature among the available analysis techniques. Time domain analysis is the primary method of analysis for prediction of extreme response. Typical application of the main techniques for dynamic analysis is indicated in Table B.3. An extensive comparison of different methods for extreme response estimation of top tensioned risers is given by Rooney et al. [33].

**Table B.2 — Finite element methods overview for global analysis**

Method	Non-linearities		
	Environmental loads	Special loads	Structure
Non-linear time domain	Morison loading Integration to actual surface elevation	Collision/interaction with other slender structures	Geometric stiffness Non-linear material
Linearized time domain		NA	Linearized at static equilibrium position
Frequency domain	Linearized at static equilibrium position (stochastic linearization)	NA	Linearized at static equilibrium position

**Table B.3 — Typical analysis techniques versus applications**

Method	Typical applications
Non-linear time domain	Extreme load effect analysis of systems with significant non-linearities, in particular compliant configurations exposed to three-dimensional excitation.  Special fatigue analyses for systems or parts of systems with highly non-linear load effect characteristics.  Verification/validation of simplified methods (e.g. linearized time domain, frequency domain).
Linearized time domain	Extreme analysis of systems with small/moderate structural non-linearities and significantly non-linear hydrodynamic loading (e.g. top tensioned risers).
Frequency domain	Fatigue analyses of systems with small/moderate non-linearities.

Hydrodynamic load effects due to vessel motions and positions, wave and current may be determined from

- time domain analysis,
- design wave analysis with full dynamic response analysis,
- non-linear stochastic dynamic analysis in the time domain,
- linearized stochastic dynamic analysis in the time domain,
- frequency domain analysis.

## **Annex C** (informative)

### **Fatigue analysis and assessment**

#### **C.1 Introduction**

##### **C.1.1 Purpose**

Annex C presents recommendations for design and analysis of steel C/WO riser components subjected to fluctuating load effects, to avoid failure by fatigue. This is done by ensuring that the components have adequate calculated fatigue lives. Calculated fatigue lives also form the basis for efficient inspection programmes during fabrication and the operational life of the C/WO riser.

##### **C.1.2 Assumptions**

The assessment procedure assumes that the C/WO riser has been designed, manufactured and fabricated in accordance with all other requirements in this part of ISO 13628.

To ensure that the C/WO riser will fulfil its intended function, a fatigue assessment should be made at all locations where there is a risk of fatigue crack initiation.

All regions or components that are fatigue-critical should be accessible for visual inspection and NDT or replaceable.

##### **C.1.3 Limitations**

The recommendations are not applicable to low cycle fatigue, where the stress range is outside the elastic limits of the material or for elevated temperature operation in the creep range.

Only environment induced fatigue load effects are considered.

##### **C.1.4 Fatigue assessment methods**

Fatigue assessment may be performed by the following:

- methods based upon fatigue tests (S-N curves for normally sound connections) and estimation of cumulative damage (Palmgren-Miner rule);
- methods based upon fracture mechanics (fatigue crack growth predictions of flawed components);
- direct experimental approach by fatigue testing of components.

The fatigue design analysis should in general be based on S-N data, determined by fatigue testing of a representative component and the linear damage hypothesis (Palmgren-Miner). The S-N method of fatigue analysis is the primary design tool used to assess fatigue resistance of C/WO risers due to its simplicity and efficiency.

If appropriate, the fatigue analysis may alternatively be based on or supplemented by fracture mechanics based fatigue assessment. This may be relevant if the remaining life of a cracked component is sought or if crack detection limits for fabrication and in-service inspection NDT are of interest.

If no representative fatigue resistance data are available, a direct experimental approach by fatigue testing of components should be applied. This may be relevant in cases where limitations on fatigue strength data are for temperature, material strength and fluids to which the material is exposed.

### C.1.5 Fatigue assessment procedure

The fatigue resistance is, in general, given as S-N curves, i.e. stress ranges,  $S$ , versus number of cycles to failure,  $N$ . If the long-term stress range distribution is expressed by a stress histogram, consisting of a convenient number of constant stress ranges,  $S_i$ , in  $k$  blocks, each with a number,  $n_i$ , of stress repetitions (see Figure C.1), the fatigue criterion reads as given in Equation (C.1):

$$D_{SN} = \sum_{i=1}^k \frac{n_i}{N_i} = \frac{1}{\bar{a}} \sum_{i=1}^k n_i \times (S_i)^m \leq \frac{1}{D_F} \quad (\text{C.1})$$

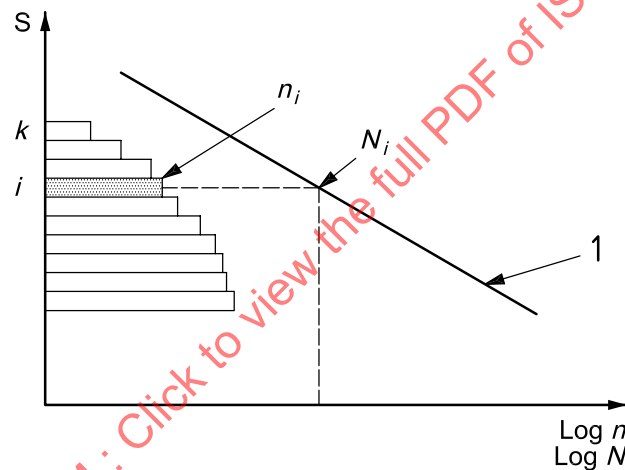
where

$D_F$  is the design fatigue factor;

$D_{SN}$  is the accumulated long term fatigue damage or Miner-Palmgren damage ratio;

$m$  is the negative inverse slope of the S-N curve;

$\bar{a}$  is the characteristic fatigue strength or intercept of the design S-N curve with the log  $N$  axis.



#### Key

- $S_i$  stress range in bin (block)  $i$
- $i$  summing index indicating the bin (block) number
- $k$  total number of stress range bins (blocks)
- $N_i$  number of cycles to failure at constant stress range,  $S_i$ , in stress block  $i$
- $n_i$  number of occurrences in stress range bin  $i$
- 1 experimental S-N curve

**Figure C.1 — Illustration of the Miner's damage caused by the stress range bin (block)  $i$**

The riser pipe nominal or membrane stress ranges have to be multiplied by relevant SCFs for calculation of stresses relevant for the S-N curve. The stress range is further modified by a thickness or size correction factor such that the design S-N curve for thickness larger than a reference thickness is changed. This means that the fatigue strength is reduced for increased thickness above a reference thickness.

The basis for fatigue damage calculations for a riser exposed to both wave frequency and low-frequency loads is global dynamic load effect analysis. These analyses establish the nominal stress range distributions in a number of short-term environmental conditions (sea-states) in the wave scatter diagram. The low-frequency wave drift load effects may be obtained by global static or dynamic analysis of the riser using the low-frequency induced motions of the vessel. Dynamic analysis should be performed if inertial load effects generated by the low-frequency vessel motions are significant. The load effects generated by vortex-induced vibrations should be obtained from a vortex-induced vibration analysis of the riser.

Fatigue damage may then be calculated for each short-term condition by analytical damage formulas for narrow-banded stress processes, i.e. Rayleigh distribution for Gaussian stress range distribution or Weibull distribution for non-Gaussian stress range distribution. Fatigue damage for wide-band stress response may be calculated by a cycle counting method, semi-empirical solutions or by simplified analytical solutions.

As an alternative approach to computation of fatigue damage for each short-term environmental condition, the long-term stress range distribution can be obtained by a summed weighting of the cycle distributions for the different short-term environmental conditions. The resulting distribution may subsequently be fitted to an equivalent analytical distribution of the Weibull type. The long-term Weibull stress range distribution can be used to establish the stress histogram. The Weibull distribution and the stress histogram are convenient forms of the long-term stress range for establishing interface fatigue loads to components, for estimating maximum allowable SCFs or for fatigue crack growth assessment.

A typical sequence in the design of a C/WO riser for fatigue is shown in Table C.1.

**Table C.1 — Summary of a typical riser fatigue assessment procedure**

Task	Comment
Define fatigue loading.	Based on operating limitations including wave frequency, low-frequency and possible vortex-induced vibrations load effects. The wave-induced fatigue damage is normally the governing source of damage for both open-sea and tubing hanger (inside marine riser) operating modes.
Identify locations to be assessed.	Structural discontinuities, welded joints, anode attachment welds, connectors, bolts, repairs of defects, etc.
Identify fatigue strength data.	Joint classification (selection of S-N curve), i.e. unwelded, welded and bolted materials. The fatigue strength data selection depends on the material and service environment (both inside and outside). For welded joints, the S-N curve selection depends on the geometry arrangement of the detail, the direction of fluctuating stress relative to detail, the method of fabrication and inspection of the detail. Include relevant thickness (size) correction factor.
At each relevant location, establish SCFs.	Determination of the SCFs not included in the S-N curve for the locations to be analysed. SCFs may be determined from parametric equations, detailed finite element analysis or by testing.
Perform global fatigue analysis.	Perform global riser fatigue analysis to calculate short-term nominal stress range distribution at each identified location and mean stress. The short-term stress range distribution may be used to establish long-term nominal stress ranges or histogram.
Perform fatigue damage calculations.	Calculate accumulated fatigue damage from weighted short-term fatigue damage or long-term stress range.
Further actions if location fails assessment.	Reassess using more refined global riser analysis method. Reassess using more refined stress analysis to establish SCF. Change unwelded detail, e.g. minimize notch stress (elliptical transition may give lower stress than radius) and/or change thickness. Reduce fabrication eccentricities of girth-welded pipes, e.g. reduce tolerances of pipe and connector. Improve fatigue performance by weld toe grinding. Perform fracture mechanics analysis. Improved inspection/replacement programme.
Note relevant implications and provide information for relevant manufacturing, inspection and operating personnel.	Requirements, extent and defect detectability requirements for NDT during fabrication and service. Manufacture/fabrication tolerances, e.g. control of or assumptions about misalignment during fabrication. Weld requirements, e.g. root improvements (tungsten inert gas welding) or weld cap toe improvements by grinding. Operation requirements, e.g. logging, monitoring and inspection/replacement intervals.

## C.2 Stresses to be considered

### C.2.1 General

The procedure for the fatigue analysis is based on the assumption that it is only necessary to consider the ranges of cyclic principal stresses and mean stress in determining the fatigue life. The mean stress is included by the stress range reduction factor,  $f_m$ . The anticipated crack-initiation site is called a hot spot.

For pipes subjected to a principal (axial) membrane stress range,  $S_m$ , the principal stress ranges,  $S$ , to be considered in fatigue assessment of welded and unwelded components are given in Table C.2. Table C.2 also gives stress ranges to be used for fatigue assessment of bolts.

**Table C.2 — Stresses to be considered for S-N fatigue assessment**

Joint/component	Stress range	Comment
Welded joints	$S = S_{gs} = f_m \times K_m \times S_m$	Local weld notch effects are included in the S-N curve. Only pipe/connector geometry deviations, e.g. axial misalignment, should be included in $K_m$ . Both weld root and weld cap should be evaluated for full penetration girth-welded pipes.
Unwelded components	$S = S_{notch} = f_m \times K_{notch} \times S_m$	No SCF is included in the S-N curve. Local notch stress should be used to scale the membrane (nominal) pipe wall stress. In case of plain pipes or stress joints, etc. the outer fibre stress should be used.
Bolts	$S = S_m + S_b$	Membrane (nominal) stress based on the bolt stress area should be applied including membrane and bending stress range. Thread root SCFs are included in the S-N curve.

where

$K_m$  is the geometric stress concentration factor;

$K_{notch}$  is the notch stress concentration factor;

$S_b$  is the bending component of the primary plus secondary principal stress range;

$S_{gs}$  is the geometric stress concentration stress range;

$S_{notch}$  is the notch stress range.

Care should be taken in calculating the stresses and SCFs to be used in the fatigue analysis. Relatively small changes in the stresses and SCFs can result in large differences in fatigue life. Fatigue life is proportional to the stress ranges and SCFs, each raised to the power of the S-N curve inverse slope (from 3 to 5). It can be demonstrated that, for an S-N slope of 3, doubling of either the stress range or SCF, or any product of these, decreases fatigue life by a factor of 8.

**EXAMPLE** If the structural component has a fatigue life of 100 years, doubling the product of the stress range and SCF reduces the fatigue life to 12,5 years.

### C.2.2 Linearized stresses

In order to avoid possible confusion between global and local bending stresses, an example of the application of the stress decomposition to the particular case of longitudinal stresses in a pipe subjected to an external bending moment is illustrated in Figure C.2; see also Equations (D.9) to (D.12) for general formulas for determining membrane and bending stress.

The following apply for this case:

- linear longitudinal stress distribution along the pipe cross-section;
- linear longitudinal stress distribution along the thickness of the wall;
- membrane stress as is given in Equation (C.2):

$$\sigma_m = \frac{16 \times M_{bm} \times (D_o + D_{int})}{\pi \times (D_o^4 - D_{int}^4)} \quad (C.2)$$

- bending stress (on each side of the wall) as is given in Equation (C.3):

$$\sigma_b = \pm \frac{16 \times M_{bm} \times (D_o - D_{int})}{\pi \times (D_o^4 - D_{int}^4)} \quad (C.3)$$

where

- $D_{int}$  is the inside diameter of pipe;
- $D_o$  is the specified or nominal pipe outside diameter;
- $M_{bm}$  is the bending moment in the pipe.



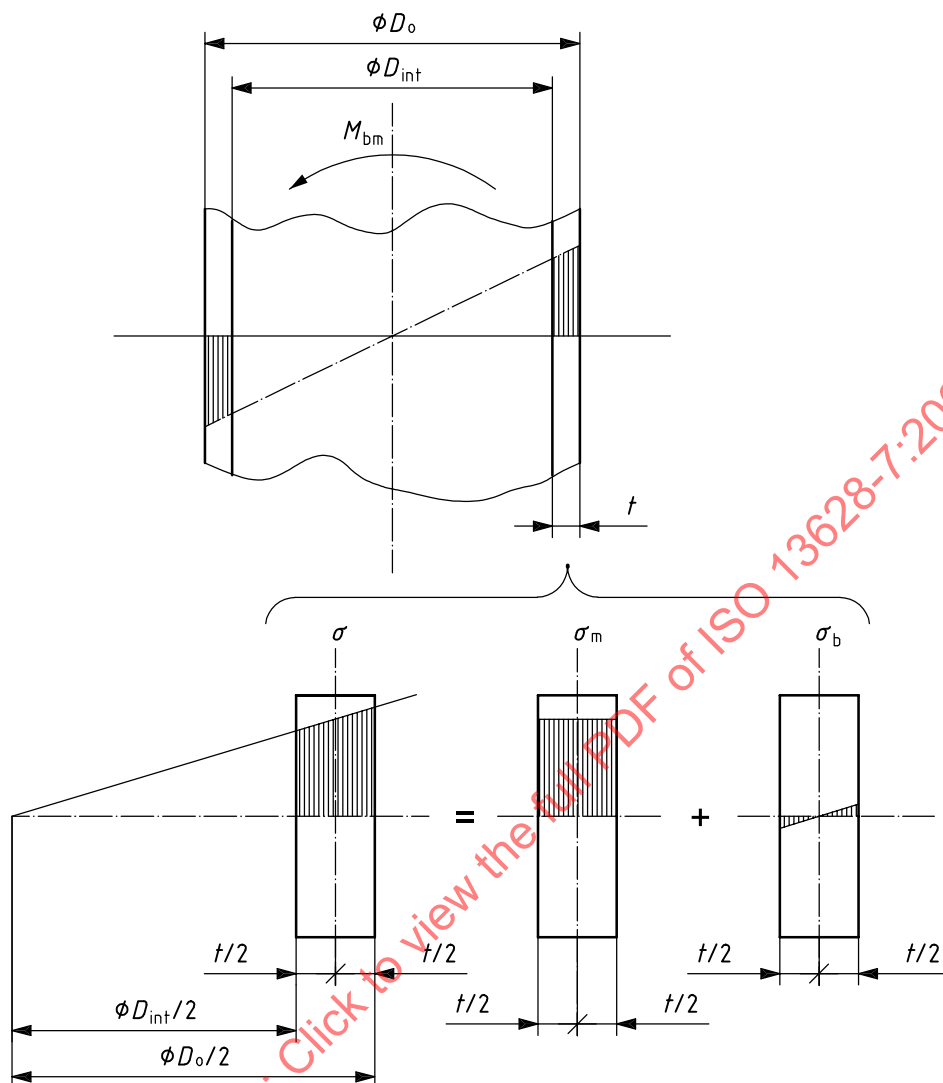


Figure C.2 — Decomposition of the longitudinal stress for a pipe subjected to a bending moment,  $M_{bm}$

### C.2.3 Welded joints

The primary plus secondary stress range,  $S_{P+Qs}$ , or structural stress range applies to fatigue assessment of welded joints and the corresponding geometric stress concentration (magnification) factor is defined as given in Equation (C.4):

$$K_m = \frac{S_{P+Qs}}{S_m} = 1 + \frac{S_b}{S_m} \quad (C.4)$$

where

$K_m$  is the geometric stress concentration factor;

$S_b$  is the bending component of the primary plus secondary principal stress range;

$S_m$  is the membrane (average) component of the primary plus secondary principal stress range.

If the structural principal (axial) stress is obtained by detailed stress analysis (e.g. finite element analysis) or by measurement, the structural hot-spot stress should be determined from the principal surface stress by

extrapolation using the procedure detailed in Figure C.3. Distance  $X_1$  and  $X_2$  may be selected to be  $0,5 t$  and  $1,5 t$ , where  $t$  is the pipe wall thickness. Different procedures may be applied; see Niemi [31]. However, when applying finite element analysis, the structural hot-spot stress may be determined as indicated in Figure C.4. The linearized through-thickness stress method (see Figure C.4) is the preferred method, as the SCF predicted by this method is not sensitive to the localization of extrapolation points; see Figure C.3.

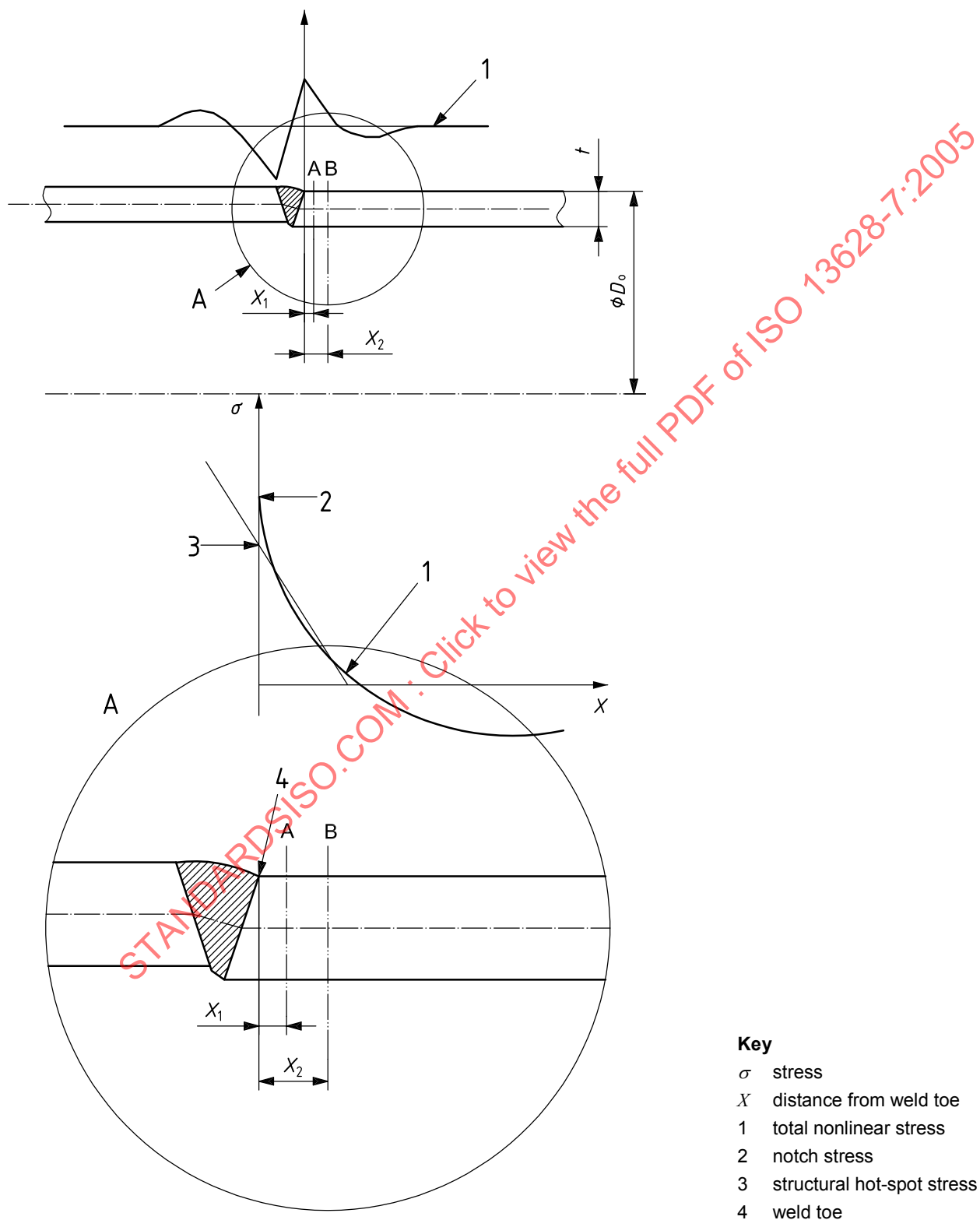
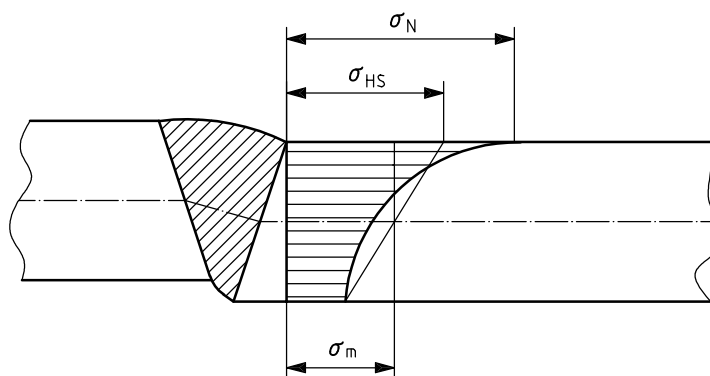


Figure C.3 — Explanation of structural hot-spot stresses in butt welded pipes

**Key**

- $\sigma_N$  notch stress  
 $\sigma_{HS}$  structural hot-spot stress  
 $\sigma_m$  membrane (nominal) stress

**Figure C.4 — Linearized stress distribution across wall thickness**

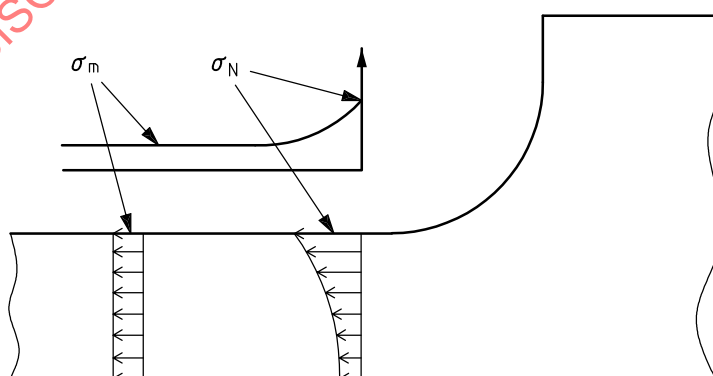
### C.2.4 Unwelded components

The maximum primary plus secondary plus peak principal stress range,  $S_{P+Qs+F}$ , or notch stress range,  $S_{notch}$ , applies to fatigue assessment of unwelded parts. The notch stresses should be calculated using principal stresses, which incorporate the full effect of gross and local structural discontinuities. The notch stress concentration (magnification) factor,  $K_{notch}$ , is defined as the notch stress range normalized by the membrane (nominal) stress range as given in Equation (C.5); see Figure C.5:

$$K_{notch} = \frac{S_{P+Qs+F}}{S_m} = \frac{S_{notch}}{S_m} \quad (C.5)$$

where  $S_m$  is the membrane (average) component of the primary plus secondary principal stress range.

For plain pipe and stress joints, etc., the outer fibre stress, i.e. membrane plus bending stress in C.2.2, should be used.

**Key**

- $\sigma_N$  notch stress  
 $\sigma_m$  membrane (nominal) stress

**Figure C.5 — Explanation of local notch stresses in unwelded components**

### C.2.5 Bolts

For bolts, the stress range,  $S$ , to apply is the membrane (nominal) plus bending stress range on the stress cross-section area,  $A_{b,s}$ , as given in Equation (C.6):

$$A_{b,s} = \frac{\pi}{4} \times (d_{b,f})^2 \quad (C.6)$$

where  $d_{b,f}$  is the mean effective bolt diameter.

The stress area of a standard inch series bolt with 60° thread angle is given by Equation (C.7):

$$A_{b,s} = \frac{\pi}{4} \times \left( d_b - \frac{0,974\ 3}{n_{thr}} \right)^2 \quad (C.7)$$

where

$d_b$  is the nominal (basic major diameter) bolt diameter;

$n_{thr}$  is the number of threads per inch.

For the corresponding metric threads, the stress area is given by Equation (C.8):

$$A_{b,s} = \frac{\pi}{4} \times (d_b - 0,938\ 2 \times I_{pitch})^2 \quad (C.8)$$

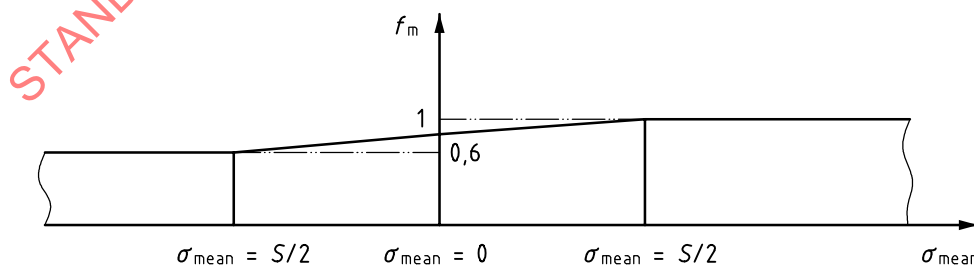
where  $I_{pitch}$  is the pitch of the threads.

**EXAMPLE** The stress area for 1 in 8UN bolts is 390,8 mm<sup>2</sup> (0,606 in<sup>2</sup>) where  $d_b = 25,4$  mm (1 in) and  $n_{thr} = 0,315$  mm<sup>-1</sup> (8 in<sup>-1</sup>) for 8UN bolts with 8 threads per inch.

Only the fluctuating stress range should be included. Pre-load normally reduces the fluctuating stress range.

### C.2.6 Mean stress influence

When assessing base material, welded joints in the post-weld heat-treated condition or other components with low residual stresses, the stress range may be reduced dependent on whether mean cyclic stress,  $\sigma_{mean} = (\sigma_{max} + \sigma_{min})/2$ , is tension or compression. The calculated stress range obtained may be multiplied by the reduction factor,  $f_m$ , as obtained from Figure C.6 before entering the S-N curve; see Table C.2. For welded joints in the as-welded condition, the stress range to be used in fatigue assessment should be based on the full stress range regardless of whether the stress range is partly or wholly compressive, i.e.  $f_m = 1,0$ .



#### Key

$f_m$  stress range reduction factor

$\sigma_{mean}$  mean cyclic stress

**Figure C.6 — Stress range reduction factor to be used with the S-N curve for unwelded components and post-weld heat-treated welded joints**

### C.2.7 Finite element analysis

For determination of hot-spot stresses by finite element analysis, it is important to have a continuous and not-too-steep change in the density of the element mesh in the areas where the hot-spot stresses should be analysed. The element mesh should be extra fine in areas where notch stresses are determined.

The geometry of the elements should be evaluated carefully in order to avoid errors due to deformed elements (for example corner angles between 60° and 120° and length/width ratio less than 5:1). The size of the model should be sufficiently large so that the calculated results are not significantly affected by assumptions made for boundary conditions and application of loads.

## C.3 S-N curves

### C.3.1 General

The present guideline on fatigue strength is based on DNV RP-C203<sup>[17]</sup>. Fatigue strength from other recognized codes, e.g. HSE Guidance<sup>[18]</sup> may be applied. Guidance for fatigue design and assessment of riser girth welds is given by Maddox et al.<sup>[30]</sup>.

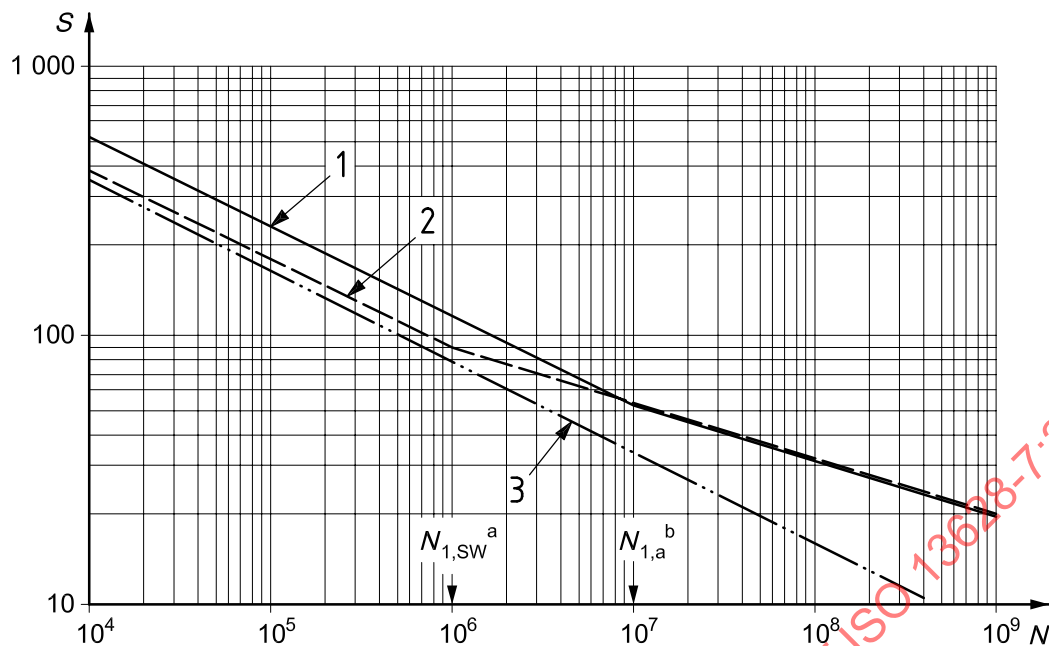
The fatigue design is based on the use of S-N curves which are obtained from tests. The design S-N curve should be based on the mean-minus-two-standard-deviation curves for relevant experimental data. The S-N curves are thus associated with a 97,6 % probability of survival.

The S-N curve should be applicable for the material, geometry of detail, the direction of the fluctuating stress relative to the detail, the method of fabrication including surface finish and inspection of the detail, as well as the surrounding environment (e.g. corrosive/non-corrosive fluid, cathodic protection in sea-water and temperature).

Each construction detail at which fatigue cracks can potentially develop should be placed in its relevant joint class. It should be noted that there are several locations at which fatigue cracks can develop at the welded joint. Examples of locations are at the weld toe/root in each of the parts joined, at the weld ends and in the weld itself; see Figure C.4. Each location should be classified separately. The joint classification given here is for typical joints/details to be analysed for a C/WO riser subjected to cyclic bending moment and effective tension.

Typical S-N curves for a pipe girth weld, DNV RP-C203 Class D weld, are illustrated in Figure C.7 for air or non-corrosive environment, for seawater environment with cathodic protection and for free corrosion and sour service.

The effect of internal C/WO riser fluid and external fluid in tubing hanger mode operating inside the marine riser should be given special attention, especially for potentially aggressive fluids. Sour service can reduce the fatigue life while fatigue life in sweet fluids can be assumed to be as in air. For sour service, S-N curves applicable for free corrosion may be considered. If internal fluid service is partly sour service and non-aggressive fluids, S-N curves for seawater with cathodic protection may be used. In tubing hanger mode with non-corrosive external fluids, S-N curves for air may be applied for this condition. In open-sea operation, the outside surface of the riser may be checked with S-N curves for seawater with cathodic protection.

**Key** $S$  stress range $N$  number of cycles to failure

1 air or non-corrosive

2 seawater with cathodic protection

3 free corrosion in seawater or sour service

<sup>a</sup>  $N_{1,sw}$  indicates the point of discontinuity in the bilinear S-N curve 2 (i.e. seawater with cathodic protection).<sup>b</sup>  $N_{1,a}$  indicates the point of discontinuity in the bilinear S-N curve 1 (i.e. air or non-corrosion).**Figure C.7 — Typical design S-N curves for girth-welded pipes, Class D in DNV RP-C202** <sup>[17]</sup>

The influence of undetectable internal and external defects or other geometry factors not included in the SCFs for the relevant component/joint is assumed to be built into the design curve for welded joints. The basic fatigue strength is given in terms of S-N curves expressing the number of cycles to failure,  $N$ , for a given constant stress range,  $S$ , as shown in Equation (C.9):

$$N = \bar{a} \times (S)^{-m} \quad (\text{C.9})$$

or equivalently, in Equation (C.10):

$$\log N = \log \bar{a} - m \times \log S \quad (\text{C.10})$$

where

$m$  is the negative inverse slope of the S-N curve;

$\bar{a}$  is the characteristic fatigue strength or intercept of the design S-N curve with the  $\log N$  axis.

A correction, i.e. a reduction in fatigue strength, to the original S-N curve is required for thickness  $t_n$  greater than the reference thickness,  $t_{ref}$ . The thickness (size) effect is accounted for by a modification on the stress range, i.e. a factor is introduced as a multiplier on the stress range, such that the design S-N curve for thickness larger than the reference thickness is given by Equation (C.11):

$$\log N = \log \bar{a} - m \times \log \left[ S \times \left( \frac{t_n}{t_{ref}} \right)^{k_1} \right] \quad (C.11)$$

where

$k_1$  is the thickness exponent on fatigue strength;

$t_n$  is the nominal (specified) pipe wall thickness;

$t_{ref}$  is the reference thickness equal to 25 mm (0,984 in) for welded connections and bolts (stress diameter).

For  $t_n < t_{ref}$ , the  $(t_n/t_{ref})^{k_1}$  factor in Equation (C.11) is equal to 1,0.

Bilinear (two-slope) S-N curves may be expressed as given in Equation (C.12):

$$N = \begin{cases} \bar{a}_1 \times S^{-m_1} & S > S_1 \\ \bar{a}_2 \times S^{-m_2} & S < S_1 \end{cases} \quad (C.12)$$

where

$\bar{a}_1$  is the intercept of the design S-N curve with the log  $N$  axis, left part of S-N curve;

$m_1$  is the negative inverse slope of the S-N curve, left part;

$\bar{a}_2$  is the intercept of the design S-N curve with the log  $N$  axis, right part of S-N curve;

$m_2$  is the negative inverse slope of the S-N curve, right part.

The point of discontinuity is denoted  $S_1$ . It is related to the corresponding number of cycles to failure,  $N_1$ , and is given by Equation (C.13):

$$S_1 = \left( \frac{N_1}{\bar{a}_1} \right)^{-\left( \frac{1}{m_1} \right)} = 10^{\left( \frac{\log(\bar{a}_1) - \log(N_1)}{m_1} \right)} \quad (C.13)$$

where

$N_1$  is  $10^7$  cycles for air condition and is  $10^6$  cycles for seawater with cathodic protection condition in DNV RP-C203 [17];

$S_1$  is the stress range at the point of discontinuity (bilinear S-N curve).

In the case of a bilinear design curve with size (thickness) correction, the S-N data are given by Equations (C.14) to (C.16):

$$\log \bar{a}_{1,thick} = \log \bar{a}_1 - m_1 \times k_1 \times \log \left( \frac{t_n}{t_{ref}} \right) \quad (C.14)$$

$$S_{1,thick} = \left( \frac{N_1}{\bar{a}_{1,thick}} \right)^{-\left( \frac{1}{m_1} \right)} \quad (C.15)$$

$$\log \bar{a}_{2,thick} = \frac{m_2}{m_1} \times \log \bar{a}_1 + \log N_1 \times \left( 1 - \frac{m_2}{m_1} \right) - m_2 \times k_1 \times \log \left( \frac{t_n}{t_{ref}} \right) \quad (C.16)$$

where

$\bar{a}_{1,thick}$  is the intercept of the design S-N curve with the  $\log N$  axis, left part of S-N curve, size corrected;

$k_1$  is the thickness exponent on fatigue strength;

$S_{1,thick}$  is the stress range with thickness correction;

$\bar{a}_{2,thick}$  is the intercept of the design S-N curve with the  $\log N$  axis, right part of S-N curve, size corrected.

### C.3.2 Unwelded materials

The surface finish is the governing property of fatigue lives for unwelded components.

For seamless pipes, rolled, extruded or forged components without any machining, the B1-SN curve should be applied. Use of the B1-SN curve requires that sharp edges and surface flaws have been improved by grinding.

For machined surface conditions, the fatigue life can be expected to be increased compared to the B1-SN curve; however, the effect has to be documented. Alternative S-N curves based on testing may be used.

As an alternative to using the B1-SN curve or a stress-based approach using S-N data, specific fatigue design curves for specific unwelded materials may also be developed using strain-based approaches and strain controlled fatigue test data on representative materials.

Plain material can contain flush ground weld repairs. The presence of such repairs can lead to a reduction in the fatigue life of the material. Hence, only materials that are certain to be free from welding should be assessed as unwelded.

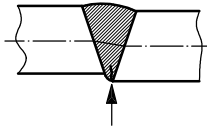
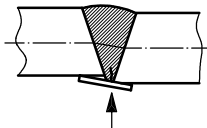
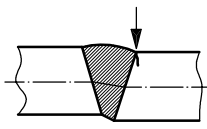
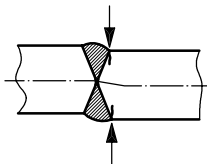
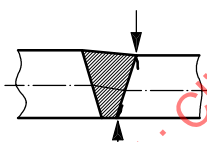
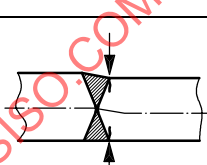
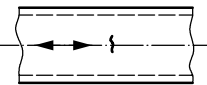
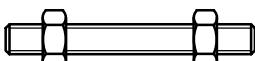
### C.3.3 Butt-welded pipes

#### C.3.3.1 General

For welds made from both sides, fatigue cracks in the as-welded condition normally initiate at the weld toe, so that the fatigue strength depends largely upon the shape of the weld overfill. If the overfill is dressed flush, the stress concentration caused by it is removed and failure is then associated with weld defects. For welds made from the outside (one side), fatigue cracks normally initiate at the root side of the weld. Classification of girth welds relevant for risers are given in Table C.3.



Table C.3 — SN-curves for risers — DNV RP-C203<sup>[17]</sup>

Description		Tolerance requirement <sup>b</sup>	S-N curve	Thickness exponent $k_1$	$K_m$
Detail/welding	Geometry and hot spot				
Single-sided		$e \leq \min [0,1 t_n, 3 \text{ mm (0,118 in)}]$	F1	0	1,0
		$e > \min [0,1 t_n, 3 \text{ mm (0,118 in)}]$ $e \leq \min [0,15 t_n, 4 \text{ mm (0,157 in)}]$	F3	0	1,0
Single-sided onto temp. backing		$e \leq \min [0,1 t_n, 2 \text{ mm (0,079 in)}]$	F	0	1,0
		$e > \min [0,1 t_n, 2 \text{ mm (0,079 in)}]$ $e \leq \min [0,15 t_n, 4 \text{ mm (0,157 in)}]$	F1	0	1,0
Single-sided		$e \leq \min [0,15 t_n, 4 \text{ mm (0,157 in)}]$	D	0,15 <sup>a</sup>	(C.20)
Double-sided		$e \leq \min [0,15 t_n, 4 \text{ mm (0,157 in)}]$	D	0,15 <sup>a</sup>	(C.20)
Single-sided, root string machined off and dressed flush		$e \leq \min [0,15 t_n, 4 \text{ mm (0,157 in)}]$	C1/C	0	(C.20)
Double-sided dressed flush		$e \leq \min [0,15 t_n, 4 \text{ mm (0,157 in)}]$	C1/C	0	(C.20)
Seamless pipe		NA	B1	0	1,0
Machined components	See Figure C.5	NA	B1	0	Calc. or [38]
Steel bolts		NA	F1 (cold-rolled) W3 (cut threads)	0,40 <sup>a</sup>	1,0

<sup>a</sup> The penalty applied only for thickness greater than 25 mm (0,984 in). No benefit can be taken for sections thinner than 25 mm (0,984 in). For bolts, the reference thickness is the stress diameter.

<sup>b</sup> For girth weld eccentricities greater than  $0,15 t_n$  or 4 mm (0,157 in), whichever is the smaller, special considerations apply, e.g. fracture mechanics assessment.

### C.3.3.2 Girth welds made from both sides — root or cap failure

The class D design curve is proposed for girth welds made from both sides by any process and in any position considering root or cap failure. The curve is to be used in conjunction with the thickness effect correction and SCF to allow for any axial misalignment arising from out-of-roundness and wall thickness of abutted pipe sections or pipe and connector sections. There is a limit set on the permissible amount of misalignment of  $0,15 t_n$  or 3 mm, whichever is smaller. Eccentricity exceeding this limit requires special design considerations, such as fracture mechanics assessment.

### C.3.3.3 Girth welds made from one side — root failure

Welds in risers are normally made with a symmetric weld groove with welding from the outside only. The tolerances are rather strict compared with other structural elements with eccentricity less than  $0,1 t_n$  or maximum 3 mm (0,118 in). The fabrication of risers also implies a systematic and standardized NDT of the root area where defects are most critical. Provided that the same acceptance criteria are used for risers with wall thickness larger than that used as reference thickness [25 mm (0,984 in)], the guidance in Table C.3 applies.

Class F1 is adopted for root failure from the inside but with no additional SCF for axial misalignment up to the lesser of  $0,1 t_n$  or 3 mm. Larger misalignment results in a downgrading to Class F3 with no additional SCF.

Single-sided welds on temporary backing fall into class F with no SCF to allow for any axial misalignment. It has a tighter tolerance on maximum permissible axial misalignment, the lesser of  $0,1 t_n$  or 2 mm, to reflect the fact that provision for limited misalignment is already included in the S-N curve.

Alternatively, for both unbacked full penetration single-sided welds and welds made onto temporary backing, the Class E design curve may be used. It should be used in conjunction with SCF to allow for any axial misalignment, but neglecting the thickness effect correction,  $k_1 = 0$ ; see Reference [30].

### C.3.3.4 Machined or dressed girth welds

The C1 curve may be used for double-sided welds if machining of the weld surface to the base material is performed on both inside and outside of the weld (dressed flush). The machining has to be performed such that local stress concentration due to the weld is removed and any undercuts at the weld toe are removed. The category C1 weld may be increased to category C when high-quality welding is achieved and the weld is proved free from significant defects by extensive NDT; see Table C.3.

## C.3.4 Steel bolts

For bolts, fatigue cracks normally initiate at the thread root, so that the fatigue strength depends largely upon the shape of the thread root. For axially loaded steel bolts and threaded rods, the F1 curve may be used for cold-rolled threads with no subsequent heat treatment like hot galvanizing. For cut threads, the W3 curve is recommended. For bolt diameters  $> 25$  mm (0,984 in), the "thickness correction" factor should be applied.

For threaded bolts, the stress concentration at the root of the threads is increasing with increasing diameter. Based on fatigue tests, it is recommended to use  $k_1 = 0,40$  which may be assumed to include size effects due both to the notch itself and to the increased length of notch around circumference with increased diameter. The thickness exponent may be less for rolled threads. Thus, for purpose-made bolts with large diameters, it may be recommended to perform testing of some bolts to verify the fatigue capacity to be used for design.

## C.3.5 Workmanship

The fatigue life of a welded joint is strongly dependent on the local stress concentrations arising from surface imperfections, consisting of weld discontinuities and geometrical deviations, during the fabrication process.

Surface weld discontinuities are weld toe undercuts, cracks, overlaps, porosity, slag inclusions and incomplete penetration. Geometrical imperfections are defined as axial misalignment, angular distortion, excessive weld

reinforcement and otherwise poor weld shapes. Embedded weld discontinuities, like porosity and slag inclusions, are less harmful for the fatigue strength when kept below normal workmanship levels.

C.4 gives equations for calculating the SCFs due to fabrication tolerances for alignment of butt joints. The S-N curves recommended for welded joints are assumed to be relevant for imperfections within limits normally accepted according to good riser welding practices; see Table 18 (assumed normal tolerance limits for fabrication imperfections).

#### C.4 Stress concentration factors for girth-welded pipes

SCFs at pipe girth welds arise from geometrical misalignments; see Table C.3. This misalignment induces local secondary bending stress in the weld root and cap. For girth-welded pipes with misalignments, the hot-spot stress due to cyclic effective tension,  $\Delta T_e$ , and bending moment,  $\Delta M_{bm}$ , should be calculated as given in Equations (C.17) to (C.19):

$$S = K_m \times S_m = K_m \times \left[ \frac{\Delta T_e}{A_c} + \frac{\Delta M_{bm}}{2 \times I} \times (D_o - t_n) \right] \quad (C.17)$$

$$A_c = \pi \times (D_o - t_n) \times t_n \quad (C.18)$$

$$I = \frac{\pi}{64} \times \left[ D_o^4 - (D_o - 2 \times t_n)^4 \right] \quad (C.19)$$

where

$S$  is the hot-spot stress range;

$K_m$  is the geometric stress concentration factor;

$S_m$  is the membrane (average) component of the primary plus secondary principal stress range;

$A_c$  is the pipe cross-section area;

$I$  is the pipe moment of inertia;

$D_o$  is the specified or nominal pipe outside diameter;

$t_n$  is the nominal (specified) pipe wall thickness.

NOTE The nominal stress for a pipe bending moment is the mean diameter stress.

Misalignment in a girth-welded joint can take the form of an offset of the pipe wall centres (axial misalignment) and peaking (angular distortion). In either case, local through-wall secondary stresses are introduced in the joint when the pipe is subjected to axial loading and bending. The axial misalignment is the important misalignment to consider in design.

Riser welding practice aims to minimize angular distortion, which is likely to be present in a similar measure in actual risers and the test specimens used to generate the test data on which the design S-N curve is based. For a riser with high cyclic axial loads, angular misalignment may be evaluated.

The global SCF induced in a girth weld with the axial misalignment (eccentricity) can be estimated from Equations (C.20) and (C.21):

$$K_m = 1 + \frac{3 \times (e - e_0)}{t_n} \exp \left[ - \left( \frac{D_o}{t_n} \right)^{-0,5} \right] \quad (C.20)$$

$$e_0 = 0,1 \times t_n \quad (\text{C.21})$$

where

$e$  is the axial misalignment (eccentricity or centre line mismatch);

$e_0$  is the misalignment (eccentricity) inherent in the S-N data.

The axial misalignment that determines the SCF at a girth weld can be based on dimensional tolerances of the matching pipes. As shown in Figure C.8, the misalignment,  $e$ , can generally be expressed as function of the out-of-roundness, OOR, and the wall thickness of the matching pipes,  $t_{n,\max}$  and,  $t_{n,\min}$ . For the purpose of design, the maximum values of each source of eccentricity that may be applied are given in Equations (C.22) to (C.26):

$$e_{\text{OOR,max}} = D_{\text{o,max}} - D_{\text{o,min}} \quad (\text{C.22})$$

$$e_{t,\max} = \frac{t_{n,\max} - t_{n,\min}}{2} \quad (\text{C.23})$$

and

$$t_{n,\max} = t_n \times \left( 1 + \frac{\Delta t_{\text{pos}}}{100} \right) \quad (\text{C.24})$$

$$t_{n,\min} = t_n \times \left( 1 - \frac{\Delta t_{\text{neg}}}{100} \right) \quad (\text{C.25})$$

where

$e_{\text{OOR,max}}$  is the maximum misalignment resulting from out of roundness;

$D_{\text{o,max}}$  is the maximum outside diameter at any cross-section;

$D_{\text{o,min}}$  is the minimum outside diameter at any cross-section;

$e_{t,\max}$  is the maximum misalignment resulting from difference in wall thickness;

$t_{n,\max}$  is the maximum nominal wall thickness;

$t_{n,\min}$  is the minimum nominal wall thickness;

$\Delta t_{\text{pos}}$  is the percentage positive wall thickness tolerance;

$\Delta t_{\text{neg}}$  is the percentage negative wall thickness tolerance.

In the case that the total eccentricity is random, the different sources of eccentricity,  $e$ , may be obtained by adding quadratically each source of deviation as given in Equation (C.26):

$$e = \sqrt{e_{\text{OOR,max}}^2 + e_{t,\max}^2} \quad (\text{C.26})$$

For fabrication the maximum value of combined effects of eccentricity,  $e$ , should be specified.

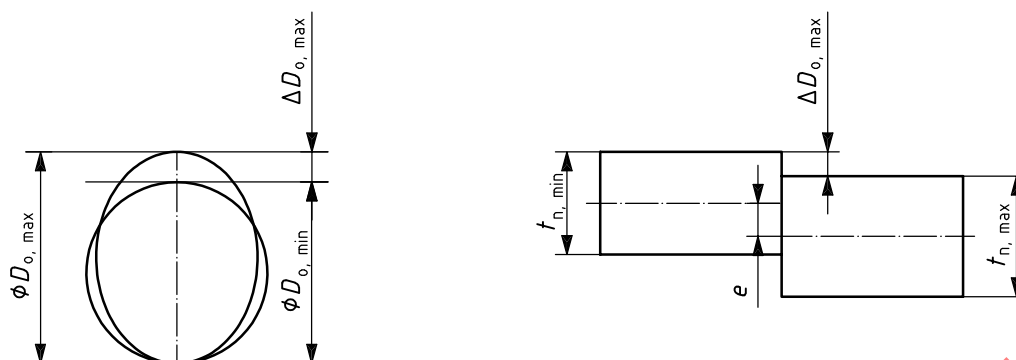


Figure C.8 — Misalignment of pipe butt welds

**EXAMPLE** For example, a 177,8 mm (7 in) outside diameter  $\times$  17,45 mm (0,687 in) seamless pipe can exhibit the following dimensional variations: a maximum OOR of 1,6 mm (0,063 in) and wall thickness variations of  $\pm 12,5\%$ . Using the expressions for maximum eccentricities and Equations (C.22), (C.23) and (C.26), the maximum SCF is calculated as 1,12 from Equation (C.20). Even with tighter tolerances on wall thickness and out-of-roundness at pipe ends, it is difficult to achieve  $SCF < 1,2$  with seamless pipes, unless special matching of ends to be welded is performed. Machining or counter-boring of the inside diameter of the pipes also reduces the SCFs.

## C.5 Global fatigue analysis

### C.5.1 General

The basis for fatigue damage calculations is global load effect analysis to establish the stress cycle distributions in a number of short-term environment conditions (sea-states).

Environment-induced fluctuating load effects can be imposed during all phases of the life of a C/WO riser including fabrication, transportation, installation/retrieval, hang-off and operation conditions. Both the open-sea and the tubing-hanging mode should be considered as appropriate. The following contributions to fatigue should be addressed: wave frequency stress cycles, low-frequency stress cycles and vortex-induced stress cycles. The two former are considered in C.5.2, while the latter is described in C.5.3.

### C.5.2 Wave and low-frequency analysis

The fatigue damage will generally have contributions from wave frequency as well as low-frequency stress cycles. The wave frequency vessel motions as well as direct wave loading on the riser will govern the wave frequency fatigue damage, while the low-frequency vessel motion will govern the low-frequency fatigue damage. The fatigue damage is a function of sea-state parameters, i.e. significant wave height,  $H_s$ , wave period,  $T_z$ , and mean wave direction,  $\theta_W$ .

A general approach for calculation of wave and low-frequency damage contributions is based on application of the following procedure.

- The wave scatter diagram is subdivided into a number of representative blocks (or all sea-states may be used).
- Within each block, a single sea-state is selected to represent all the sea-states within the block, typically the centre sea-state. The probabilities of occurrence for all sea-states within the block are lumped to the selected sea-state.
- The fatigue damage is computed for each selected short-term sea-state for all the blocks.

- The long-term fatigue damage,  $D_{SN}$ , is found as a weighted sum of the damages,  $D_{SN,ij}$ , induced by the individual short-term sea-states,  $j, (H_s, T_p)$ , and the main wave direction,  $(i, \theta_W)$ , as given in Equation (C.27):

$$D_{SN} = \sum_{i, \theta_W} \sum_{j, (H_s, T_p)} q_i \times q_j \times D_{SN,ij} \quad (C.27)$$

where

$H_s$  is the significant wave height;

$i$  is the wave direction number;

$\theta_W$  is the main wave direction;

$j$  is the sea-state number;

$q_i$  is the probability of wave direction  $i$ ;

$q_j$  is the probability of sea-state  $j$ ;

$T_p$  is the wave peak period;

$D_{SN,ij}$  is the fatigue damage in the sea-state,  $j$ , and wave direction,  $i$ .

Closed form expressions can be found for the expected Miner damage for narrow-band stress history; see C.6.2.

The fatigue sea-states normally utilize two-dimensional long crested sea. Fatigue wave conditions are specified by wave scatter diagrams and corresponding vessel offset. For top-tensioned C/WO risers, vessel static offset and current can be taken as zero for the purposes of wave-induced fatigue riser analysis. Long-term wave directionality should be accounted for in the damage calculation. Consideration may also be given to use of a short-term spreading sea correction factor.

The importance of non-linear effects should accordingly be carefully observed and accounted for. However, as compared to extreme response analysis, sea-states with lower significant wave height will typically dominate. Consequently, the degree of non-linearity is generally smaller. Accurate analyses of local responses in the splash zone, would require time domain analyses.

Vessel motions and wave-induced fatigue will generally lead to the most critical locations being near the upper end of the top tensioned C/WO riser (slick joint/splash zone) or in the stress joint region. Fatigue analysis should be performed only for weather conditions (sea-states) relevant for the use of the riser, i.e. within the operation limitations.

The longitudinal stress component is dominant for fatigue analysis of a plain riser pipe and hence the internal forces refer to bending moments and effective tension in specified elements. The contribution due to cyclic effective tension is normally low due to the heave compensating system (i.e. ideal tensioning system).

Fatigue assessment should be performed at eight equally spaced points around the circumference of the pipe, weld or component in order to identify the critical one.

The relative importance of wave frequency and low-frequency fatigue damage is system dependent and will vary with the location along the riser. It is recommended to do an assessment of the relative contributions from wave frequency and low-frequency stress cycles to the fatigue damage to support rational decisions regarding choice of method of analysis. Low-frequency fatigue damage may be disregarded if it is documented by proper analysis that the low-frequency damage is negligible when compared to the wave frequency fatigue.

### C.5.3 Vortex-induced vibrations

The C/WO riser system exposed to flow of seawater due to currents and waves may be subjected to a phenomenon commonly referred to as vortex shedding. Susceptibility to such vibrations depends on the coincidence of a structural natural frequency and a vortex shedding frequency acting over a substantial extent of the riser.

Vortex shedding may introduce cross-flow riser vibrations commonly termed vortex-induced vibrations. The cross-flow vibration amplitude is normally small when compared to the riser vibrations induced by the vessel motions. However, the high-frequency nature of vortex-induced vibrations means that it can add an important contribution to the fatigue damage, especially for deep-water risers. A comprehensive review of vortex-induced vibrations can be found in Vandiver<sup>[34]</sup> and Pantazopoulos<sup>[32]</sup>.

Several approaches are proposed to predict vortex-induced vibrations, response of tensioned risers, including simplified semi-empirical methodologies, numerical calculation of the viscous flow around the riser and tests. A comparison between different methods has been performed by Larsen and Halse<sup>[29]</sup>. This comparison showed large deviations between compared methods. The fundamental principle is that for cases where vortex-induced vibrations are likely to represent a design problem, refined assessment methods preferably supplemented by tests are required.

Many aspects of vortex-induced vibrations causing fatigue damage in C/WO risers are not understood. However, assessment should be performed to investigate the possible susceptibility for vortex-induced vibrations. Whenever practical, vortex-induced vibrations should be prevented. The possibility for vortex-induced vibrations may be reduced by modifying the properties of the riser by increased tension, increased damping or by introduction of vortex suppression devices. If vortex-induced vibrations are expected to cause significant fatigue damage, monitoring of the C/WO riser during operation should be considered.

## C.6 Cumulative fatigue damage calculations

### C.6.1 General

The development of fatigue damage under stochastic or random loading is, in general, termed cumulative damage. According to the form of stress history, the variable amplitude loading can be characterized as narrow-band loading [see Figure C.9, curve a)] or wide-band loading [see Figure C.9, curve b)]. Wave-frequency stress history and low-frequency stress history are each often assumed to be narrow-banded, however the combined stress history of wave frequency and low-frequency stress history is, in general, wide-banded. Closed-form damage expressions for narrow-banded stress histories are presented together with methods for estimation of fatigue damage of wide-banded stress histories.

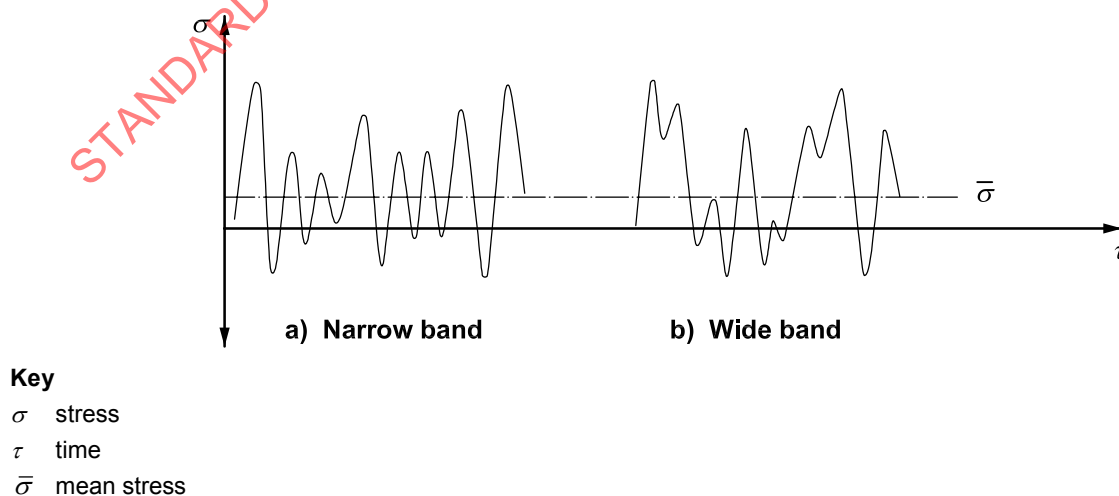


Figure C.9 — Narrow-band (a), and wide-band (b) stress history



## C.6.2 Narrow-banded fatigue assessment

### C.6.2.1 General

The basic assumption in narrow-banded fatigue damage estimation is that the stress-cycle range,  $S$ , can be determined directly from the stress maxima,  $S_{a,lm}$ , (amplitude). In a narrow-band process, the stress range is assumed twice the value of the corresponding value of the local stress maximum or stress amplitude as shown in Equation (C.28):

$$S = 2 \times S_{a,lm} \quad (C.28)$$

Furthermore, the number of stress cycles per unit time is given directly by the zero crossing frequency,  $\nu_0$ , of the stress response and is calculated directly from the stress response spectrum moments; see C.6.2.3. This model is conservative when the stress process is wide-banded.

The expected fatigue damage per unit time can for a linear S-N curve be expressed as given in Equation (C.29):

$$D_{FAT} = \frac{\nu_0}{\bar{a}} \int_0^{\infty} S^m \times f_s(S) dS = \frac{\nu_0}{\bar{a}} \times E(S^m) \quad (C.29)$$

where

- $D_{FAT}$  is the fatigue damage;
- $\nu_0$  is the average zero-crossing frequency of the stress response;
- $\bar{a}$  is the characteristic fatigue strength or intercept of the design S-N curve with the log  $N$  axis;
- $f_s(S)$  is the stress-cycle probability density function;
- $m$  is the negative inverse slope of the S-N curve.

The expected fatigue damage is hence directly related to the  $m$ th order moment,  $E(S^m)$ , of the stress-cycle probability density function. For a bilinear S-N curve, the corresponding expression becomes as shown in Equation (C.30):

$$D_{FAT} = \frac{\nu_0}{\bar{a}_2} \int_0^{S_1} S^{m_2} \times f_s(S) dS + \frac{\nu_0}{\bar{a}_1} \int_{S_1}^{\infty} S^{m_1} \times f_s(S) dS \quad (C.30)$$

where

- $\bar{a}_2$  is the intercept of the design S-N curve with the log  $N$  axis, right part of S-N curve;
- $S_1$  is the stress range at the point of discontinuity (bilinear S-N curve);
- $m_2$  is the negative inverse slope of the S-N curve, right part;
- $\bar{a}_1$  is the intercept of the design S-N curve with the log  $N$  axis, left part of S-N curve;
- $m_1$  is the negative inverse slope of the S-N curve, left part.

Equations (C.29) and (C.30) constitute the basic formulations for assessment of the short-term fatigue damage in each stationary environmental condition; see C.5.2. These equations can also be applied to compute the fatigue damage directly from the long-term distribution of stress ranges; see C.6.4.



### C.6.2.2 Narrow-banded Gaussian fatigue damage

If the stress response process is assumed narrow-banded and Gaussian, the distribution of local stress maxima (amplitude),  $S_{a,lm}$ , is defined by a Rayleigh probability density as given in Equation (C.31):

$$f(S_{a,lm}) = \left( \frac{S_{a,lm}}{\sigma_{SD}^2} \right) \times \exp \left( \frac{-S_{a,lm}^2}{2\sigma_{SD}^2} \right) \quad (C.31)$$

where

$S_{a,lm}$  is the local stress maxima (amplitude);

$\sigma_{SD}$  is the standard deviation of the stress response process.

For a linear S-N curve, the expression is given by Equation (C.32):

$$D_{SN,ij} = \frac{\nu_0 \times \tau_{ss}}{\bar{a}} \times (2\sqrt{2} \sigma_{SD})^m \times \Gamma \left( \frac{m}{2} + 1 \right) \quad (C.32)$$

where

$\tau_{ss}$  is the duration of short-term sea-states;

$\Gamma(\cdot)$  is the gamma function.

The gamma function is given by Equation (C.33):

$$\Gamma(\phi) = \int_0^{\infty} e^{-\tau} \times \tau^{\phi-1} d\tau \quad (C.33)$$

where  $\phi$  is a variable.

For a bilinear S-N curve, the corresponding expression can be obtained as:

$$D_{SN,ij} = \nu_0 \times \tau_{ss} \times \left\{ \frac{(2\sqrt{2}\sigma_{SD})^{m_1}}{\bar{a}_1} \times \Gamma \left[ \left( 1 + \frac{m_1}{2} \right); \left( \frac{S_1}{2\sqrt{2}\sigma_{SD}} \right)^2 \right] + \frac{(2\sqrt{2}\sigma_{SD})^{m_2}}{\bar{a}_2} \times \gamma \left[ \left( 1 + \frac{m_2}{2} \right); \left( \frac{S_1}{2\sqrt{2}\sigma_{SD}} \right)^2 \right] \right\} \quad (C.34)$$

where the complementary incomplete gamma function and incomplete gamma function are defined as given in Equations (C.35) and (C.36):

$$\Gamma(\phi; z) = \int_z^{\infty} \tau^{\phi-1} \times e^{-\tau} d\tau = \Gamma(\phi) - \gamma(\phi; z) \quad (C.35)$$

$$\gamma(\phi; z) = \int_0^z \tau^{\phi-1} \times e^{-\tau} d\tau \quad (C.36)$$

where

$\Gamma(\cdot; \cdot)$  is the complementary incomplete gamma function;

$\gamma(\cdot; \cdot)$  is the incomplete gamma function;

$\phi$  and  $z$  are variables.

The fatigue damage is hence directly expressed by the standard deviation and zero-crossing frequency of the stress response. This formulation is of special convenience for frequency domain analysis where the results from the global analysis are expressed in the form of the autospectral density,  $S_{\sigma\sigma}(\omega_{SR})$ , of the stress response, where  $\omega_{SR}$  is the angular frequency of the stress response.

The standard deviation,  $\sigma_{SD}$ , and zero-crossing frequency,  $\nu_0$ , are hence as given in Equations (C.37) and (C.38):

$$\sigma_{SD} = \sqrt{I_0} \quad (C.37)$$

$$\nu_0 = \frac{1}{2\pi} \times \sqrt{\frac{I_2}{I_0}} \quad (C.38)$$

where

$I_0$  is the zero-order moment of stress spectrum;

$I_2$  is the second-order moment of stress spectrum.

The  $n$ th order response spectral moment,  $I_n$ , is given by:

$$I_n = \int_0^{\infty} \omega_{SR}^n \times S_{\sigma\sigma}(\omega_{SR}) d\omega_{SR} \quad (C.39)$$

### C.6.2.3 Narrow-banded non-Gaussian fatigue damage

For time domain analysis, the two-parameter Weibull distribution model is frequently employed as a generalization of the Rayleigh distribution for the local maxima, i.e. for non-Gaussian stress response processes. The Weibull probability density function for the stress amplitude,  $S_{a,lm}$ , is given by Equation (C.40):

$$f(S_{a,lm}) = \alpha^{-\beta} \times \beta \times S_{a,lm}^{\beta-1} \times \exp \left[ - \left( \frac{S_{a,lm}}{\alpha} \right)^{\beta} \right] \quad (C.40)$$

where

$\alpha$  is the distribution scale parameter;

$\beta$  is the Weibull distribution dimensionless shape parameter.

NOTE The Rayleigh distribution in Equation (C.31) is obtained for  $\alpha = 2$  and  $\beta = \sqrt{2}\sigma_{SD}$ .

The Weibull distribution may be fitted to the short-term (or long-term) distribution of local maxima. The Weibull distribution parameters are linked to the statistical moments,  $\hat{\mu}_{st}$  and  $\hat{\sigma}_{st}$ , for the local maxima as shown in Equations (C.41) and (C.42):

$$\hat{\mu}_{st} = \alpha \times \Gamma \left( 1 + \frac{1}{\beta} \right) \quad (C.41)$$

$$\hat{\sigma}_{st} = \alpha \times \sqrt{\Gamma \left( 1 + \frac{2}{\beta} \right) - \Gamma \left( 1 + \frac{1}{\beta} \right)^2} \quad (C.42)$$

These equations can be used to establish moment estimates of the distribution parameters with basis in sample estimates,  $\hat{\mu}_{st}$  and  $\hat{\sigma}_{st}$ , from time domain simulations.

For a linear and bilinear S-N curve, the fatigue damage for a sea-state becomes as shown in Equations (C.43) and (C.44), respectively:

$$D_{SN,ij} = \frac{v_0 \times \tau_{ss}}{\bar{a}} \times (2\alpha)^m \times \Gamma\left(1 + \frac{m}{\beta}\right) \quad (C.43)$$

$$D_{SN,ij} = v_0 \times \tau_{ss} \times \left\{ \frac{(2\alpha)^{m_1}}{\bar{a}_1} \times \Gamma\left[\left(1 + \frac{m_1}{\beta}\right); \left(\frac{S_1}{2\alpha}\right)^\beta\right] + \frac{(2\alpha)^{m_2}}{\bar{a}_2} \times \Gamma\left[\left(1 + \frac{m_2}{\beta}\right); \left(\frac{S_1}{2\alpha}\right)^\beta\right] \right\} \quad (C.44)$$

It should be noted that the shape parameter,  $\beta$ , in the Weibull distribution has a significant impact on calculated fatigue damage. When the fatigue damage is calculated based on closed form solutions with an assumption of a Weibull long-term stress range distribution, a shape parameter to the safe side should be used.

### C.6.3 Wide-banded fatigue damage

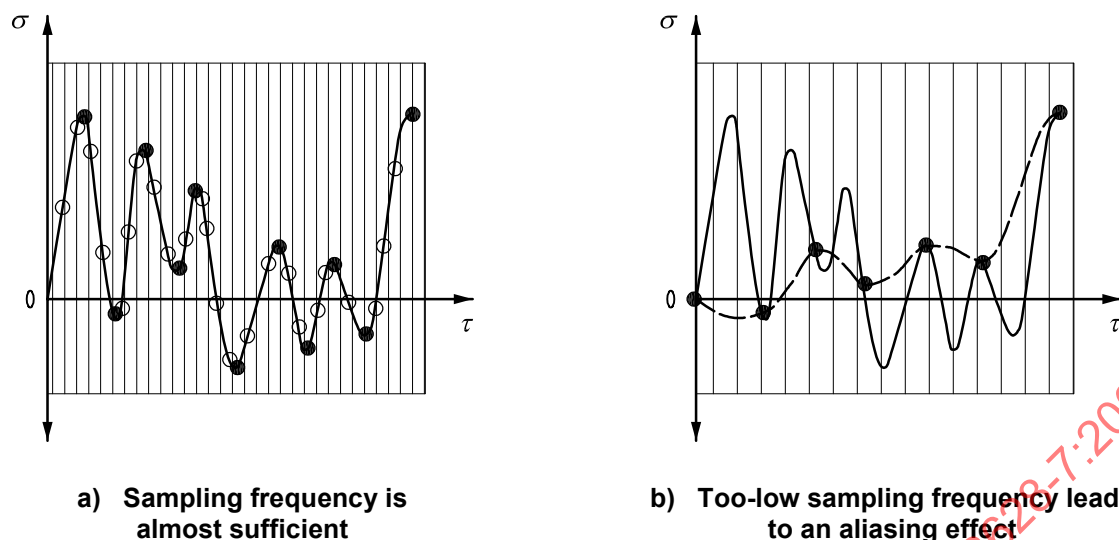
For risers, the stress response is normally neither narrow-banded nor completely wide-banded, see Figure C.10. In a wide-band response history there is no strict relationship between the stress cycles and stress maxima and minima. For this reason, the distribution of stress cycles cannot be evaluated from the distribution of stress maxima. Wide-band fatigue assessment is of special importance for fatigue assessment of combined wave frequency and low-frequency stress response. It is, in general, applicable to results from time domain analysis but can also be applied in connection with frequency domain analysis through a transformation of frequency domain results to time domain, by e.g. fast Fourier transformation simulation.

The following procedures may be applied to estimate fatigue damage for a wide-band process:

- cycle-counting algorithms;
- semi-empirical corrections based on a corrected narrow-band result; or
- simplified analytical solutions for bimodal spectra.

The general and recommended approach to calculate fatigue damage is by counting the stress cycles in the actual or simulated stress time series. Special purpose counting algorithms have been developed. The recommended method is the rainflow counting method.

The stress history recorded is digitized at short intervals, and peak and valleys are recognized; see Figure C.10 a). Using these, the rainflow counting is performed. It is important to use a sufficiently high enough sampling frequency such that the peaks and valleys are properly found. Otherwise, the so-called aliasing phenomenon occurs, and false cycles are found; see Figure C.10 b). The sampling frequency should be at least ten times higher than the highest frequency of the stress history.

**Key** $\sigma$  stress $\tau$  time**Figure C.10 — Method of finding the peaks and valleys**

The counting results are finally presented, e.g. as histogram plots of stress range versus the number (frequency) of fatigue stress cycles per unit time. The average mean stress and the standard deviation stress are also computed. However, the stress range primarily causes fatigue damage.

Instead of applying histogram plots, the corresponding cumulative distribution of stress cycles can be computed and fitted to an analytical model, e.g. a Weibull distribution.

**C.6.4 Long-term fatigue damage**

As an alternative approach to computation of fatigue damage for each sea-state, the long-term stress cycle distribution can first be obtained by summed weighting of cycle distributions for the different sea-states. The resulting distribution is subsequently fitted to an equivalent analytical distribution of the Weibull type. The corresponding fatigue damage is finally computed by application of the statistical parameters of this long-term distribution.

The long-term Weibull stress range distribution can be used to establish a stress histogram. Applying a histogram to express the stress distribution, the number of stress blocks,  $k$ , should be large enough to ensure reasonable numerical accuracy, and should not be less than 20. Due consideration should be given to selection of the integration method as the position of the integration points can have a significant influence on the calculated fatigue life dependent on the integration method. The part of the stress history contributing most significantly to the fatigue damage should be most carefully evaluated.

The Weibull distribution and the stress histogram are convenient for establishing

- fatigue design loads or interface fatigue load effects;
- optimizing SCF for components;
- fatigue crack growth assessment.

A fatigue analysis may be based on an expected stress history, which can be defined as expected number of cycles at each stress range level during the predicted life span. A practical application of this is to establish a long-term stress range history that is to the safe side. The part of the stress range history contributing most significantly to the fatigue damage should be most carefully evaluated.

The long-term stress range distribution may be expressed as a two-parameter Weibull distribution as given in C.6.2.3. This is done by only replacing the duration of the sea-state duration and the average zero-cross frequency with the service life,  $L_S$ , and the average zero-crossing frequency,  $\nu_{0,S}$ , for the service life, respectively. For a linear and bilinear S-N curve, the long-term fatigue damage becomes respectively:

$$D_{SN} = \frac{\nu_{0,S} \times L_S}{\bar{a}} \times (2\alpha)^m \times \Gamma\left(1 + \frac{m}{\beta}\right) \quad (C.45)$$

$$D_{SN} = \nu_{0,S} \times L_S \times \left\{ \frac{(2\alpha)^{m_1}}{\bar{a}_1} \times \Gamma\left[\left(1 + \frac{m_1}{\beta}\right); \left(\frac{S_1}{2\alpha}\right)^\beta\right] + \frac{(2\alpha)^{m_2}}{\bar{a}_2} \times \Gamma\left[\left(1 + \frac{m_2}{\beta}\right); \left(\frac{S_1}{2\alpha}\right)^\beta\right] \right\} \quad (C.46)$$

## C.7 Fatigue crack growth assessment

Fracture mechanics may be used for fatigue analysis as supplement to S-N data.

Fracture mechanics is recommended for use in assessment of acceptable defects, evaluation of acceptance criteria for fabrication and for planning of in-service inspection for fatigue cracks. It accounts explicitly for the presence of crack-like defects and enables prediction of their growth with number of stress cycles to be quantified.

Crack propagation calculations typically contain the following main steps.

- Determination of the expected long-term distribution of membrane (nominal) stress range.
- Selection of the appropriate crack growth law with appropriate crack growth parameters for the relevant environment; see BS 7910 [16] or API RP 579 [10]. The crack growth parameters should be determined as mean plus 2 standard deviations.
- Estimation of the expected (50 % probability of detection) initial crack size left after manufacture, fabrication and applied NDT methods or expected size of any found defect.
- Determination of cyclic crack growth in the prospective crack growth plane.
- Determination of final crack size.
- Integration of the fatigue crack propagation relation with respect to the long-term stress range distribution to determine the number of design crack growth cycles.

In a fracture mechanics based fatigue assessment, the amount a crack extends during each fatigue cycle,  $da/dN$ , is a function of the cyclic stress intensity factor,  $\Delta K$ , as follows:

$$\Delta K = S \times Y \times \sqrt{\pi \times a} \quad (C.47)$$

where

$S$  is the nominal (membrane) stress range;

$Y$  is the stress intensity correction factor;

$a$  is the crack depth for surface flaws or half depth for embedded crack.

Once  $\Delta K$  is calculated, the resulting crack growth per cycle,  $da/dN$ , can be found from the linear material growth constants,  $C$ , and,  $k_{cg}$ :

$$\frac{da}{dN} = C \times (\Delta K)^{k_{cg}} \quad (C.48)$$

The calculated number of design cycles to failure,  $N_p$ , is the number of cycles required to propagate a crack from the initial crack size,  $a_0$ , to the allowable final crack depth,  $a_f$ . This may be found by integration of the Paris equation as shown in Equation (C.49):

$$N_p = \int_{a_0}^{a_f} \frac{da}{C \times (\Delta K)^{k_{cg}}} \quad \Delta K > \Delta K_{th} \quad (C.49)$$

where  $\Delta K_{th}$  is the threshold stress intensity factor range below which fatigue crack growth does not occur.

Guidance regarding fatigue crack analysis, i.e. crack propagation equations, crack growth parameters,  $C$  and  $k_{cg}$ , crack growth threshold range, stress intensity factor range calculation, etc. can be found in BS 7910 [16], API RP 579 [10] or other recognized code.

The fatigue crack growth analysis should allow for crack growth in both depth and width directions and account for the through-thickness and circumferential stress distribution normal to the assumed crack growth propagation plane.

The initial crack size to be used for the calculation of the crack propagation design cycles should be based on the NDT method to be used or used. If the NDT used measures the length of a surface indication, an assumption should be made regarding the depth and shape of an assumed initial crack. A surface defect at a stress concentration, e.g. the weld toe or root, should be assumed to be semi-elliptical with a ratio of depth to total surface length greater than 5. The initial crack size used can be based on the NDT capability, defined as the 50 % probability of detection level for the applied method.

For surface cracks starting from the transition between weld/base material, a crack depth of 0,15 mm may be assumed if no other documented information is available. These surface cracks are due to undercuts and micro-cracks at the bottom of the undercuts. The crack depth to total surface length ratio assumed should be low, e.g. less than 1:5. Light grinding of these locations may be considered to remove undercuts, increase reliability of the NDT and improve fatigue quality.

For single-sided girth welds, lack of penetration defects at the weld root is hard to detect by NDT. Typical defect depths between 1,0 mm and 2,0 mm may be considered as practical limits of root flaw detection with current UT technology. In cases of good-quality UT, an initial weld root crack size of 1,5 mm  $\times$  10 mm may be used for fatigue assessment. Tungsten inert gas welding of the root pass in combination small girth weld eccentricities may be considered to improve weld root fatigue quality. Preparing pipes/components with internal upset and machining of the root pass may also be considered to improve the fatigue quality.

The allowable final crack size should not be deeper than a quarter wall thickness; see 7.2.10 (normal practice) or the critical crack size determined from a failure assessment diagram analysis; see BS 7910 [16] and API RP 579 [10].

It is normally assumed that compressive stresses do not contribute to the crack propagation. However, for welded components containing residual stresses, the entire stress range should normally be applied, regardless of the mean level. Only stress components normal to the propagation plane need to be considered.

The number of design cycles may be calculated by numerical integration of the crack growth rate. To ensure that the interval of crack depth/width is sufficiently small, the calculation should be repeated using intervals of decreasing size until no significant change in the calculated number of design cycles is obtained.

The defect size used in the calculation of the crack propagation cycles for found defects should be based on the accuracy of the used equipment in determining length, height, location and orientation of crack-like defects.

Known fatigue cracks are allowed for the C/WO in operation. For repair of found defects by grinding, see guidance in C.8.2.

## C.8 Improvements of fatigue life by fabrication

### C.8.1 General

The methods for increasing the fatigue strength of welded joints can be categorized into two basic categories:

- weld defect removal and weld profile modifications, e.g. machining methods like burr/disc grinding or remelting methods like tungsten inert gas/plasma dressing;
- residual stress methods, e.g. peening methods or overload methods.

It should be noted that improvements of the toe will not improve fatigue life if fatigue cracking from the root is the most likely failure mode. The considerations made in the following are for conditions where the root is not considered the critical initiation point. The most common methods for improving the fatigue life during fabrication of a C/WO riser are weld profiling, grinding, tungsten inert gas dressing and hammer peening. Only weld grinding is covered here. Peening of local areas, like weld toes, is applied together with grinding where grinding serves the purpose of removing stress raisers, such as surface defects, and to define a steering groove for the tool in the area to be peened. Both grinding and peening require skills and preparations not normally available in fabrication yards. For more information, see DNV RPC-203<sup>[17]</sup>, Fatigue Handbook<sup>[27]</sup> and Haagensen<sup>[28]</sup>.

### C.8.2 Grinding of welds

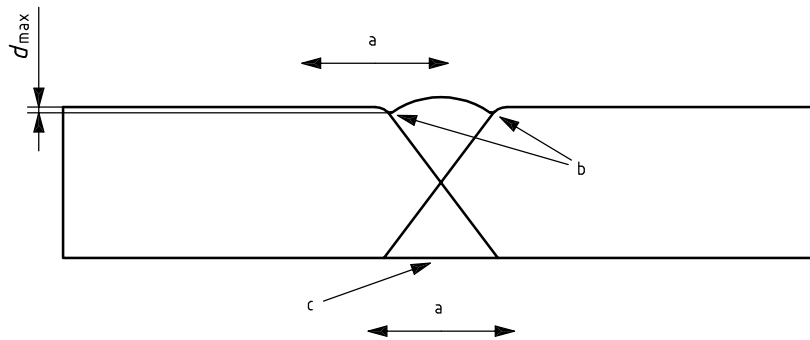
For welded joints involving potential cracking from the weld toe, an improvement in fatigue strength by a factor of at least two on the fatigue life can be obtained by controlled local machining or grinding of the weld toe. This is done by giving the toe a favourable shape to reduce the notch SCF and to remove harmful defects at the toe; see Figure C.11. The following should be noted.

- For removal of undercuts the toe of the weld should be blended in a smooth transition and extended below the surface in order to remove the toe defects.
- Grinding should extend below the surface to a minimum 0,5 mm (0,020 in) below the bottom of any visible undercut and ensuring that no exposed defects remain, using a rotary burr grinder. Grinding marks should be at right angles to weld axis and under no circumstances parallel to it.
- The maximum depth of grinding should not exceed 2 mm (0,079 in) or 5 % of the thickness, whichever is smaller.
- The minimum diameter of the rotary burr should be 6 mm (0,236 in) generating a minimum radius of weld profiles after blending of less than 6 mm (0,236 in).
- Upon completion of blending of the toe, the whole of the ground surface should be inspected with 100 % visual inspection and 100 % MPI.
- Ground surface should be free of any cracks or crack-like indications and there should be no evidence of undercut or overlap.

The grinding should be performed according to a detailed procedure. Grinding tools, direction, surface roughness and final profile should be specified. Reference samples of typical joints and sections may be prepared and used for acceptance of treated welds.

The benefit of grinding may be claimed only for welded joints in air or adequately protected from seawater corrosion.

Grinding also improves the reliability of inspection after fabrication and during design life.

**Key**

$d_{\max}$  maximum depth below surface for blend

- a Grinding direction.
- b Blend out to remove edge of undercut.
- c Remove overlap flush with pipe surface.

**Figure C.11 — Grinding of the weld toe**

## C.9 Extended fatigue life

An extended fatigue life may be considered when the calculated fatigue life is longer than the total service life times the fatigue design factor. Otherwise, an extended life may be based on results from hot-spot inspections performed throughout the life of the riser. Such an evaluation should be based on

- calculated crack growth analysis presenting crack growth characteristics, i.e. crack length/depth as function of time/number of cycles;
- reliability of inspection methods used and elapsed time from last inspection performed. It is recommended to use eddy current or MPI for inspection of surface cracks.

For welded connections that are ground and inspected for fatigue cracks, the following procedure may be used for calculation of an extended fatigue life. Provided that material is removed by grinding to a depth of approximately 1,0 mm (0,039 in) below the surface and that no fatigue cracks are found by a detailed MPI of the considered hot-spot region at the weld toe, the fatigue damage at this hot spot may be considered to start again at zero. If a fatigue crack is found, a further grinding should be performed to remove any indication of this crack. If more than 10 % of the thickness is removed by grinding, the effect of this on the increased stress should be included when a new fatigue life is assessed and also for the ultimate strength checks like burst and excessive yielding.

It should be noted that fatigue cracks growing from the weld root can hardly be detected by NDT. In addition, the fatigue life of such regions cannot be improved by grinding of the surface.

It should also be remembered that if renewal of one hot-spot area is performed by local grinding due to found cracks, there are likely to be other areas close to the considered hot-spot region that are not ground and that also experience significant cyclic loading and may contain initial fabrication defects.