Verification and Validation of Subsea Connectors

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Contents

Introduction

This technical report has been prepared to provide a validation test protocol for subsea connectors for validating the verification analysis. The verification analysis methodology provides guidance to generate connector performance capacity charts.

The intention is to facilitate and complement the connector selection process by ensuring that capacities are determined using common industry design criteria, and to demonstrate leak tightness and structural capacities through testing. This report is not intended to replace sound engineering judgement, nor should it limit additional scope validation tests.

Verification and Validation of Subsea Connectors

1 Scope

This Technical Report provides requirements and recommendations for the verification and validation of subsea connectors. It is intended to serve as a common reference for designers, manufacturers, and users to improve the performance assessment of subsea connectors and to improve the reliability and integrity of subsea systems.

This technical report is applicable to subsea connectors along the vertical centerline of subsea hardware (i.e. tree, tubing head, tree cap, tree running tool, well control package connectors, and EDP connectors), the subsea wellhead, and the completion/workover riser. The methodology provided herein may also be used in other connector designs. Connectors outboard of the vertical centerline are addressed in API 17R.

The scope of this Technical Report includes connectors subjected to structural and pressure loads for wellhead, tree, tubing head, tree cap, tree running tool, and EDP connectors, and is intended to define general performance capacities for API 17D, API 17G, and other applications.

In the development of this Technical Report, verification and validation of casing and tubing connectors and welded connectors are recognized as ongoing work. At this time, casing and tubing connectors and welded connectors are not within the scope of this document and are deferred to their applicable specifications.

Differential external pressure effects are not within the scope of this document—refer to API 17TR12.

Fatigue verification through analysis is included. Fatigue testing of subsea connectors is not a mandatory requirement.

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.

API Specification 6A, *Specification for Wellhead and Christmas Tree Equipment*

API Specification 17D, *Design and Operation of Subsea Production Systems—Subsea Wellhead and Tree Equipment*

API Recommended Practice 17G, *Recommended Practice for Completion/Workover Risers*

API Technical Report 17TR8, *High-pressure High-temperature Design Guidelines*

ASME BPVC Section VIII, *Rules for Construction of Pressure Vessels Division 2—Alternative Rules*

ASME BPVC Section VIII, *Rules for Construction of Pressure Vessels Division 3—Alternative Rules for Construction of High Pressure Vessels*

BS 7608: Guide to fatigue design and assessment of steel products

DNVGL-RP-C203: Fatigue design of offshore steel structures

3 Terms, Definitions, Abbreviated Terms, and Symbols

3.1 Terms and Definitions

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

3.1.1
acceptance criteria
Specified limits of acceptability applied to process or product characteristics.

3.1.2
connector
Mechanical device used to connect adjacent components to create a pressure-containing structural joint resisting applied loads and preventing leakage.

3.1.3
cyclic loads
Any alternating mechanical loads (internal or external), pressures or temperatures that induce cyclic stresses on the entire connector assembly or components within.

3.1.4
design factor
Factor used in working stress design and fatigue evaluation.

3.1.5
design life
Period for which subsea equipment 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 termination of the subsea equipment.

3.1.6
design validation
(validation testing or qualification)
Process of proving a design by testing to demonstrate conformity of the product to design requirements.

NOTE Design validation can include one or more of the following (this is not an all-inclusive list):

a) prototype tests,

b) functional and/or operational tests of production products,

c) tests specified by industry standards and/or regulatory requirements,

d) field performance tests and reviews.

3.1.7
design verification
(verification analysis)
Process of examining the result of design and development output (both during and after the design and development phase) to determine conformity with specified requirements.

NOTE Design verification activities can include one or more of the following (this is not an all-inclusive list):

a) confirming the accuracy of design results through the performance of alternative calculations,

b) review of design output documents independent of activities of design and development,

c) comparing new designs to similar proven designs.

3.1.8
external loads
Includes global load effects like axial loads, bending moment, torque, and shear.

3.1.9
finite element analysis
FEA
Numerical method for analyzing dynamic and static response by dividing the structure into small continuous elements with the given material properties.

NOTE The analysis can be local or global.

3.1.10
fracture mechanics
Assessment and analysis where critical defect sizes under design loads are identified to determine the crack growth life, i.e. leak or fracture.

3.1.11
functional capacity
Loading condition where the functional failure criteria specified for the component is met but not exceeded.

3.1.12
hub face separation
Separation is defined as zero contact forces between the mating hubs (from ID to OD) on the tension side of the applied load condition.

3.1.13
leak tightness capacity
Maximum load combination that may reliably be applied before leakage occurs in the connector.

3.1.14
load, extreme
Conditions that include the unavoidable but predictable load conditions due to the environmental and operating scenarios.

3.1.15
load, normal
Conditions that corresponds to a design factor of 0.67 with respect to SMYS.

3.1.16
load, survival
Conditions which include the unplanned, unavoidable, and unpredictable load conditions due to the environmental, operating, or any other scenarios.

NOTE 1 Also referred to as accidental load.

NOTE 2 Survival loads of a component means that the component does not fail but it can present one or more kinds of degradations that may impact its specified performance or service life.

3.1.17
permanent equipment
Equipment installed for production over the life of the well.

3.1.18
rated working pressure
RWP
Maximum internal pressure that the equipment is designed to contain and/or control.

3.1.19
service life
Duration of time in which the equipment performs under the specified design conditions, i.e. time in active connected riser operations, excluding storage periods.

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

3.1.20
S-N curve
Quantitative relationship between the fatigue stress, S, and the number of cycles, N, corresponding to a specific probability of failure for a detail, derived from test data.

3.1.21
specified minimum yield strength
SMYS
Minimum yield strength at room temperature prescribed by the specification or standard under which the material is purchased.

3.1.22
stress amplification factor
SAF
Equal to the local peak alternating stress in a component (including welds) divided by the nominal alternating stress in a defined reference section somewhere in the system (e.g. through wall section of the wellhead above or below the locking profile).

NOTE This factor is used to account for the increase in the stresses caused by geometric stress amplifiers which occur in connector components.

3.1.23
stress concentration factor
SCF
Equal to the local peak stress in a component (including welds) divided by the nominal stress in the component cross-section at the location of the local peak stress.

3.1.24
structural capacity
Maximum load(s) the connector can sustain without exceeding the allowables for normal, extreme, or survival conditions and still maintain functional requirements.

3.1.25
temporary equipment
Equipment that is used on a well for installation or workover purposes and is not considered a permanent part of the production equipment.

3.1.26
test series
Group of tests at the same load condition (i.e. normal, extreme, survival) that are related to each other in some manner such as capacity or type of test.

EXAMPLE A Normal Capacity Test Series is all the tests that are conducted to a load level that corresponds to a normal capacity rating.

3.1.27
yield capacity
Maximum load(s) of the connector that cause the primary membrane stress to reach the specified minimum yield stress.

3.2 Abbreviated Terms and Symbols

For the purpose of this document, the following terms and symbols apply.

A	cross-sectional area
Ag/AgCL	silver/silver chloride
c	distance from the neutral axis to the reference section
CP	cathodic protection
C-R	circumferentially oriented specimen with a radial flaw
da/dN	increment of crack growth for a given cycle
D_f	fatigue design factor
Δ	denotes a change in the variable
DCB	double cantilever beam
EDP	emergency disconnect point
F	applied force
F_d	design factor
FCGR	fatigue crack growth rate
FEA	finite element analysis
FM	fracture mechanics
FMECA	failure modes effects criticality analysis
FT	fracture toughness
H_2S	hydrogen sulfide
I	area moment of inertia or second moment of area
K	elastic crack driving force parameter, stress intensity factor, or a parameter in the multi-point constraint stress-strain curve model, as applicable
ΔK	$K_{max} - K_{min}$; if $\Delta K > \Delta K_{th}$ crack growth occurs; otherwise, if $\Delta K \leq \Delta K_{th}$ crack growth does not occur, or da/dN = 0.0
K_{IEAC}	environmentally assisted fracture toughness for a Mode 1 crack
K_{th}	threshold stress intensity factor for the material and environment, above which measurable crack extension will occur
kips	1000 lbs force
ksi	1000 lbs force per square inch
LAS	low alloy steel

LEFM	linear elastic fracture mechanics
L-C	longitudinally oriented specimen with a circumferential flaw
LRFD	load resistance factor design
LVDT	linear variable differential transformer (also called linear variable displacement transducer)
M	applied bending moment
∆M-N	(also shown as M-N) curve showing applied moment and number of applied cycles
Ni	calculated number of cycles to failure at a constant stress range
NDE	nondestructive examination
PoD	probability of detection
QC	quality control
SAF	stress amplification factor
SCF	stress concentration factor
STF	stress transfer function (also known as a load to stress curve)
SMYS	specified minimum yield strength

4 General

4.1 Purpose

The aim of the connector design is to ensure that the connector has adequate structural capacity, leak tightness, fatigue performance, and functionality for all relevant load cases. Resistance against survival (accidental) loads shall be considered in the design process.

Connectors shall be qualified for the application based on verification analysis in combination with validation testing.

The manner in which the pressure-containing body is connected to adjacent bodies above and physically locked to the mating profile hub below is key to the overall performance of a connector. Various types of interfaces can be used to assemble and mount a connector to an adjacent assembly. This interface could be a clamp style, collet style, flanged, or a threaded connection.

The capacity of each connector shall be provided independently of adjacent connectors (e.g. the wellhead connector will be rated independently of the adjacent flanged connection).

The connector performance validation testing program shall consist of verification analysis and full-scale testing. The combined load capacities shall be defined by design verification calculations. Full-scale testing shall be performed to validate the verification analysis results and to explore performance parameters that are not easily quantified through calculations, e.g. preload loss and leak tightness. Once testing is complete, test and analysis results shall be compared as part of the design documentation. If there is a crucial discrepancy in the results in critical areas, the analysis shall be studied and changes shall be made to the analysis or test program. Consideration shall be given for re-analyzing or re-testing, whichever be the case, after careful evaluation of the results. If discrepancies between analysis and testing are not resolved, the test results shall override the analysis.

Validation testing of the subsea connectors should meet the functional requirements of the applicable governing API specifications.

NOTE FMECA may be used to identify all failure modes of the connector.

4.2 Connector Descriptions

Subsea connectors are mechanical devices used to connect adjacent components in the system to create a structural joint that resists applied loads and prevents leakage. Specific connector types covered by this document are as follows.

a) Hydraulic connectors: mechanical connectors that are activated hydraulically.

b) Flanged connectors: bolted flange connections designed for face-to-face contact including two flanges, bolts, and gasket/seal ring(s).

c) Radial bolt connectors: dog-type connectors where dogs act as wedges mechanically driven between the box and pin for engagement and include gasket/seal ring(s).

d) Collet connectors: collet-type connectors that have a slotted cylindrical element joining mating connector members and include gasket/seal ring(s).

e) Clamp connectors: clamped hub types designed for face-to-face contact including two hubs, clamps, bolts, and gasket/seal ring(s).

4.3 Performance Requirements

4.3.1 Structural Performance

The structural capacities of the connector shall be verified through calculations and validated with full-scale testing. The performance validation testing program shall include, at a minimum, one physical full-scale test for design documentation to provide the operating range of various load combinations.

Local bearing damage failure between the connector's locking mechanism and the body may result in preload loss, which should be carefully assessed to ensure that the performance of the connector is not adversely affected.

4.3.2 Leak Tightness

Leak tightness capacity is the maximum load combination that may reliably be applied before leakage occurs in the connector.

For normal and extreme load conditions, the connector shall be leak tight for the applicable fluid. If a connector is not leak tight at survival load conditions, the connector shall be re-tested and shall meet the leak tightness criteria at extreme load conditions. If the connector is not leak tight for survival load conditions, it shall be documented as such on the capacity chart. The applicable fluid may be used during load capacity testing of connectors for use in gas service, but the seal shall be qualified with gas per API 6A, Annex F. The requirements for leak tightness are the same for both internal and external pressure.

4.3.3 Hub Separation

Finite element analysis (FEA) methods are ways of analyzing the hub separation behavior. For systems where any area exceeds yield, care should be taken when using elastic analysis as predicted deformations may diverge from reality after the yield is exceeded. This could potentially result in an inaccurate estimation of the hub separation load. Hub face separation and leak tightness may or may not correlate and it may be necessary to consider them separately.

The allowable hub face separation for both internal and external pressure shall be established through testing either by a separate seal test fixture or with the connector. The hub face separation measured in the load combination test shall be correlated with the separation measured in the seal test fixture.

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).

4.3.4 Fatigue Performance

The fatigue performance of any connector may be evaluated using calculation methods provided in any established codes of practice used by the offshore industry. The reader is advised to refer to the design practices of the applicable code of practice for more information regarding fatigue capacity calculation methods. If fatigue is identified as a failure mode, then fatigue verification analysis shall be performed. Although fatigue analysis is within the scope of this document, fatigue testing of connectors is not a requirement of this document.

Some effects from cyclic loading, such as leakage due to fretting, are also beyond the scope of this Technical Report.

5 Verification Analysis Requirements

5.1 Purpose

Guidance is given to establish connector performance capacity charts. These charts identify combined load capacities for normal, extreme, and survival conditions.

5.2 Structural Analysis

5.2.1 Design Loads and Load Conditions

The connector shall be given separate load capacities for each of three operating conditions: normal, extreme, and survival. The criteria for each condition, assuming elastic material properties, shall be as defined in Table 1.

Table 1—Criteria for Elastic Analysis

Operating Conditions	Criteria
Normal	The lower of: $^2/_3$ of minimum specified yield capacity, F_d=0.67; or Functional capacity for applicable fluids.
Extreme	The lower of: 0.8 of minimum specified yield capacity, F_d=0.8; or Functional capacity for applicable fluids
Survival	The lower of: Minimum specified yield capacity, F_d=1.0; or Functional capacity for applicable fluids.

The proposed LRFD load factors for each loading condition are given in Table 2. The extreme and survival factors are derived from the normal factors to maintain the same ratio between each condition as the elastic analysis methods.

Table 2—Proposed LRFD Load Factors for Elastic-Plastic Analysis

Operating Conditions	Elastic-Plastic (LRFD) Ref. ASME Section VIII, Div. 2		Elastic-Plastic (LRFD) Ref. ASME Section VIII, Div. 3	
	w/o Thermal Loads	w/ Thermal Loads	w/o Thermal Loads	w/ Thermal Loads
Normal	2.40	2.10	1.80	1.58
Extreme	2.00	1.75	1.50	1.32
Survival	1.60	1.40	1.20	1.05

NOTE Although elastic and elastic-plastic verification analysis methods are listed above, other methods may be used. The verification analysis method is left up to the manufacturer as long as it is validated with testing.

The three operating conditions (normal, extreme, and survival) and their failure criteria in terms of the minimum specified yield capacity are illustrated in Figure 1.

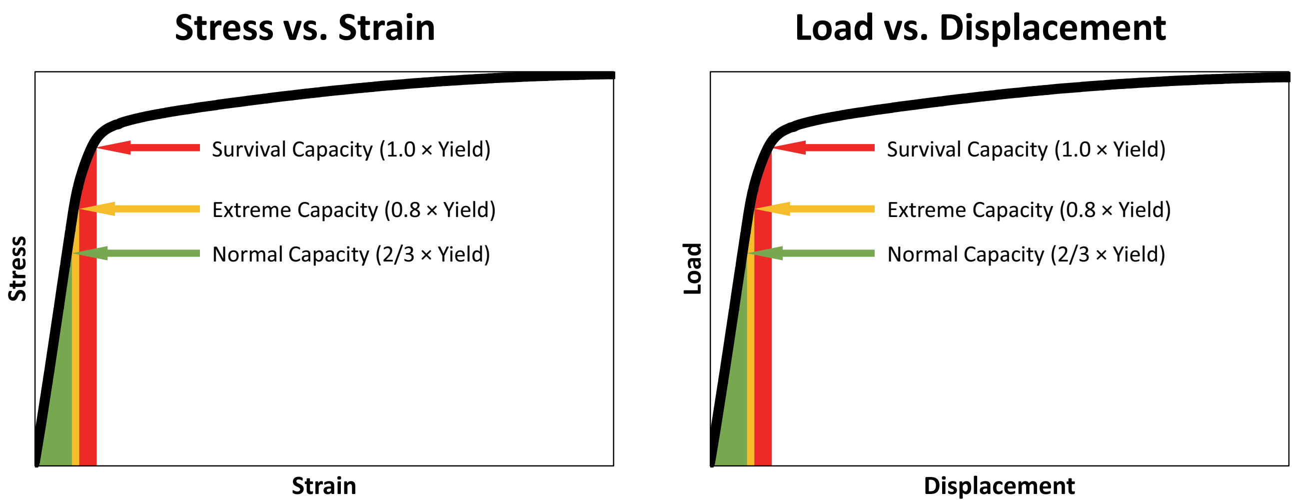

Figure 1—Normal, Extreme, and Survival Structural Capacity Illustration

NOTE The intent of Figure 1 is to illustrate the normal, extreme, and survival capacities and establish that the survival load/capacity conditions do not correspond to failure.

5.2.2 Design Criteria

In addition to validation testing, verification analysis shall be performed to establish a structural capacity and functional capacity chart based on SMYS for varying combinations of external loads and pressures. Structural and functional capacity charts for normal, extreme, and survival conditions shall be developed for a combination of applied bending moment, axial force, and pressure. The manufacturer may choose to present one capacity chart for both structural and functional capacity. At a minimum, the capacity charts shall be generated with load combinations starting at a pressure of 0 ksi and continuing in 5 ksi increments to the rated pressure. The manufacturer determines the additional number of combined load points needed to establish the shape of the connector capacity envelope.

The manufacturer shall document the capacity for the connector in a chart format that provides a relationship of the internal pressure versus bending moment at various tension/compression levels. It is recommended that the capacity chart be generated using 3D FEA. The capacity charts shall include the normal, extreme, and survival capacities. The number of tension/compression lines and the magnitude of the external tension/compression applied might vary depending on the application. An example of a connector capacity chart is shown in Figure 2.

The capacity charts shall be validated by physical testing as described in Section 6. In this example, the normal capacity is based on 0.67 × SMYS, the extreme capacity is 0.8 × SMYS, and survival capacity is at 1.0 × SMYS. The capacity charts shall clearly note what fluid medium was used during the validation test. The type of seal and the sealing diameter used to determine the pressure end load shall be stated. Having more load combination data points provides a more realistic representation of the capacity envelope. The manufacturer may choose to define the normal, extreme, and survival structural capacity as less than the allowable criteria provided that the relative design margin between them is maintained.

The capacity chart is used to determine the acceptability of the connector strength for the planned application including both static and dynamic loading conditions. Connector torsion capacity may be provided, as applicable.

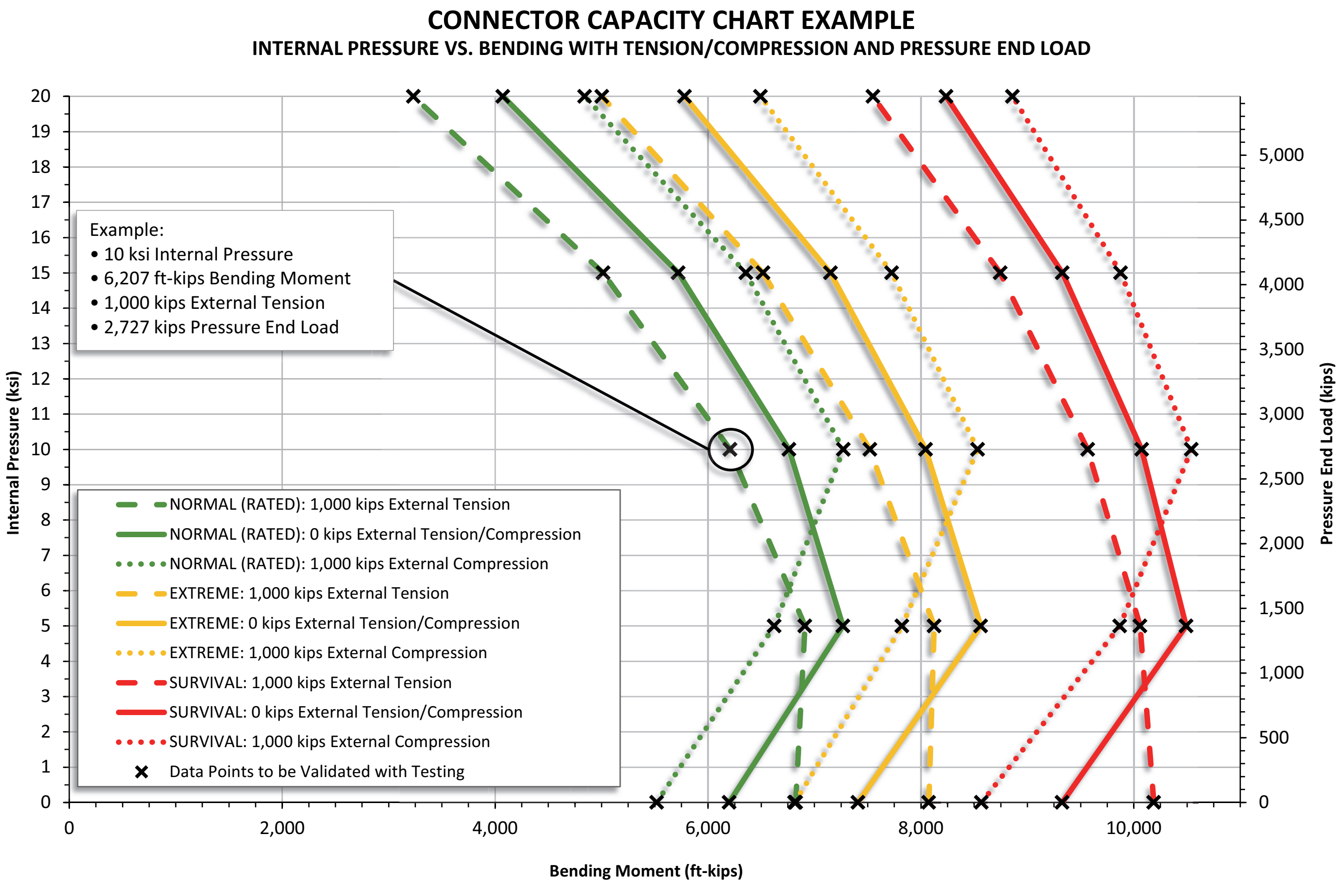

Figure 2—Connector Capacity Chart Example

The capacity chart (Figure 2) only includes the connector assembly and not the adjacent connector (e.g. the wellhead connector will be rated independently of the adjacent flanged connection). The adjacent connector can be presented as a separate capacity chart.

5.2.3 Analysis Modeling and Methodology

The following requirements should be followed when performing FEA in order to obtain accurate results.

a) 3D analysis is recommended in order to accurately model non-axisymmetric geometry (e.g. bolt holes, bolts, latch dogs) and non-axisymmetric loads such as bending moments. The FEA model should include interactions of individual connector components, characterizing peak stress/strain response of a connector assembly relative to a locked (pre-loaded) connector and/or gasket setting. Sub-modeling may be necessary to accurately define complex geometry (i.e. notches, root radii).

b) The model shall include the relevant surrounding structure including, for example, the mating component, the tree spool, and the wellhead. The model shall also include appropriate boundary conditions to ensure they do not impact the areas of assessment and applied loads.

c) The mesh shall be selected to accurately model the connector geometry. Mesh refinement around critical areas of stress and strain concentrations may be required. The analysis of one or more finite element models may be required to ensure that an accurate description of the stress and strains in the connector is achieved.

d) Contact elements with friction should be used between contact bodies, e.g. mechanical locking mechanism. Finite element modeling requires contact interactions to permit individual components to slide and lift-off during locking and subsequent loading (i.e. hub-face separation). It is important that the coefficient of friction between components be assessed in order to accurately model locked/pre-loaded states. Non-linear geometry (also known as large displacement theory) should be used in analysis.

e) If linear elastic analysis techniques are used, the appropriate checks against allowable stresses should be performed.

f) In the case of elastic-plastic analysis, the material curve to be used shall utilize the true-stress, true-strain curve at operating temperature. A true-stress, true-strain curve can be obtained from testing or from ASME Div. 2 Annex 3-D or ASME Div. 3 Article KD 231.4. True-stress, true-strain curves from test data shall be properly adjusted so they are representative of the SMYS. Material properties shall be de-rated for high temperatures, as applicable.

g) FEA models of pre-loaded structures when subjected to cyclic loading often require a number of load cycles to “shakedown” to a stable response. This can be due to relative motion of components and can occur in both linear elastic and elastic-plastic models (where initial work-hardening may also be occurring). Care should be taken to ensure this effect is accounted for in any connector analysis involving cyclic loads.

5.3 Fatigue Assessment

5.3.1 Fatigue Screening

Fatigue screening may be adopted for connectors that do not see significant cyclic loading (e.g. capping stack connectors). The provisions of ASME Div. 2 Paragraph 5.5.2 should be used as the fatigue screening process. The ASME screening process has three primary options; the first is based on experience with comparable equipment operating under similar conditions. Successful experience over a sufficient time frame obtained with comparable equipment subject to a similar loading histogram can be used as the basis for fatigue screening. The remaining two options, Method A and Method B, are based on the materials of construction, the construction details, the loading histogram, and smooth bar fatigue curve data. The loading histogram and fatigue curve data consider the specified minimum tensile strength, full range pressure/temperature cycles, and operating pressure/temperature cycle ranges as applicable. Method A has limited applicability; the application of Method B is unlimited.

If the connector design does not satisfy the fatigue screening criteria, then a fatigue assessment through the S-N or FM design methods shall be performed.

NOTE FMECA may also be used as a tool to determine if fatigue assessment is required.

5.3.2 Fatigue Assessment Methods

5.3.2.1 General

If fatigue assessment is deemed necessary, there are two methods considered in this document to perform a fatigue assessment:

1) S-N design based on alternating stress ranges using the fatigue stress parameter (see 5.3.2.2) consistent with the definition of the S-N curve;

NOTE M-N design curves are an alternative way of presenting fatigue performance and, in this document, are considered as a subset of S-N design because they are based on S-N curves.

2) FM design based on the material's fatigue crack growth data and load cycles that result in an alternating range of the crack tip stress intensity factor.

Strain-based methods may be used although such methods are not addressed in detail in this Technical Report.

Some methods require an applicable stress amplification factor (SAF) or stress transfer function (STF), both of which are defined in 5.3.2.3 and 5.3.2.4, respectively.

In addition for calculation of fatigue damage, these methods require the load histograms and any pertinent material properties. The manufacturer is responsible for providing the SCF/SAF information. It is the end user's responsibility to provide the information necessary to calculate fatigue damage.

Fatigue assessment due to cyclic loading should be based on an alternating stress range using the appropriate fatigue stress parameter or the bending moment range for a given number of cycles, as defined in load histograms by the end user. In the absence of specific criteria, the manufacturer may assume a representative load histogram or produce data as M-N curves as the basis for standard product offerings. The equipment end user shall determine if the product design fatigue life meets project requirements. The fatigue assessment should consider applicable cyclic loadings for the life of the component.

The S-N and M-N methods are both based on the determination of a relationship between input loads and cycles to failure. The engineering calculation that derives the appropriate fatigue stress parameter from the bending moment load is implicit to the M-N method because the SAF is inherent to the M-N curve. It should be noted that the M-N curve is specific to the connector design, and changes in geometry, location, or load conditions require a different M-N curve. For the S-N method, it is important to know the specific cross section properties used to obtain both the reference stress ranges and the associated SAF.

Traditional S-N and M-N fatigue analyses are based on the assumption that the fatigue life of engineered structures can be calculated using an anticipated stress range and associated cycles to failure test data. Compared to the FM approach, the S-N approach may estimate a longer fatigue life because it is based upon flaw initiation and propagation. The FM approach would assume that metallurgical or fabrication flaws exists (i.e. initiation has occurred), so the fatigue life of the connector is only the number of loading cycles required to propagate the flaw to failure.

When the stress field in a hotspot shows multi-axial effects, i.e. the direction of the principal stresses/strains changes with load, a method capable of assessing such a hotspot should be used.

5.3.2.2 S-N Design

The S-N design method for fatigue assessment can be based on the methodology prescribed in established codes of practice used by the offshore industry such as ASME Div. 2 Paragraph 5.5, ASME BPVC Div. 3 Article KD-3, DNVGL-RP-C203, or BS 7608. These codes of practice can differ significantly in both the definition of the S-N curve to be used and the definition of the fatigue stress parameter with which to enter the S-N curve. For example, the mean stress-corrected stress range (ASME BPVC Div. 3, Article KD-3) should not be used to calculate fatigue life using S-N curves generated from DNVGL-RP-C203. It is important to choose one code of practice and stay within this code to the extent possible. Otherwise S-N curves should be modified using validated (tested) correction factors to account for any degradation in performance or design life.

Furthermore, the material fatigue properties and/or data should be representative of operating conditions and the S-N curves used should be based on the same class of materials and environmental conditions (i.e. air, salt water immersion, salt air/salt water spray, high humidity, H_2S, caustic agents, cathodic protection) as expected in service. The design S-N curves with “built-in” design margins (for example, two standard deviations from the mean curves) should be used as opposed to the mean curves. In addition to S-N curves from industry design codes, S-N curves generated with test data may be used, with supporting documentation, as long as the generation of the S-N curve is consistent with the chosen code of practice.

Fatigue-sensitive locations, such as structural discontinuities, notches, and welds, should be identified and fatigue analysis performed at these locations. In all cases, the procedures prescribed in the chosen code of practice should be followed.

As a result of the fatigue analysis, the number of design cycles for each type of operating condition is calculated. When more than one type of operating condition exists, the cumulative number of design cycles for all operating conditions is calculated. The accumulated fatigue damage should be based on a linear cumulative damage rule (such as the Palmgren–Miner rule) as defined in the chosen code of practice.

5.3.2.3 Stress Amplification Factor

The stress amplification factor (SAF) is defined as the ratio of the incremental change of local peak stress (maximum cyclic principal stress) to the corresponding incremental change of the reference stress (see Equation 1). The reference stress and reference section dimensions shall be clearly defined and documented. Typical examples of the incremental change in reference stresses are the incremental change in stress due to tension/compression ($\Delta F/A$) or bending moment ($\Delta M \times c/I$).

$$\mathrm{SAF} = \frac{\text{incremental change in peak stress at the location of interest}}{\text{incremental change in nominal stress in the reference section}} \qquad \text{(Eq. 1)}$$

where

ΔF = Total change in axial force in the component

A = Cross-sectional area of the reference section

ΔM = Total change in bending moment in the component

c = Distance from neutral axis to the reference location

I = Area moment of inertia of the reference section

The manufacturer shall provide an SAF curve along with the reference information considering that the SAF may vary as a function of the applied load magnitude. It should be noted that the SAF and SCF differ and are often incorrectly interpreted as being the same thing and therefore are used interchangeably. The SAF and the SCF represent two different phenomena and produce entirely different fatigue life estimates.

5.3.2.4 Stress Transfer Functions

The stress transfer function (STF) methodology provides a relation of the peak stress response (including preload effects) of a connector to the applied loading (including combinations of tension and bending moment loads). STFs can be used as an alternate to SAFs. STFs remove the necessity of relating the peak stress to a reference geometry (as required for defining an SAF).

Figure 3 presents a typical bending moment STF at a peak stress location in a connector assembly, illustrating the functional relationship between ΔM and Δσ. It is noted that the STF is calculated from a zero load to ±maximum loading. However, other mean bending moments may be used to generate additional STFs. A stress range, Δσ, is calculated for each bin of a load histogram with the STF that is used in fatigue damage/life calculations.

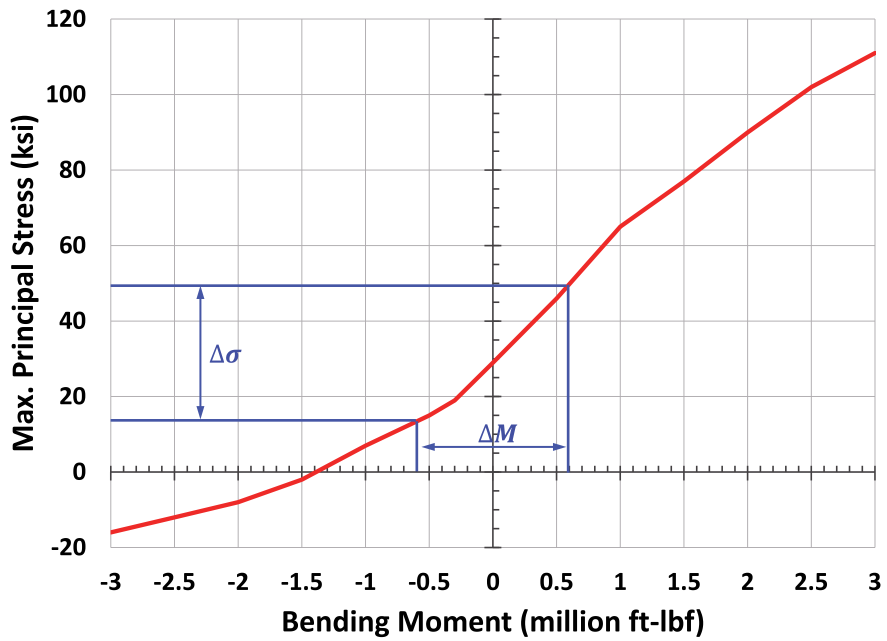

Figure 3—Example Stress Transfer Function (STF)

NOTE The critical stress locations and ranges may change with the load combinations applied. It may be necessary to evaluate STFs for several peak locations in the connector to characterize the connector assembly for fatigue sensitivity.

5.3.2.5 M-N Design

Fatigue assessment of connectors using the M-N design method should include the following steps.

1) Build an analysis model representing the static loads, contact interactions, boundary conditions, and mesh refinement around the critical areas of stress and strain concentrations.

2) Apply bending moment $+M_i$ and $-M_i$ (i = 1,2,3,...) to get bending moment range of $\Delta M_i = |\ 2M_i\ |$.

3) Calculate the range of the appropriate fatigue stress parameter at each location of interest.

4) Using the fatigue stress range and an applicable S-N curve for each fatigue critical location, determine the fatigue life N_i for the bending moment range ΔM_i.

5) Repeat steps 2–4 to obtain a representative M-N curve. The M-N curve should determine fatigue lives in the cycle ranges addressed by the applicable S-N curve.

The fatigue damage should be calculated by the Palmgren–Miner rule using the bending moment histogram and M-N curve obtained in Step 5. The number of moment ranges should be large enough to ensure any non-linear stress response is captured.

NOTE 1 Typically four to six moment range levels are necessary to establish a M-N curve.

NOTE 2 This method assumes zero mean moment. When using a non-zero mean moment, modify the applied bending moments accordingly.

5.3.2.6 Fracture Mechanics Design

The FM design method for fatigue assessment can be based on ASME Sec VIII Div. 3 Article KD-4, API 579-1/ASME FFS-1—Part 9 and Annex F, or BS 7910. Annex A provides guidance on establishing the fatigue crack growth data associated with FM design. The choice of using either elastic or elastic-plastic FM methodology should be complimentary with the level of sophistication used for the design analyses.

When the FM method is used, the alternating stresses defining the path of crack growth should be based on the maximum principal stress range. In theory, the flaw propagates in a plane perpendicular to the direction of the maximum principal stress.

NOTE As the orientation of the principal stress changes, the orientation of the flaw plane changes (i.e. the flaw plane may not remain in the same plane). Typical FM software assumes that flaw propagation remains in the same plane and that the stress distribution perpendicular to the flaw plane drives the flaw propagation.

It should be noted that fatigue crack growth is load path–dependent. Evaluation of load sequence to determine the load combinations which result in the least number of cycles to failure should be identified. Where life cycle estimation represents the number of load cycles to failure based on FM design, the allowable cycles for the intended service life shall be based on the critical crack depth.

FM design requires that the equipment designer provides, as applicable, the following critical elements.

a) Fatigue crack growth data: Cyclic fatigue crack growth data, da/dN vs ΔK, including the fatigue threshold, K_{th}, and the environmentally assisted fracture toughness, K_{IEAC}, which is used to determine unstable fracture, may be determined by testing (in environment) or by data that are determined to be as conservative as or more conservative than the actual material properties in the defined environment and loading conditions. Cyclic crack growth material properties for FM design are defined in API 579-1/ASME FFS-1, Annex F, or BS 7910. Guidance for fatigue crack growth data is provided in Annex A.

b) NDE capability: The equipment designer should define the initial flaw size based on the NDE acceptance criteria for the component with consideration to the NDE capability of the selected method. For complex geometry and assemblies, the ability to identify flaw size and locations should be identified in the application of FM design. The defined initial flaw size is critical in calculating the cyclic fatigue crack growth. The flaw should be defined in both the length and width or depth directions. Typically, internal surface breaking flaws (semi-elliptical) are the most critical in limiting the fatigue life and thus require length and depth dimensions. The NDE method's capabilities and probability of detection (PoD) should define the acceptance criteria of each parameter. Sizing of flaws may require multiple NDE methods to get the complete geometry, orientation, and location. Each of these parameters is a required input for the cyclic fatigue crack growth evaluation. The NDE methods defined in ASME Div. 2 Part 7 or ASME Div. 3 Part KE should be used to define the starting flaw size. Guidance for NDE is provided in Annex B.

c) Critical crack depth: The allowable fatigue cycle life for a surface-breaking flaw propagating through the thickness should be equal to or less than 50 % of the total fatigue cycles to failure (ref Table 3 factor). Failure is the end-of-life fracture limit under maximum design load or through wall flaw, whichever comes first. Alternative fatigue life design margins can be applied on a case-by-case basis with appropriate technical justifications in accordance with recognized industry standards and/or validated publication.

d) Multiple flaws: The cyclic fatigue crack growth analysis should define the acceptance criteria for multiple flaws. The cyclic fatigue crack growth analyses should show the flaws are spaced sufficiently for non-interaction over the life of the component or should be based on multiple flaws combined. Additionally, the potential for multiple flaws initiating at several locations should be identified. Methods of defining flaw geometry, of combining multiple flaws, and multiple flaw interaction are provided in API 579-1/ASME FFS-1, Part 9, or BS 7910.

e) Residual stress effects from hydrostatic body testing or other loading conditions may be applicable when determining the fatigue life, as a means of defining a shakedown condition for alternating stresses.

f) Evaluate with proper loading which should include crack face pressure.

A fracture mechanics analysis starts with the assumption that a flaw exists at peak stress locations. The size of this assumed flaw is based on the NDE acceptance criteria for the component with consideration to the NDE capability of the selected methods that are used to manufacture of the component(s). It should be noted that it is possible for the fatigue life calculated using the fracture mechanics approach to be greater than that calculated using the S-N approach, particularly in low-cycle fatigue (e.g. a design life less than about 10,000 cycles). However, in high-cycle fatigue (e.g. a design life greater than about 100,000 cycles), the fracture mechanics approach may result in a shorter life unless a large SAF is used with the S-N approach or a very small initial flaw size can be justified for the FM approach.

5.4 Fatigue Load Design Format and Fatigue Factors

The fatigue load design format for components should be according to Equation (2):

$$\text{Service life} \leq \frac{\text{Fatigue life}}{D_{fp}} \tag{Eq. 2}$$

The fatigue load inspection format for components should be according to Equation (3):

$$\text{Inspection interval} \leq \frac{\text{Fatigue life}}{D_{ft}} \tag{Eq. 3}$$

The proposed fatigue design factors D_f should be in accordance with Table 3.

Table 3—Proposed Design Fatigue Factor, D_f

Fatigue Analysis Method	Permanent Equipment	Temporary Equipment
	D_{fp}	D_{ft}
Method based on S-N (stress-life)	10	3
Method based on fracture mechanics	2	1.5
NOTE Fatigue design factors from other applicable industry standards may be used.		

6 Validation Testing Requirements

6.1 General

Connectors shall be tested under multiple loading conditions to confirm structural integrity when subjected to combined tension/compression and bending loads while under pressure and preload. These tests shall confirm that the capacity of the connector meets or exceeds the defined normal, extreme, and survival design capacities. For elastic analysis this would be 67 %, 80 %, and 100 % of SMYS.

At a minimum, validation testing of the connector shall be performed starting at a pressure of 0 ksi and continuing in 5 ksi increments to the rated pressure from the capacity chart. The same conditions/assumptions (preload, bending, tension/compression, pressure end-load, etc.) used in the verification analysis to generate the capacity chart shall be used in the test.

A full-scale test shall be performed to validate structural and functional capacities for all of the following.

— Normal Capacity Test Series

— Extreme Capacity Test Series

— Survival Capacity Test Series

The test shall be performed at all the load combination points of the structural capacity chart. The actual load levels used to validate structural capacity by testing shall be adjusted to account for the difference between the SMYS and the actual yield strength of the governing components in the test connector.

Pre-test dimensional inspection of all critical areas shall be done and should be within acceptable manufacturing tolerances. The critical geometry of the test connector should be the same as the production connector. Design changes meant to improve the performance of the connector may be made to the connector after validation testing, but subsequent verification analysis of the new design may be required to ensure the design changes have no unintended detrimental effects to the design capacities. Any increase to the capacity rating of the connector shall be validated by re-testing.

As a minimum, after each normal and survival test series, the connector shall be disassembled and a post-test dimensional inspection of all critical areas shall be performed. Photographs shall be taken and documented in the test report.

Strain gages and LVDTs can be used to determine stresses and hub separation in critical areas. Hub face preload/separation shall be measured/determined at multiple circumferential locations to confirm performance under various combinations of pressure, tension/compression, and bending. Strain gauges shall be used to verify the applied external loads.

The allowable hub face separation shall be established by the manufacturer.The maintenance performed on the test connector throughout validation testing shall not exceed the maintenance specified as minimum required to be performed on production connectors.

6.2 Setup and Monitoring

All tests shall be done in conjunction with a suitable data acquisition system using calibrated strain gauges, pressure sensors, temperature sensors, etc. For all tests, the pressures, axial loads, deflections, leak rates, strains, and temperatures shall be recorded continuously vs time. The test connectors shall have strain gauges in suitable amounts and locations to allow for comparison with verification analysis results. Wherever possible, strain gauges shall be placed to verify preload stresses, stresses close to predicted stress concentrations, and stresses away from predicted stress concentrations.

Redundant monitoring devices are recommended to corroborate values from adjacent devices.

6.3 Test Media

As a minimum, liquid shall be used as the test medium for pressure-hold periods. Manufacturers may substitute a gas test for some or all of the required validation pressure tests. The test medium for a liquid tightness test may be water, while nitrogen may be used for a gas tightness test.

6.4 Hold Periods

Hold periods shall start after pressure and temperature stabilization has occurred and the equipment with a pressure-monitoring device has been isolated from the pressure source. At target loads, the test hold period shall be a minimum of 5 min.

6.5 Acceptance Criteria

The normal, extreme, and survival combined load values are determined by verification analysis. Each of these combined load values shall be validated by physical testing within 0 % to +5 %. The external combined load(s) applied shall be specified by the manufacturer. If acceptance criteria are not met for any of the test series (normal, extreme, and survival), then all ratings are invalid.

a) Pre-Test Dimensional Inspection

A pre-test dimensional inspection of all critical dimensions shall be performed and recorded.

b) Normal

Upon completion of the normal structural capacity test series, the connector shall be disassembled and a visual and dimensional inspection of critical dimensions identified by the manufacturer shall be performed. These critical dimensions shall be recorded and compared to the pre-test dimensions. This should demonstrate that no permanent deformation has occurred. If local deformations are allowed by the design, they shall not compromise the functionality of the connector. The critical dimension values recorded post-test shall be within the range of manufacturing tolerances when compared to the values from the pre-test dimensional inspection. Any post-test dimensions that fall outside the manufacturing tolerance range shall be documented and further evaluation may be needed and justification shall be provided for it to be acceptable. The justification shall demonstrate that the deviations do not compromise the design functionality and capacity of the connector.

c) Extreme

Upon completion of the extreme structural capacity test series, the connector should be disassembled and a visual and dimensional inspection of critical dimensions identified by the manufacturer should be performed. If the connector is disassembled critical dimensions shall be recorded and compared to the pre-test dimensions. This should demonstrate that no permanent deformation has occurred. If local deformations are allowed by the design, they shall not compromise the functionality of the connector. The critical dimension values recorded post-test shall be within the range of manufacturing tolerances when compared to the values from the pre-test dimensional inspection. Any post-test dimensions that fall outside the manufacturing tolerance range shall be documented and further evaluation may be needed and justification shall be provided for it to be acceptable. The justification shall demonstrate that the deviations do not compromise the design functionality and capacity of the connector.

d) Survival

Upon completion of the survival structural capacity test series, the connector shall be disassembled and a visual and dimensional inspection of critical dimensions identified by the manufacturer shall be performed. These critical dimensions shall be recorded and compared to the pre-test dimensions. This should demonstrate that no permanent deformation has occurred. If local deformations are allowed by the design, they shall not compromise the functionality of the connector (unlock functionality). The critical dimension values recorded post-test should be within the range of manufacturing tolerances when compared to the values from the pre-test dimensional inspection. Any post-test dimensions that fall outside the manufacturing tolerance range shall be documented and further evaluation may be needed and justification shall be provided for it to be acceptable. The justification shall demonstrate that the deviations do not compromise the design functionality and capacity of the connector.

If a leak occurs during the survival test series, the extreme structural capacity test series shall be re-performed to prove that the seal remains leak tight under extreme load conditions.

NDE shall be performed on critical components. If crack(s) are revealed, their depth should be recorded and evaluated per the manufacturer specifications.

Leak tightness at specified loads shall meet the following maximum allowable test leakage rates at room temperature.

1) Liquid Test

The initial test pressure shall not be greater than 5 % above the specified test pressure or 500 psi, whichever is less. The liquid test is passed if no visible leakage occurs during the specified pressure hold periods of the test and the chart record should have an acceptable pressure settling rate not exceeding 3 % of the test pressure per hour. The final settling pressure shall not fall below the test pressure before the end of the test hold period.

2) Gas Test

Prior to design validation, all production testing requirements shall have been met. The gas test shall be acceptable if no sustained bubbles are observed. If leakage is observed, the rate shall be less than 20 cm^3/hr measured at atmospheric pressure during specified pressure-hold periods.

6.6 Post-test Examination

The test connector shall be disassembled and inspected after the normal and survival test series. All relevant items shall be photographed. The dimensions of critical 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.

6.7 Pressure Test Procedure

6.7.1 Hydrostatic Tests

Hydrostatic tests exceeding rated working pressure shall be done per the applicable industry product specification.

6.7.2 Internal Pressure Tests

Internal pressure testing shall be done per Section 6. It should be noted the same RWP for normal conditions is to be used as the maximum pressure for extreme and survival conditions.

6.7.3 External Pressure Tests

External pressure test for the connector is not required per this document. If external pressure test for seals is required, appropriate industry standards shall be used.

6.8 External Load Test Guidelines

1) The connector shall be locked at the designed preload value.

2) The test shall be performed at each load combination (target loads) identified on the capacity chart (see Figure 2). The actual yield strengths of components in the tested connector may be higher than SMYS and may mask deficiencies of the design and performance of the connector. To address this concern, the structural test loads of the connector being validated shall be adjusted to account for actual material yield strength of the governing components tested.

3) The connector shall be unlocked, removed from the hub, and disassembled for inspection of critical components after testing at each structural capacity series (normal and survival).

4) The test must show that the connector can be unlocked and removed from the hub after testing is completed.

7 Documentation

A comprehensive test report documenting the capacity tests shall be written and shall include the following items at a minimum:

a) connector capacity chart(s);

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 the lock and unlock pressure (and stroke for tapered locking mechanisms) for each cycle throughout testing;

e) calculations of the stress data for each external load test;

f) material test reports for critical components;

g) pre- and post-test dimensional inspection reports;

h) a comparison of the validation test results with any verification analysis that has been performed, and an explanation of the final determination of the connector capacity and performance characteristics. Note that this bridging information may be included in the test report, the verification analysis report, or a separate document.

Annex A
(informative)

Material Properties for Fatigue Assessment

A.1 General

Fatigue can be a significant design consideration for offshore and subsea applications. Fatigue loading arises due to vessel motions that are caused by wave and current action, as well as pressure and/or temperature changes during the well's production phase. Fatigue evaluation of materials for use in oil and gas applications is either based on stress-cycle (S-N design) or fracture mechanics (FM design) by means of fatigue crack growth rate (FCGR) and the fracture toughness (FT).

A.2 S-N Fatigue Curve

The basis of the S-N fatigue curve is to determine a plot of alternating constant-amplitude applied stress range versus cycles to failure or design cycles depending on design codes applied. S-N fatigue data in the production environment and in a seawater plus cathodic protection environment should be developed at similar test cyclic frequencies as used to develop fatigue crack growth rates. A test cyclic frequency of 0.1–0.2 Hz is recommended in both environments.

Determination of S-N fatigue data in production environments should follow standard NACE MR0175/ISO 15156 procedures for tests environment preparation. Development of S-N data in seawater plus cathodic protection should be performed in simulated seawater prepared in accordance with ASTM D1141. The equipment designer may elect to use the S-N curves provided in the code of practice chosen to govern the fatigue assessment, if they are valid for the appropriate materials and environmental conditions.

A.3 Unstable Fracture and Fatigue Crack Growth Rate

A.3.1 General

The FCGR is determined by testing combined with linear elastic fracture mechanics (LEFM). LEFM is necessary to compute the stress intensity factor that is used to develop the increment of crack growth for a given cycle (da/dN) as a function of ΔK. The FCGR determination procedure should be performed in accordance with ASTM E647.

Materials used for deep water oil and gas applications are either exposed to production environments (that may contain H_2S), hydraulic fluid, or seawater plus cathodic protection (CP). Limited existing data for certain group of materials such as low-alloy steels (LAS) show an increase in fatigue crack growth rates in both seawater plus CP and production environments (that may contain H_2S) as compared to the base line data in air.

Materials which are susceptible to the exposed environment should be tested to determine the environment specific fatigue crack growth, da/dN vs ΔK. Tests should be conducted in accordance with ASTM E647. Both temperature and fluid chemistry should be considered in these tests.

To determine the FCGR, the specimen orientation should be based on the component loading direction. This orientation may be either L-C (a longitudinally oriented specimen with a circumferential flaw) or C-R (a circumferentially oriented specimen with a radial flaw). The L-C orientation as designated by ASTM 399 is preferred unless there is a specific circumferentially oriented radial flaw identified by the FM analysis.

A.3.2 Fatigue Crack Growth: Production Fluids

Limited existing data for LAS show that FCGR for most materials in production environments is highly dependent on cyclic load test frequency. That is, the lower the cyclic frequency, the higher the fatigue crack growth rate. As a result, frequency scan experiments under a constant crack "driving force" should be conducted to assess fatigue crack growth rates over a range of cyclic loading frequencies.

The goal of the test is to determine a saturation frequency below which the crack growth rate per cycle no longer increases with decreasing frequency. Testing should be performed at the saturation frequency determined from frequency scan experiments. Environmental preparation for determination of the FCGR in production environments should follow standard NACE MR0175/ISO 15156 procedures.

A.3.3 Fatigue Crack Growth: Seawater and Cathodic Protection

The outside surface of equipment used in subsea applications is normally protected from seawater corrosion by CP with sacrificial anodes. The surface potential achieved by sacrificial anodes is typically between –950mV to –1100mV (vs Ag/AgCl) or by consideration of the applicable regional design current density (mA/ft^2) as specified in NACE SP0176 Table A1. At these potentials, direct reduction of water occurs on the exposed surface producing enough atomic hydrogen to diffuse into susceptible materials, reducing its FT and fatigue performance. Limited existing data for materials such as LAS show that exposure of these materials to seawater and CP increases its FCGR as compared to baseline air data.

Development of FCGR in seawater plus CP should be performed in simulated seawater prepared in accordance with ASTM D1141. Simulated seawater has adequate electrical conductivity but lower ionic species that contribute to the formation of calcareous scale on the surface of the test specimen which can affect the results.

FCGR in seawater and CP that is similar to production environment is also affected by cyclic frequency and shows an increased growth rate at low frequencies.

A.4 Fracture Toughness Evaluation

A.4.1 General

FT is a critical parameter for a fracture mechanics evaluation of planar (crack-like) flaws in components. The presence of hydrogen in a material can lead to a significant reduction in the apparent fracture toughness due to its embrittling effects. Atomic hydrogen can be generated from the production environment or through CP.

A.4.2 Fracture Toughness: Sour Production Environments

FT values in sour environment to be put into the FM evaluation should be determined when using either linear elastic or elastic-plastic fracture mechanics based on the applicable material properties. Although constant displacement tests through the double cantilever beam (DCB) method adequately describe the FT behavior of relatively less ductile materials, a rising displacement test (J-R curve method) is required to ascertain the FT of materials that exhibit elastic-plastic behavior.

Depending on the yield strength of the material, DCB tests have a limited range of stress intensity factors (K) over which they are valid. Therefore, the current industry practice for FT assessment of materials exposed directly to sour environments is to utilize a toughness parameter known as J_{IC}, which can be converted to equivalent parameters in terms of K_{IC}.

The J-parameter for a material of interest in a corresponding environment should be determined by generating a J-R curve, also known as fracture resistance (R) curve, as described below.

1) FT testing should be performed in accordance with ASTM E1820.

2) FT tests should be performed in a representative sour production environment at relevant temperatures to simulate both production (high temperature) and shut-in conditions (low temperature).

3) Test specimen geometry should comply with ASTM E399 and ASTM E1820; however, single-edge-notched bend (SENB) type specimens are generally utilized for generating J-R curves.

4) The recommended loading rate (K) for FT testing of carbon steels and LAS is 0.0014 ksi√in./s (0.05 $Nmm^{-3/2}$/s), under rising displacement control. Other recommended loading rates may be acceptable depending upon the material selected and previous experience/repeatability. This low K-rate enables sufficient time for diffusion of hydrogen through the fracture process zone to cause damage and lower the toughness, thereby providing conservative values.

5) Testing should be performed using a single specimen method. The crack-mouth opening on the CTOD specimen during the test should be measured using a clip gage in situ.

6) The J-R curve and CTOD-R curve from testing should be reported along with J and CTOD at maximum load.

These provisions are in addition to the material testing for the qualification process of crack resistant carbon/LAS and CRAs (e.g. NACE MR0175/ISO 15156).

A.4.3 Fracture Toughness: Seawater with Cathodic Protection

Fracture resistance of materials that are exposed to seawater and subjected to CP in service should be evaluated through determination of their FT characteristics in simulated seawater prepared in accordance with ASTM D1141. Cathodic charging should be simulated through application of appropriate CP potential values to the test specimen, as determined through measurements of surface potential achieved by sacrificial anodes utilized in service. It is generally recommended to perform cathodic charging at potential values ranging between –950mV to –1100mV (vs Ag/AgCl).

FT evaluation using a J-R curve approach should be conducted in the simulated seawater environment (with CP) by following the guidance provided in A.4.2.

Annex B
(informative)

Nondestructive Examination

B.1 General

NDE and the acceptance criteria are to be performed in accordance with the governing design standard and/or the equipment PSL's designation. Multiple methods of NDE may be employed to detect flaws in components. Some NDE methods are only suitable for examining the surface of components while other NDE methods are suitable for volumetric examination. Additional guidance on NDE methodology and appropriate application are provided in API 17TR8.

NDE personnel performing these examinations should have the necessary experience, training, certifications, and qualifications in accordance with ASNT SNT TC 1A, ASNT CP-189, or equivalent.

An indication classified as a flaw because it is larger than the acceptance standard may be deemed acceptable provided additional analysis of the flaw, such as location, orientation, nature, and size, to determine the component's “fitness for service” for the duration of the intended service life. Acceptance of flaws larger than those permitted by the acceptance standard should be approved by the responsible person within the equipment manufacturer and end user's organization.

B.2 NDE for Fracture Mechanics—ASME Div. 3

The NDE procedure should be determined by the required sensitivity to achieve the necessary PoD in sizing capability, as determined by the smallest allowable defect deriving from the agreed upon acceptance criteria between the manufacturer and the material producer. In addition to individual indications, design should also consider the possibility of multiple, closely spaced indications that may interact and behave as an individual planar flaw.

The maximum allowable flaw size, location, and orientation of individual flaws as well as the size, spacing, and number of closely spaced flaws (multiple flaws), are defined based on the design verification process. The selected NDE method should demonstrate its capability to detect the defined flaw size reliably.

B.3 NDE Reliability Demonstration for Fracture Mechanics—ASME Div. 3

The objective of an NDE reliability demonstration is to determine the PoD vs an actual flaw size relationship. This process defines the performance of an NDE method and procedure under certain manufacturing conditions. Variation in NDE methods and procedures produce various responses and subsequently cause an uncertainty in the detectability of a flaw. This is a combined product of both the physical attributes of a flaw and the NDE process parameters.

The uncertainty caused by differences between flaws is accounted for by using representative test specimens with flaws of a known size to demonstrate the effectiveness of the NDE test method. The uncertainty caused by the NDE process can be accounted for by a qualification test of different examinations on various test specimens. If the test is properly conducted, a secondary objective of identifying those factors that influence the PoD for the system may be achieved (i.e. part geometry, part finished surface condition, part temperature, process, and system parameters, etc.).

B.4 Probability of Detection

The PoD for a given indication depends upon a variety of conditions, which may include but is not limited to:

1) the specific NDE method employed;

2) the training and skill of the technician;

3) the condition of the surface of the component being examined;

4) the environment (i.e. lighting, orientation of component, etc.) under which the examination is performed;

5) the nature (planar or volumetric) of the indication;

6) the location, orientation, and size of the indication.

The PoD of a large indication is typically higher than the PoD of a relatively small indication. Conditions that influence the PoD of indications should be considered when establishing acceptance standards for QC examinations. The application of ASME Div. 3 for fracture and fatigue analyses in the design of a component requires an understanding of the PoD of relevant flaws in that component.

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