Title:

System requirements for primary load bearing components/structures in subsea systems subjected to loads from drilling, completion, workover and well intervention operations.

Prepared by:

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Task group lead for ISO 13628-7

Revision: 3

Scope of proposal:

The proposal specifies requirements for design principles, loads and load effect analysis for primary load bearing components/structures in subsea systems subjected to loads from drilling, completion, workover and well intervention operations. These requirements are intended to ensure subsea well system integrity during life of field operations. The relevant sections of this proposal should be included into ISO 13628-1 and ISO 13628-4.

Motivation

1) In ISO 13628-1:2005 5.4, 5.6.2.2 and 5.7.3.5 general system requirements are specified with regard to well system and barrier integrity during drilling and well intervention from temporary riser systems (i.e. drilling and C/WO risers). Code break inconsistencies between typical riser codes/standards and component codes/standard makes documentation of system compliance difficult to perform. It is proposed that overall system design requirements and acceptance criteria for the primary load bearing structure(s) subject to riser loads (e.g. riser, BOP, subsea tree, wellhead, conductor, template etc.) are specified in ISO 13628-1, that ensure subsea well system integrity during life of field operations.

2) Components within the scope of ISO 13628-4 form part of the primary load bearing structure. Part 4 is a component standard and therefore, cannot take account of overall system requirements. These components are design based on rated capacity (i.e. pressure rating based design) in accordance with ISO 10423 (i.e. surface tree design specification). Part 4 does not give any guidance on how to account for extreme and accidental loads. Part 4 does not give any guidance or requirements for determination of component capacities for applicable limits states that ensure compliance with overall system requirements.

3) Components within the scope of ISO 13628-7 form part of the primary load bearing structure. Part 7 is a sub-system standard and therefore, cannot take account of overall system requirements. Design requirements in Part 7 are based on limit state design and account for relevant failure modes and normal, extreme and accidental loading conditions. Material, qualification and documentation requirements ensure documentation of overall system requirements.
4) Components with the scope of ISO 13553 (API 16A) form part of the primary load bearing structure. ISO 13553 is a component standard and therefore, cannot take account of overall system requirements. These components are design based on rated capacity (i.e. pressure rating based design). ISO 13553 does not give any guidance on how to account for extreme and accidental loads. ISO 13553 does not give any guidance or requirements for determination of component capacities for applicable limits states that ensure compliance with overall system requirements.

5) Components within the scope of API RP 16Q form part of the primary load bearing structure. API 16Q is a sub-system standard and therefore, cannot take account of overall system requirements. Design requirements in API RP 16Q are based on working stress design method and accounts for normal and extreme loading conditions only. Accidental loading conditions are outside the scope of API RP 16Q.

6) It is normal practice to use ISO 10423 (API 6A) BX flanges for the connection of components which part of the primary load bearing structure. It widely accepted that ISO 10423 BX flanges are not suitable for dynamic applications if face-to-face contact is not guaranteed. The flange capacities specified in API Bul 6 AF1, AF2 and AF3 are none conservative for dynamic applications. ISO 13628-4 and 13628-7 highlight this issue and specify flange preload requirements to ensure face-to-face contact, but do not specify suitable capacities based on limit state methodology. This situation makes documentation of compliance with the overall system requirements a variable (i.e. engineer dependant) involved process (i.e. plastic finite element analysis is required).

7) Subsea templates, well conductor and casings are at present within the scope of ISO 13628-1. Design methodology to account for interface with components within the scope of ISO 13628 parts 1,4 and 7, ISO 13553, API RP 16Q is not specified.

**Method of execution:**

It is recommended that a top down approach is used for the implication of these requirements. Overall system design requirements and acceptance criteria should be given in ISO 13628-1. Detailed requirements should be addressed in the sub system and components standards (i.e. parts 4 and 7). The task group leaders of these two standards should agree on how to implement the proposed requirements.

Specification of these design requirements and acceptance criteria is considered to be the first step in harmonisation of ISO 13628-1 with other relevant code standards. It is recommended that the future work items listed below are implemented to ensure further harmonisation.

**Future Work Items:**

1) Material requirements for pressure containing load bearing structures are presently given in ISO 13628-7. For the future it is recommended that a separate material standard is developed for the ISO 13628 series of standards.

2) ISO 13553 and API RP 16Q are not within the scope of ISO/TC67/SC/WG6 and API 17 series committee. It is proposed that a work item is established to ensure harmonisation of design, qualification, material and component capacity documentation requirements with ISO 13628.

3) A work item should be established to document the capacity of ISO 10423 BX flanges for dynamic applications. These capacities could either be published a separate technical report/bulletin or as an annex in ISO 13628-4.
4) A work item should be established to development minimum requirements for a design methodology that ensures well system integrity. This methodology should address the following:

i) Failure modes;

ii) Loads and load effects;

iii) Design capacities;

iv) Wellhead, conductor, guide base or template interface;

v) Soil, conductor, guide base or template interaction;

vi) Sensitivities to casing program, cement shortfall and seabed scour;

vii) Sensitivities to water depth and riser operating parameters;

viii) Vessel motions characteristics;

ix) marine drilling riser operating parameters.
Key
1  Wave motions due to first order wave motions
2  Draw works tension and stroke
3  Surface equipment
4  Surface pressure (Choke or mud-pump)
5  Slick joint
6  Drill floor
7  Tensioner sheaves
8  Tensioner tension and stroke
9  Tensioner joint
10 Outside diameter
11 Riser joints
12 Bending stiffness
13 External pressure
14 Stress joint
15 Subsea equipment
16 Soil restraint
17 Tool
18 Conductor bending stiffness
19 Upstream
20 Downstream
21 Excitation zone
22 Shear zone
23 Damping zone
$F_{w,c}$ Wave and current forces
$F_G$ Gravity forces
$T_e$ Effective tension
$V_w$ Wave velocity
$V_c$ Current velocity
$L_{so}$ Vessel offset (+)

Principal parameters involved in the design and analysis of riser and wellhead systems.
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1 Normative References


ISO 19900, Petroleum and natural gas industries: General requirements for offshore structures.


API RP 2A-LFRD\(^1\), Recommended Practice for Planning, Designing and Constructing Fixed Offshore Structures – Load and Resistance Factor Design.

API RP 2RD\(^2\), Recommended Practice for Design of Risers for Floating Productions (FPSs) and Tension-Leg Platforms (TLPs).

API RP 16Q\(^3\), Recommended Practice for Design, Selection, Operation and Maintenance of Marine Drilling Riser Systems.

DNV OS F-201. Dynamic Risers

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1) For the purposes of this part of ISO 13628, API RP 2A-LFRD will be replaced by ISO 19912 when it becomes publicly available.

2) For the purposes of this part of ISO 13628, API RP 2RD will be replaced by ISO 13628-11 when it becomes publicly available.

3) For the purposes of this part of ISO 13628, API RP 16Q will be replaced by ISO 13624 when it becomes publicly available.
2 Terms, definitions, abbreviated terms and symbols

2.1 Terms and definitions

2.1.1 Limit state design method
Limit state design is a design method that results in sufficient safety against all relevant failure modes (i.e. limit states) during the intended life of the subsea system.

2.1.2 Primary load bearing structure
Structural elements and components that are essential for the overall integrity of the structure.

2.1.2 Mechanical connector
mechanical device used to connect adjacent components that can resist applied loads and prevent leakage

2.2 Abbreviated terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LRFD</td>
<td>load and resistance factor design</td>
</tr>
<tr>
<td>WSD</td>
<td>Working stress design</td>
</tr>
</tbody>
</table>

3 Design Requirements

This clause specifies requirements for design principles, loads and load effect analysis for primary load bearing components/structures in subsea systems subjected to loads from drilling, completion, workover and well intervention operations.

3.1 Scope

These design requirements shall apply for the following drilling and well intervention operations from a floating vessel:

b) Drilling;

c) C/WO operations;

d) Subsea wireline well intervention;

e) Subsea coiled tubing intervention;

f) Other drilling or well intervention methods.

These design requirements shall be apply for the relevant primary load bearing components subjected to riser and intervention equipment loads within the scope of the following standards:

— ISO 13628-1;

— ISO 13628-4;
Typical primary load bearing components/structures within the scope of these standards are listed in Table 1

**Table 1 — Typical primary load bearing components/structures**

<table>
<thead>
<tr>
<th>ISO 13628-1</th>
<th>ISO 13628-4</th>
<th>ISO 13628-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsea trees</td>
<td>Subsea wellheads</td>
<td>Lower workover riser package</td>
</tr>
<tr>
<td>Low pressure conductors</td>
<td>Tree connectors</td>
<td>Conductor housings</td>
</tr>
<tr>
<td>High pressure intermediate casings</td>
<td>Tubing heads</td>
<td>Conductor housing pup joints</td>
</tr>
<tr>
<td>Production guide base</td>
<td>Valves and valve blocks</td>
<td>Wellhead housings</td>
</tr>
<tr>
<td>Subsea templates</td>
<td>Re-entry interfaces</td>
<td>Wellhead housing pup joints, also called a wellhead extensions</td>
</tr>
<tr>
<td>High pressure production casing/tubing</td>
<td>Tree caps</td>
<td>Permanent guide bases</td>
</tr>
<tr>
<td>Tree running tools a</td>
<td>Temporary guide bases</td>
<td></td>
</tr>
<tr>
<td>Tubing Hanger Systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tubing hangers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Running tools</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Components and systems that are outside the scope of these requirements are:

— All components in the scope of ISO 13628-4 which are outside the primary load bearing path.

— Mudline suspension systems and drill through mudline suspension systems as defined in ISO 13628-1 and 13628-4 are outside the scope of these requirements.

### 3.2 Design Methods

The limit state design method shall be used for the design of the components included in the scope of this specification.

For pressure containing primary load bearing components included in the scope of ISO 13628-1, ISO 13628-4 and ISO 13628-7 shall be designed by the working stress design method (WSD) in accordance with ISO 13628-7.

For fabricated primary load bearing components/structures included in the scope of ISO 13628-1 and ISO 13628-4 may be designed by the WSD or the load and resistant design method (LRFD) in accordance with internationally recognised standards such as ISO 19900, API RP 2A-LFRD and API RP 2A-WSD.
3.2.1 Working Stress Design

Design method where the structural safety margin is expressed by one central safety factor for each limit state. The central safety factor is the ratio between a resistance and the load effect.

\[
U = \frac{S_d}{R_d} = \frac{\text{Design load effect}}{\text{Design capacity (resistance)}} = \frac{S_d}{F_d \times R_{uc}} \leq 1.0
\]  

(1)

where

- \( U \) is the utilization;
- \( S_d \) is the design load effect upper fractiles or maximum values;
- \( R_d \) is the design capacity (resistance);
- \( F_d \) is the design factor (inverse of safety factor);
- \( R_{uc} \) is the characteristic capacity (resistance) lower fractiles or minimum values (mean – 2SD) e.g. structural, preload and leakage capacities.

3.2.2 Load and resistance factor design

Design format based upon a limit state and partial safety factor methodology. The partial safety factor methodology is an approach where separate safety factors are applied for each load effect (response) and resistance term.

\[
S_d(\gamma_F \cdot S_k) \leq \frac{R_d}{\gamma_M}
\]  

(2)

where

- \( S_d \) is the design load effect, upper fractiles or maximum values;
- \( S_k \) is the design load effect;
- \( \gamma_F \) is the load effect factor for functional, environmental and accidental loads;
- \( R_d \) is the design capacity (resistance);
- \( \gamma_M \) is the resistance factor to account for material and resistance uncertainties.

3.2.3 Fatigue safety format

\[
\frac{L_F}{D_F} \geq L_S
\]  

(3)

where

- \( L_F \) is the calculated fatigue life;
\( D_F \) is the design fatigue factor;

\( L_S \) is the service life;

### 3.3 Material design strength

For pressure containing, primary load bearing components designed by the WSD method, material design strength and properties shall be in accordance with ISO 13628-7:2005, 6.4.6.

For fabricated, primary load bearing structural components/structures design by the WSD or LRFD method, material design strength and properties shall be in accordance with internationally recognised standards such as ISO 19900, API RP 2A-LFRD and API RP 2A-WSD.

### 3.4 Leakage criteria

Component leakage criteria shall comply with ISO 13628-7:2005, 6.4.11.5. These criteria are summarised in Table 2.

#### Table 2 — Component leak tightness requirements

<table>
<thead>
<tr>
<th>Load Condition</th>
<th>Leak tightness requirement due to internal over pressure</th>
<th>Leak tightness requirement due to external over pressure b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrostatic body test</td>
<td>Liquid</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Normal</td>
<td>Gas</td>
<td>Liquid</td>
</tr>
<tr>
<td>Extreme</td>
<td>Gas</td>
<td>Liquid</td>
</tr>
<tr>
<td>Accidental</td>
<td>Liquid a</td>
<td>Not applicablec</td>
</tr>
</tbody>
</table>

a Components should be liquid tight during the accidental event. Following an accidental event all connections in the primary barrier envelope shall be gas tight.

b For bi-diectonal seals the leakage criteria for internal over pressure shall apply.

c External leakage is acceptable provided that following an accidental event all connections in the primary barrier envelope shall be gas tight.

### 3.5 Design factors

#### 3.5.1 Structural

For pressure containing, primary load bearing components designed by the WSD method, the following design factors shall apply:

a) excessive yielding design factors, \( F_d \) shall comply with ISO 13628-7:2005, 6.4.7;

b) burst design factors, \( F_d \) shall comply with ISO 13628-7:2005, 6.4.7;

c) hoop buckling design factors, \( F_{hb} \) shall comply with ISO 13628-7:2005, 6.5.2.3;

d) fatigue design factor, shall comply with ISO 13628-7:2005, 6.4.9.

For fabricated, primary load bearing structural components/structures design by the WSD or LRFD method, design factor and load and resistance factors shall be in accordance with internationally recognised standards such as ISO 19900, API RP 2A-LFRD and API RP 2A-WSD.
3.5.2 Preload

Design factors for structural preload of mechanical connector's applicable for the WSD method are specified in Table 3.

Table 3 — Design factors for preload of mechanical connectors

<table>
<thead>
<tr>
<th>Load Condition</th>
<th>Design Factor, $F_d$ for hub face separation (i.e. loss of preload) of mechanical connectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make-up</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Hydrostatic body test</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Normal</td>
<td>1.0 a</td>
</tr>
<tr>
<td>Extreme</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Accidental</td>
<td>Not applicable b</td>
</tr>
</tbody>
</table>

a In cases where hub face separation is allowed for normal operation, necessary performance qualification testing shall be performed to qualify the connector for its application. Qualification testing shall document both sealing integrity and fatigue integrity are maintained for the field life.

b Following an accidental there shall be no loss in preload of connections in the primary barrier envelope.

3.5.3 Leakage

Design factors for leakage of mechanical connector's applicable for the WSD method are specified in Table 4.

Table 4 — Design factors for leakage mechanical connectors

<table>
<thead>
<tr>
<th>Load Condition</th>
<th>Design Factor, $F_d$ for leakage (internal and external overpressure) of mechanical connectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make-up</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Hydrostatic body test</td>
<td>1.0</td>
</tr>
<tr>
<td>Normal</td>
<td>1.0</td>
</tr>
<tr>
<td>Extreme</td>
<td>1.0</td>
</tr>
<tr>
<td>Accidental</td>
<td>1.0</td>
</tr>
</tbody>
</table>
3.6 Loads and load effects

All relevant loads transferred to the subsea facilities during drilling, completion, workover, intervention and production operations, shall be analysed and accounted for. Codes and standards applicable for the determination of loads and load effects are listed.

**Table 5 — Codes and standards for determination of loads and load effects**

<table>
<thead>
<tr>
<th>Operations</th>
<th>Applicable code requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling</td>
<td>ISO 13628-1:2005 5.6.2.2</td>
</tr>
<tr>
<td></td>
<td>ISO 13628-1:2005 5.4</td>
</tr>
<tr>
<td></td>
<td>API RP 2RD</td>
</tr>
<tr>
<td></td>
<td>API 16Q</td>
</tr>
<tr>
<td></td>
<td>DNV-OS-F-201</td>
</tr>
<tr>
<td>Completion, workover and well intervention</td>
<td>ISO 13628-1:2005 5.7.3.5</td>
</tr>
<tr>
<td>Subsea wire and coiled tubing</td>
<td>ISO 13628-7 clause 6.3</td>
</tr>
<tr>
<td>Through tubing rotary drilling</td>
<td>ISO 13628-7 clause 6.3 plus additional requirements to account for drilling phase</td>
</tr>
</tbody>
</table>
3.7 Connector capacities and loading conditions criteria

3.7.1 Capacities

Connector capacities should be determined by plastic analysis in accordance ISO 13628-7:2005 Annex D 2.4. Verification of the calculated capacities shall be verified by test in accordance and verified by testing in ISO 13628-7:2005 Annex D 2.4.

3.7.2 Loading conditions Criteria

Connector capacities for three operating conditions: normal (working), extreme, and accidental (survival) shall be determined. The criteria for each loading condition shall be as specified in Table 6.

<table>
<thead>
<tr>
<th>Loading Condition</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal (working) conditions:</td>
<td>The lower of:</td>
</tr>
<tr>
<td></td>
<td>1) 2/3 of structural (plastic) capacity, $F_d=0.67$; or</td>
</tr>
<tr>
<td></td>
<td>2) Hub face preload (start separation) capacity, if applicable; or</td>
</tr>
<tr>
<td></td>
<td>3) Leak tightness capacity (internal) for applicable fluids for connectors that separate at normal conditions; or</td>
</tr>
<tr>
<td></td>
<td>4) Leak tightness capacity (external) for applicable fluids for connectors that separate at normal conditions.</td>
</tr>
<tr>
<td>Extreme conditions</td>
<td>The lower of:</td>
</tr>
<tr>
<td></td>
<td>1) 80% of structural (plastic) capacity, $F_d=0.8$; or</td>
</tr>
<tr>
<td></td>
<td>2) Leak tightness capacity (internal) for applicable fluids.</td>
</tr>
<tr>
<td>Accidental (survival) conditions:</td>
<td>The lower of:</td>
</tr>
<tr>
<td>Permanent equipment</td>
<td>1) 90% of structural (plastic) capacity, $F_d=0.9$; or</td>
</tr>
<tr>
<td></td>
<td>2) Loss of connector preload; or</td>
</tr>
<tr>
<td></td>
<td>3) Leak tightness capacity for applicable fluids</td>
</tr>
<tr>
<td>Temporary equipment</td>
<td>The lower of:</td>
</tr>
<tr>
<td></td>
<td>1) 100% of structural (plastic) capacity, $F_d=1.0$; or</td>
</tr>
<tr>
<td></td>
<td>2) Loss of connector preload $b$; or</td>
</tr>
<tr>
<td></td>
<td>3) Leak tightness capacity for applicable fluids</td>
</tr>
</tbody>
</table>

$^a$ Following an accidental event, the connections shall be gas tight (internal) and liquid tight (external) for normal and extreme conditions.

$^b$ Following an accidental event there should be no significant loss of connector preload.
4 Material Requirements

4.1 Pressure containing primary load bearing structures

Material requirements pressure containing primary load bearing components shall comply with ISO 13628-7:2005, 7.0.

If any other material requirements are to be used they shall be based on prolongation samples satisfying the material requirements given in 13628-7:2005, Table 15.

4.2 Fabricated primary load bearing structures

For fabricated, primary load bearing structural components/structures design by the WSD or LRFD method, material requirements shall be in accordance with internationally recognised standards such as ISO 19900, API RP 2A-LFRD and API RP 2A-WSD.
Annex A
(normative)

Performance verification (qualification) of wellhead connectors

A.1 Introduction

This annex addresses performance verification (qualification) of wellhead, tree, tree cap, LRP, and EDP connectors.

Note: The scope of ISO 13628-4 includes LRP and EDP connectors, see Table 1 in ISO 13628-7. Functional and design requirements for LRP and EDP connectors are given in ISO 13628-7.

A.2 General principles

Connectors shall be qualified to demonstrate that the design and functional requirements specified for the connector have been met.

The performance verification (qualification) program shall include calculations, physical full scale testing and a bridging document comparing calculations and testing and concludes on the capabilities of the connector.

Calculations shall be performed to identify design limitations/safety margins, e.g. ultimate (failure) capacities, dimensional tolerances, coefficient of friction, etc. Some of the tests shall be continued until failure occurs, e.g. maximum number of lock/unlock the connector can sustain, gasket leakage (hub face separation limits) and structural failure, to verify calculated design limitations/safety margins.

The qualification shall be based on the following principles:

a) Functional requirements shall be quantified and compliance with requirements shall be documented by the qualification. The following shall be considered:

1) Establish the relationship between lock pressure/roll over pressure and minimum hub face preload, i.e. determine the mechanical advantage and coefficient of friction of the connector locking mechanism for applied lubrication and applicable environments (air and submerged in sea water).

2) Demonstrate lock/unlock ability for field condition and repeatability of proper lock/unlock.

3) Field maximum landing speed with maximum alignment set down weight (max/min) for landing/locking and over-pull for unlocking/disconnect.

4) For tapered locking mechanism the following shall be determined:

   i) minimum down-stroke to ensure sufficient structural strength and maximum down-stroke to avoid stroke out; and

   ii) minimum unlock pressure to prevent unintended release during operation.

b) Structural, hub face preload (start separation), leak tightness and fatigue performance of the connector shall be established. Leak tightness capacities shall be established for internal and external pressure for both liquid and gas service. External gas service may not be applicable for wellhead housing/connector seal. Load capacities shall be presented for different sealing diameters, e.g. wellhead housing/connector seal and extension sleeve/stinger/stab seal. Cyclic
load or fatigue test shall be performed on connectors that allow for hub face separation under normal operating conditions to verify leak tightness (e.g. gasket fretting) and fatigue strength (e.g. connector locking elements, bolt). For connectors which maintain hub face preload (contact) under normal operating conditions, fatigue strength may be ensured by calculations.

c) Demonstrate that the connector can unlock/lock, maintain hub face preload for normal operating conditions and is leak tight for normal operational conditions after an accidental (survival) condition, if applicable.

d) The connector performance verification (qualification) program shall consist of calculations including finite element analysis (FEA) and full-scale testing. Forecasted load capacities shall be defined by calculations. Full scale testing shall be performed to verify the calculation results and to explore performance parameters that cannot be studied through calculations, e.g. galling resistance, leak tightness, wear, fretting and preload. The final performance shall be determined by comparing and evaluating calculation and test results in a bridging document.

e) For EDP connectors shall minimum overpull to release the connector versus applied bending moment performance be determined to ensure riser disconnect at representative vessel offsets.

f) Hydrostatic body/shell testing of test equipment shall be performed prior to qualification testing.

A.3 Load capacities and load conditions

The connector shall be given separate load capacities for each of three operating conditions: normal (working), extreme, and accidental (survival).

The criteria for each loading condition are given in Table 6.

The capacities shall be given in accordance with the failure mode definitions given below:

a) The **structural (plastic) capacity** is defined as maximum load the connector can sustain without structural failure (e.g. exceeding plastic strain limitations and thread jump out), and still maintain some functional requirements such as minimum hub face preload, leak tightness and latch/unlatch capabilities, if applicable, see D.2.4 ISO 13628-7. The minimum specified material strength shall be used to establish structural strength by calculations. The actual load levels to be used to verify structural capacity by testing shall be adjusted to account for the difference between the minimum specified material yield strength and the actual yield strength of the governing components in the connector.

b) The **leak tightness capacity** is the maximum load which may reliably be applied to the connector before leakage occurs. Leak tightness of the connector correlates directly to hub face separation for pressure energized and depends on the gasket used. The amount of allowable hub face separation for the gasket varies based on the pressure level and the fluid to be sealed. The allowable hub face separation or separation limit for both internal and external pressure shall be established through testing either by separate gasket test specimens or with the connector. For stab/seal subss the sealing performance may be independent of hub face separation. The leak tightness capacity from connector qualification shall be determined as the load which causes the connector to reach the separation limit determined through separate gasket testing. ISO 10423:2003 F.1.11 shall be used for metallic seal qualification and ISO 10423:2003, F.1.11 and F.1.13 shall be used for non-metallic seal qualification.

c) The **hub face preload capacity** is the maximum load the connector can sustain before the hub face separates based on minimum hub face preload. Separation is defined as zero contact forces between the mating hubs.
A.4 Calculations

Calculations, i.e. hand calculations and finite element analysis (FEA), shall be performed to establish structural, hub face preload (start separation), leak tightness, locking/unlocking and fatigue performance of the connector design. Sensitivities of locking, mechanical preload and unlocking performance due to changes in friction and dimensional tolerances shall be evaluated. Unlocking force due to zero friction on locking mechanism shall be established and used as bases for design of the secondary unlock mechanism. Resistance charts (or performance envelopes) for normal (working), extreme and accidental (survival) conditions shall be developed for a combination of bending moment, applied axial force, internal pressure and external pressure. Fatigue performance shall be established by calculation of stress concentration factors and cyclic bolt stresses, if applicable.

The following requirements shall be followed in performing FEA in order to obtain accurate results which can be used to compare with test results:

a) 3D analyses in order to accurately model non-axisymmetric geometry (e.g. bolt holes, bolts, latch dogs) and non-axisymmetric load such as bending moment on the connector. The model shall include relevant geometry characteristics. The mesh for the FEA shall be selected to model accurately the connector geometry including the tree spool and wellhead, boundary conditions, and applied loads. Contact elements with friction shall be used between contact bodies, e.g. mechanical locking mechanism. In addition, mesh refinement around areas of stress and strain concentrations shall be provided. The analysis of one or more finite element models may be required to ensure that an accurate description of the stress and strains in connector is achieved.

b) Elastic-plastic analysis including material strain hardening shall be used to establish structural performance. The material curve to be used shall have yield stress equal to minimum specified yield stress (at actual temperature), not the actual yield stress found by tensile tests taken from the component. The material curve may be linear elastic till 0.1% strain, while 80% of yield stress should be used to 0.3% strain, yield stress should correspond to 0.5 % total strain (0.2 % plastic strain) and 1.02 times yield stress should correspond to 2 % total strain. A realistic strain hardening may be used for strains above 0.5 % total strain. Elastic ideal plastic behaviour shall not be assumed. Elastic analysis shall be used to establish stress concentration factors.

c) All relevant load conditions like lock/unlock, internal/external pressure, temperature and external loading (tension/compression and bending), including cyclic conditions, shall be considered. For more details on criteria for establishing structural capacity or plastic capacity see D.2.3 in ISO 13628-7. Leak tightness shall be evaluated in form of seal contact stress (contact load per unit contact width of 1 mm) during seating and separation.

d) For connector locking/unlocking, hydraulic activation pressure vs. stroke, hydraulic activation pressure vs. bolt stress and hydraulic activation pressure vs. hub face preload shall be presented. FEA results shall be presented as external load vs. response (e.g. end displacement (end rotation), bolt stress, hub face separation, seal contact stress and plastic strains for critical regions/components). Seal/seat and locking mechanism manufacturing extreme dimensional tolerances shall be evaluated. Locking/unlocking performance shall also be evaluated for minimum and maximum friction.

NOTE Elastic plastic 3D FEA with contact elements provides reliable, accurate and detailed knowledge of the mechanism of connectors. A well-defined qualification program of a few carefully planned full-scale tests is a necessary complement to elastic plastic 3D FEA. FEA provides significantly more insight into connector behavior than physical testing. E.g. FEA can be used to evaluate quantitatively a metal seal quality, whereas the physical test results are binary (i.e. "leak" or "no leak"). For example, although the FEA may indicate marginal seal performance, it is possible that a leak is not observed during testing due to limited test duration.

The connector capacities for the relevant failure modes, e.g. structural (plastic) capacity with and without maintaining functional requirements after accidental (survival) load condition, minimum hub face preload (start separation) capacity, leak-tightness capacity internal and external pressure for applicable fluids, shall be presented as follows:
\[
\left( \frac{T_s}{T_c} + \frac{M_{bm}}{M_c} \right) \times \frac{1}{F_d} \leq 1
\]

\[
T_s = T_c + \frac{\pi}{4} \left( p_{int} - p_o \right) \times D_s^2
\]

where

- \( T_s \) is the total axial separation load tending to separate the connector \( \text{N} \)
- \( T_c \) is the axial load capacity (single load) for the applicable failure mode \( \text{N} \)
- \( M_{bm} \) is the absolute value of the externally applied bending moment \( \text{Nmm} \)
- \( M_c \) is the bending moment capacity (single load) for the applicable failure mode \( \text{Nmm} \)
- \( F_d \) is the design factor; for minimum structural strength see Table 11 in ISO 13628-7. \( F_d=1.0 \) for minimum hub face preload and leak tightness.
- \( T_e \) is the effective tension (externally applied tension). \( T_e \) is positive for loads which tend to part the connection \( \text{N} \)
- \( p_o \) is the external pressure \( \text{N/mm}^2 \)
- \( p_{int} \) is the internal pressure \( \text{N/mm}^2 \)
- \( D_s \) is the gasket/seal sealing diameter. Capacities shall be established for several seal diameters, e.g. wellhead housing/tree connector seal diameter (leakage to the largest redundant seal diameter) and sleeve/sub/stab seal diameter. \( \text{mm} \)

The structural strength limits as function of total hub face separation load and bending moment is illustrated in Figure 1. Similar capacity charts should be presented for hub face preload limit and leak tightness (internal pressure and external pressure).
Figure 1 – Structural strength limits as total axial separation load vs. bending moment.

The bending moment may be converted to an equivalent axial load (tension and compression) $T_{bm}$ as follows:

$$T_{bm} = \pm \frac{4 \times M_{sw}}{D_m}$$

where $D_m$ is the moment reaction diameter for the applicable failure mode. Note that $D_m$ may depend on the total separation load acting on the connector $T_s$. The moment reaction diameter may be constant before hub face separation occurs. After hub face separation, the relationship between applied bending moment and equivalent axial load (tension and compression) will change. The selection of $D_m$ shall be documented by calculations and/or testing.

The connector capacity format may alternatively be presented as follows:

$$\frac{T_s + T_{bm} \times \frac{1}{F_d}}{T_c} \leq 1$$

The calculated stress concentration factor (SCF) values for the connector shall be documented at the locations of highest stress in the connection during cyclic loading. The SCF is defined as follows; see C.2.4 in ISO 13628-7:

$$SCF = \frac{\Delta \sigma_{y}}{\Delta \sigma_{n}}$$

where
\[ \Delta \sigma_{lp} \] is the cyclic local peak stress
\[ \Delta \sigma_{n} \] is the nominal stress or remote stress in the connecting cylinder ("pipe")

The bolts in the connector experiences stress variations due to cyclic loading. The following equation format may be used to calculate the bolt stress variation due to cyclic effective tension and cyclic bending moment:

\[ \Delta \sigma_{bolt} = f_{Te} \cdot \Delta T_{e} + f_{Me} \cdot \Delta M \]

where

\[ \Delta \sigma_{bolt} \] is the bolt stress range (double amplitude)
\[ f_{Te} \] is the effective tension cyclic factor
\[ \Delta T_{e} \] is the effective tension range (double amplitude)
\[ f_{Me} \] is the bending moment cyclic factor
\[ \Delta M \] is the bending moment range (double amplitude)

The tension and bending cyclic factor may be determined by calculations/testing for applicable mean load level. Typical cyclic bending moment is the governing fatigue loading.

Structural capacity as function of total separation axial loads and bending moments may be established by performing tension analysis with low pressure and design pressure to investigate the pressure (hoop) effect on the capacity. If this effect can be neglected, simple total axial tension load and bending moment analysis with low pressure can be used to determine \( T_{e} \) and \( M_{e} \), see Figure 1. Leak tightness evaluations (hub face separation limits) with design pressure for pressure energized gaskets are not applicable for low pressure leak tightness separation limits. 3D bending analysis shall be used to establish \( D_{m} \) for the applicable failure mode (strength, hub face preload and leak tightness). One cyclic load to accidental load condition shall be performed to ensure that the connector maintains functionality and minimum required hub face preload after an accidental load, if required. Necessary overpull to ensure disconnect vs. bending moment shall be established for the EDP connector.

**A.5 Qualification testing**

**A.5.1 Overview**

Full-scale qualification tests shall be performed to document the design with respect to function, structural integrity and leak-tightness as follows:

a) a lock/unlock test to demonstrate the ability of the connector to correctly made up in the field and repeatability of proper make-up;

b) a seal qualification test to check pressure integrity and seal effectiveness; and

c) a combined pressure and external load test to confirm hub face preload, structural strength, and leak tightness performance in additional to demonstrate functionality after an accidental (survival) condition, if applicable.

Fatigue testing shall be performed for connectors which do not maintain hub face contact at normal conditions. Optional cyclic load or fatigue tests may be performed to verify fatigue calculations and to check that no areas of stress concentrations were overlooked in the design analysis. Cyclic testing to failure yields a data point that aids in predicting fatigue life.
The minimum overpull versus applied bending moment characteristics shall be determined by full scale testing for the EDP connector if overpull is necessary to release the connector. The bending moment shall be varied to simulate a disconnect situation with combined applied bending moment and wellhead inclination/vessel offset.

A.5.2 Basis for testing

The performance testing of the connector shall be corrected to the actual strength values rather than minimum specified values. Consequently, the external test loads shall be adjusted to take into account the actual material strength being greater than the minimum. Material certificates of all components shall be available before the test starts. Load capacities for actual strength values shall be determined. QTC specimens may not be representative for actual strength, see ISO 13628-7 Annex D.2.5.

As built dimensions of critical components including locking mechanism, hub, seal seat and seal geometry shall be recorded prior and after testing.

Connector qualification testing may be performed in room temperature, if temperature effects can be neglected.

Lock and unlock testing of the connector shall be performed submerged in salt water as the coefficient of friction depends on the external environment and hold time.

A procedure shall be established to ensure consistent lubrication during both testing and operation.

The gasket shall not be lubricated.

Low pressure is defined as 750 psi - 300 psi. High pressure is rated (design) pressure. Hold periods shall start after pressure and temperature stabilization. Hold period is 1 hour for gas leakage testing.

All tests shall be done in conjunction with suitable data acquisition system for strain gauges, displacement devices, pressure, temperature, etc. Strain gauges shall be placed at bolts (preload) and at other critical locations to allow for comparison with FEA results. Locking actuator stroke shall be monitored during locking and hub face separation shall be monitored during external load testing. For bend tests shall hub face separation monitored on both the tension and compression side of the connector.

The connector shall be assembled in accordance with specified assembly procedure. The connector shall be tested in a test fixture which shall simulate the actual tension and bending loads to be applied in the field.

The maintenance performed on production connectors shall match or exceed maintenance performed on the connector throughout qualification testing. This includes, but is not limited to, the re-greasing schedule for the connector. The maintenance program for the connector shall specify a re-greasing schedule for the connector with at least the same frequency (with respect to number of lock/unlock cycles) as performed in qualification testing.

A.5.3 Function test

A series of tests shall be performed to:

a) Determine the relationship between lock pressure and preload, as well as the corresponding stroke and unlock pressure representative for field conditions, i.e. submerged in saltwater at +4°C and in air. The following criteria shall be met for the submerged connector:

1) Verify smooth operation of the connector.

2) The connector shall generate minimum required preload for specified locking pressure.
3) A minimum of two cycles shall be performed for each preload value to show repeatability.

4) Lock and unlock the connector minimum 25 times for the tree connector. For the tree cap, EDP, and LRP connectors a minimum of 100 cycles shall be performed without losing functionality. The cyclic testing shall be performed for the maximum preload of the connector. For parallel locking mechanism the "roll over pressure" shall be maximum 80% of the hydraulic design pressure. For tapered locking mechanism, the hydraulic pressure shall be used. Re-greasing and inspection may be performed in intervals which are in accordance with the maintenance program, however, not more often than after every fifth cycle.

b) For connectors with tapered locking mechanism, testing in field conditions with pressure pulses and thermal effects, if applicable, shall be considered to confirm that unintended release of the locking mechanism does not occur. Both lock and unlock lines shall be vented to atmosphere. The testing shall be performed with and without the secondary lock activated.

c) Perform a test to simulate field landing, locking, unlocking and disconnecting to confirm maximum landing speed with angled wellhead. All operations shall be smooth and no damage shall occur, e.g. on seals and guide pins.

A.5.4 Leak tightness test

Seals shall be qualified for both internal and external fluid pressures, if applicable. Metallic seals shall be qualified in accordance with ISO 10423:2003 F.1.11. Non-metallic seals shall be qualified in accordance with ISO 10423:2003 F.1.11 and F.1.13. Design and low pressure gas and liquid leak tightness hub face separation limits shall be established for seals which sealing performance is affected by hub face separation, typically wellhead housing/connector gaskets. The hub face separation limits shall be determined after qualified the seal in accordance with ISO 10423:2003 F.1.11. If temperature is not applicable, 3 pressure cycles shall be applied before the leak tight separation limit is determined for both internal and external pressure. Leak tightness acceptance criteria shall be as given in 6.4.11.5 ISO 13628-7. The leak tightness test may be performed with a test connector or a separate gasket test specimen.

A.5.5 External load/leakage test

An external load test shall be performed to prove the structural strength, hub face preload (start separation) and leak tightness characteristics of the connector. The testing shall determine the mechanical advantage of the connector, the amount of hub face preload and hub face separation capacity under various loading conditions based on locking pressure.

Testing should be performed with combined pressure, tension and bending. The external load shall be applied in increments and shall be sustained for a minimum of 5 minutes at each increment.

The testing shall be performed at the minimum preload that is expected to be achieved in the field. If over a period of time critical surfaces will get damaged resulting in increased friction and reduction in preload, this shall be accounted for during the testing.

a) Lock the connector on the wellhead housing and vent the lock pressure to atmosphere.

b) Apply low internal pressure (gas), then perform three loads cycles to the normal operating envelope and three load cycles to extreme operating condition envelope to verify gas leak tightness and hub face-preload capability in addition to verify applicable moment reaction diameters.

c) Apply design external pressure (water) then external load to normal operating and extreme operating condition envelope to verify liquid leak tightness due to external pressure and verify applicable moment reaction diameters.

d) Apply design pressure (water) then external load to accidental (survival) operation condition to verify liquid leak tightness, structural strength and applicable moment reaction diameters.
e) Apply design pressure (gas) then external load to normal operation condition determined to verify
gas leak tightness, hub face-preload capability and applicable moment reaction diameters after
accidental (survival) load condition.

f) Unlock the connector and inspect.

g) Lock the connector on the test stump.

h) With hydrostatic pressure applied, external load shall be applied in a set of increments until
structural failure occurs.

i) If possible, several test coupons shall be taken from the failed component(s) to determine the
yield strength of the actual components as accurately as possible.

A.5.6 Post-test examination

The test connector shall be disassembled and inspected. All relevant items shall be photographed.
The examination shall include a written statement that the connector does not contain defects or
deformations to the extent that any performance requirements are not met.

The dimensions of key components shall be measured before and after the testing in order to quantify
any permanent deformation introduced during the testing. This shall be used in the validation of the
connector with respect to preload, strength and sealing performance.

A.5.7 Data processing and test documentation

A thorough, comprehensive test report shall be written and shall include the following items as
minimum:

a) A listing of each of the connector performance variables determined by testing.

b) An overview of the test configuration, including the test fixture and instrumentation used.

c) A summary of the sequence of testing performed.

d) A tabulation of lock pressure (and stroke for tapered locking mechanism), preload and unlock
pressure for each cycle throughout testing.

e) Plots of stress and hub face separation for external load test.

f) Material test reports and dimensions before and after testing for critical components.

A.6 Bridging and summary document

The bridging document shall also include a summary of the testing and calculations performed of the
connector including the connector capacities and performance data, see A.3. A validation between
test results and calculations shall be performed as part of the qualification. Typical items to be
compared are locking actuator stroke/roll over pressure vs. connector preload, tension/bending
moment vs. hub face separation and bolt stress vs. tension/bending moment in addition to comparison
of stresses/strains at critical locations.

A performance data summary sheet shall be prepared. It shall include the following information, as
applicable,

a) the production designation, pressure and temperature rating, main dimensions, mass and material
designations;
b) a description of how the connector works including the design features and benefits of the threads, seals, shoulder and body configuration including connection preload, external load (axial tension/compression and bending) transmission and locking systems;

c) functional performance data such as locking/unlocking area and hydraulic pressure, maximum landing speed, maximum locking angle (hub/connector) and maximum number of lock/unlock for applicable connector preload;

d) capacity data such as structural capacity with and without requirement on loss of preload after accidental load conditions, hub face preload capacity and leak tightness for applicable sealing diameters and fluids, e.g. both gas and liquid. Capacities shall be presented as $T_c$ and $M_c$ for applicable seal diameters and fluid for structural, hub face preload and leak tightness capabilities. For structural capacities, the limiting component shall be identified and for leak tightness shall the maximum hub face separation for the applicable fluid and pressure be identified;

e) fatigue data such as stress concentration factors and location with corresponding pipe diameter and thickness and bolt cyclic stress for cyclic external loads.

f) bending moment-tension-release angle capabilities of the EDP connector;

g) function testing requirements for lock/unlock FAT of the connector, e.g. locking/roll over pressure, stroke range for tapered locking mechanism and unlock pressure;

h) references to calculation and test documents.

The following shall be agreed between manufacturer and customer when establishing project specific capabilities for a connector:

1) maintain preload during normal (working) operation;

2) maintain functionality after an accidental (survival) condition, i.e. maintain hub face preload and be possible to latch/unlatch the connector;

3) applicable fluids (e.g. gas or liquid) to be sealed; and

4) seal diameters to be used for all load conditions.