

DEP SPECIFICATION

ELASTOMERIC FLEXIBLE ELEMENTS FOR USE IN TLP TENDONS

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DESIGN AND ENGINEERING PRACTICE



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The information set forth in these publications is provided to Shell companies for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual Operating Units to adapt the information set forth in DEPs to their own environment and requirements.

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1. INTRODUCTION

1.1 SCOPE

This new DEP specifies requirements and gives recommendations for design, manufacture, testing, inspection, storage and transportation of Elastomeric Flexible Elements (EFE) for use in TLP Tendons. This DEP only includes flexible elements to be used for TLP Tendons.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorized access to DEPs does not for that reason constitute an authorization to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to oil and gas production, gas handling, oil refining, chemical processing, gasification, distribution and supply/marketing. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorized to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Abbreviations

Term	Definition
AFC	Approved for Construction
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
CTOD	Crack Tip Opening Displacement
EFE	Elastomeric Flexible Element
ESR	Electroslag remelt
FAT	Factory Acceptance Testing

Term	Definition
FEA	Finite Element Analysis
HSSE	Health Safety Security and Environment
ID	Internal Diameter
ISO	International Standards Organization
KIP	Kilo-pound (1 Kip = 1,000 pounds)
LAST	Lowest Anticipated Service Temperature
MOC	Management of Change
MPS	Manufacturing Procedure Specification. Reference ISO 9000 Paragraphs 2.7.2.c, 2.7.2.e, 3.4.5 and 3.7.3. The MPS shall clearly define the sequence of operations and process controls to be implemented at each manufacturing step as well as specifically annotate any procedures, processing parameters or requirements that deviate from this DEP. It is required that the PCP be approved by the Principal and Contractor, if applicable.
MDR	Master Document Register
MT	Magnetic Particle Examination
NCR	Non-Compliance Report
OD	Outside Diameter
ppi	Pounds per inch
PTR	Prototype Test Reinforcement
QA/QC	Quality Assurance / Quality Control
QP	Quality Plan. Reference ISO 9000 Paragraphs 2.7.2.b and 3.7.5 shall include inspection and test requirements and provide columns or spaces for the Principal and Contractor, if applicable, to indicate 3rd party inspector inspection activities, e.g., monitor, witness, hold points, etc. for the operations to be undertaken. It is required that the QP be approved by the Principal and Contractor, if applicable.
QTS	Qualification Test Sample
RFQ	Request for Quotation
SL	Service Life
SPR	Specific Project Requirements
SMYS	Specified Minimum Yield Strength
TLP	Tension Leg Platform
TSA	Thermal-sprayed aluminum
UT	Ultrasonic Examination
VIV	Vortex Induced Vibration
VT	Visual Examination

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets (). Other documents referenced by this DEP are listed in (11).

1.5 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using the DEP Feedback Form by:

- Entering comments directly in the DEP Feedback System on the Technical Standards Portal <http://sww.shell.com/standards> (mandatory for users with access to Shell Wide Web);
- Clicking on the DEP Feedback Form button on the DEPs DVD-ROM main page (for users without access to Shell Wide Web);
- Requesting a copy of the DEP Feedback Form from the Administrator at standards@shell.com (for users without access to Shell Wide Web).

For the last two options, the completed DEP Feedback Form can be attached to an email and submitted to the Administrator at standards@shell.com. Only feedback that is entered into the Feedback Form will be considered.

1.6 DOCUMENT PRIORITY

In the event of conflicts between Contract documents, AFC Drawings, Specifications and other referenced standards, the following document priority shall apply:

1. Contract Documents (including any approved exceptions)
2. AFC Drawings - Latest Revision
3. Principal Specifications (including project specific data sheets)

In the event of conflict between the content of this document and the content of the documents referenced herein, the order of precedence is as follows:

1. Government Regulations (if applicable)
2. This DEP
3. Manufacturer/Supplier and Contractor, if applicable, Specification
4. Manufacturer/Supplier and Contractor, if applicable, referenced documents and standards.

1.7 VARIANCES

This document is to be a controlling specification for the elastomeric flexible element design and fabrication. Previous reports, requirement lists, position papers, drawings or other documentation are superseded by this document. In the event that requirements stated in subsequent documentation (such as the Contract, etc.) are found to be in conflict with this DEP, those requirements are to be brought to the attention of the Principal for resolution.

Any variances from the requirements of this DEP require prior written approval from the Principal.

The Principal does, however, request that the Manufacturer/Supplier and Contractor, if applicable, question any apparent or perceived inconsistencies in this DEP as it relates to any other specifications or codes. Additionally, the Principal encourages the Manufacturer/Supplier and Contractor, if applicable, to make suggestions for clarifying/improving this DEP.

1.8 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

2. GENERAL

2.1 QUALITY REQUIREMENTS, QP AND MPS

The Manufacturer/Supplier shall implement an ISO 9001 Quality Management System or equivalent as approved by the Principal and Contractor, if applicable. A QP and an MPS shall be specifically developed for each order and shall be approved by the Principal and Contractor, if applicable, prior to commencement of manufacturing operations. For verification purposes during manufacturing, the Manufacturer/Supplier and its Subcontractors shall provide representatives of Principal with appropriate liaison assistance at the location(s) where work is occurring during working hours and unrestricted access to work place, personnel and documentation.

2.2 CONTRACTOR PROCUREMENT SPECIFICATION AND APPROVAL BY THE PRINCIPAL OF THE CONTRACTOR AND MANUFACTURING FACILITIES

This DEP may be used directly for procurement or, at the Contractor's option, the Contractor may prepare a detailed procurement specification, which is compatible with the Contractor's document format and quality system. At a minimum, the Contractor's procurement specification shall incorporate all requirements contained herein and shall require approval by the Principal. The Contractor and manufacturing facilities, as identified in the manufacturing procedure specification, shall require approval by the Principal.

2.3 GENERAL SCOPE OF SUPPLY

The scope of supply includes the elastomeric flexible element and protective structure and fixture(s). The tendon top termination assembly and tendon bottom termination assembly may be procured separately and are not covered by this DEP.

- Set of Elastomeric Flexible Elements for tendon (each set contains a top elastomeric flexible element and bottom elastomeric flexible element).
- Protective structure(s) for storage of the flexible elements as needed, including storage, transportation and installation activities (such as pre-installation on tendon porch).

The performance requirements for the above, such as loading etc., shall be specified in the specific project requirements. See (Appendix A).

The Contractor shall provide all the temporary protective equipment needed and/or handling instructions until the installation of the elastomeric flexible element on the tendon top termination assembly or tendon bottom termination assembly. The Manufacturer/Supplier shall provide handling guidelines once installed such as allowable loading during transportation. In addition, the Contractor shall provide all the necessary documentation for the design, testing, handling, installation, operation and maintenance of Elastomeric Flexible Elements. The Contractor shall participate in all the relevant interface discussions and assist the Principal in interface management with other project components and their Manufacturers/Suppliers. Relevant interface issues include alignment/fit-up of parts, delivery schedule and installation methods.

2.4 ELASTOMERIC FLEXIBLE ELEMENT

Each elastomeric flexible element shall be part of the tendon top termination assembly (which attaches the tendon to the tendon porch on the hull, see Figure 2.2) or the tendon bottom termination assembly (which attaches the tendon to the receptacle on the top of the pile, see Figure 2.3). These parts help to accommodate environmental forces offsetting the TLP with respect to its foundation without inducing large bending moments at the tendon connections. Each flexible element shall be interchangeable with the other flexible elements. If the tendon top termination assembly and tendon bottom termination assembly require flexible elements of different size/configurations, then the flexible elements for the bottom termination assemblies shall be interchangeable with the other bottom flexible elements, and the flexible elements for the tendon top termination assemblies shall be interchangeable with the other top flexible elements.

Figure 2.1 shows a schematic cross-section of the tendon elastomeric flexible element assembly.

2.5 MOCK-UP

The flexible elements shall be checked for proper interface with other tendon components. A first article flexible element should be used for these interface checks. Alternatively, due to schedule constraints, a mock up may be required for this purpose. If required by the specific project requirements, the Manufacturer/Supplier shall supply mock-ups, which replicate the outer dimensions of the flexible element.

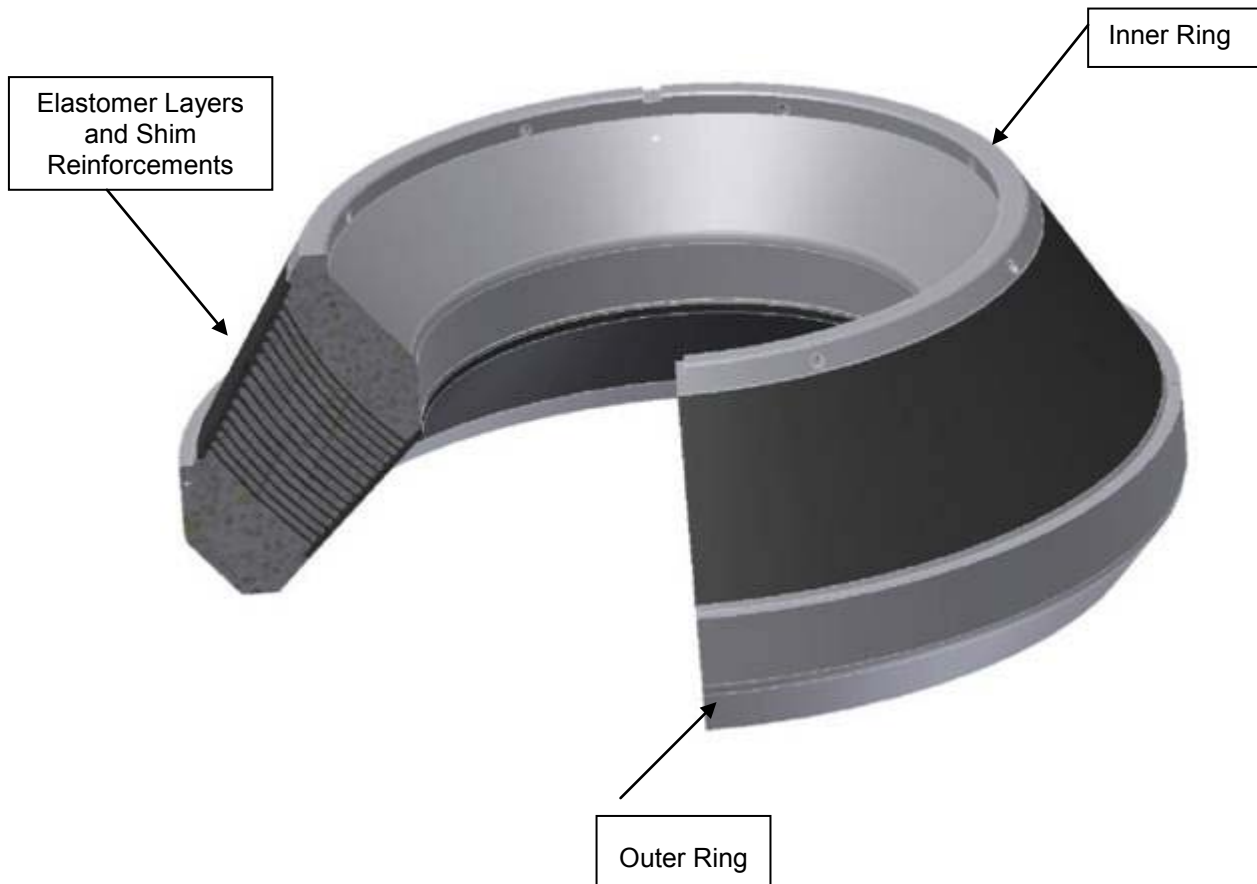


Figure 2.1 Schematic cross-section of the top tendon elastomeric flexible element assembly (iso-metric view)

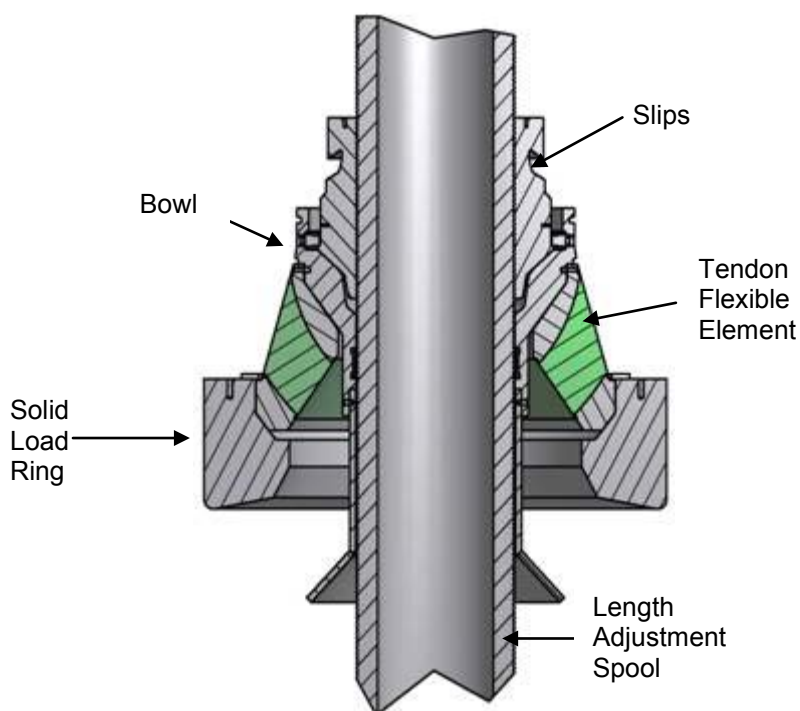


Figure 2.2 Tendon top termination assembly

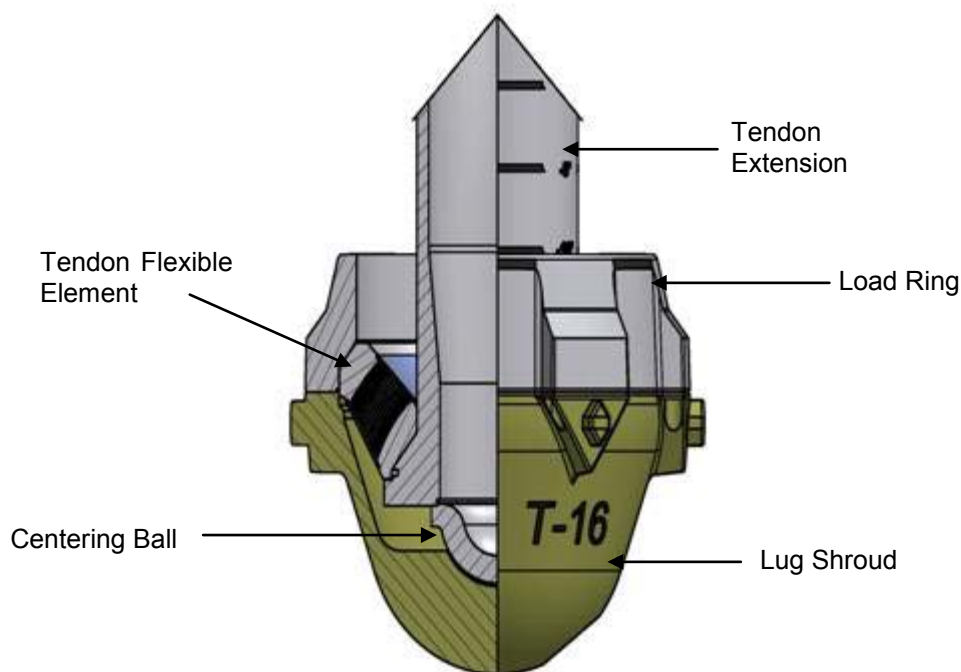


Figure 2.3 Tendon bottom termination assembly

2.6 TEMPORARY PHASES

Each elastomeric flexible element may be transported to several locations prior to its final installation and therefore exposed to various environmental conditions. The Specific Project Requirements (SPR) will include more details regarding these environments. Each flexible element shall be designed for storage in these environments. The Manufacturer/Supplier shall provide protective crating and/or temporary coverings for the flexible elements to ensure safe handling and storage in these conditions as required for each loading condition

specified in the SPR. Also, if required by the SPR, the Manufacturer/Supplier shall supply a means of handling.

Depending on the installation method, the flexible elements are exposed to different loading patterns. The SPR will have detailed information regarding the installation method and anticipated loading. The Contractor shall determine if there is a need for temporary physical restraints for either the tendon top termination assembly or tendon bottom termination assembly during the storage, handling and temporary installation phases. These restraints shall be part of the scope of the Manufacturer/Supplier.

2.7 CHANGES IN THE SCOPE OF SUPPLY

The general scope of supply is described in (2.3). The specifications to which the equipment shall be designed are defined in the SPR (Appendix A). The disposition of any changes in the scope of supply or operation criteria shall be mutually agreed upon by the Principal and the Contractor and, if warranted, Change Order(s) shall be made to the contract.

2.8 INTERFACE MANAGEMENT

The Manufacturer/Supplier and Contractor, if applicable, shall participate in all the relevant interface discussions and assist the Principal in the management of interface between elastomeric flexible element and other project components and their Contractors.

The Manufacturer/Supplier and Contractor, if applicable, shall respond to interface queries within three (3) working days.

The Manufacturer/Supplier and Contractor, if applicable, shall bring any issues and concerns with respect to mechanical interfaces to the Principal's attention as soon as possible.

The Contractor and Principal, if applicable, shall review and comment on interface drawings within five (5) working days.

The Manufacturer/Supplier and the Contractor, if applicable, shall request in a timely manner all the interface data required for the design and manufacturing of elastomeric flexible element components from the Principal.

2.9 HEALTH, SAFETY AND ENVIRONMENT

The Manufacturer/Supplier and Contractor, if applicable, shall have a functioning HSSE system in place. The Manufacturer/Supplier shall provide documentation of an HSSE system to the Principal upon request.

3. ELASTOMERIC FLEXIBLE ELEMENT DESIGN AND TECHNICAL REQUIREMENTS

3.1 GENERAL

The elastomeric flexible elements shall be designed in accordance with the design parameters and performance specification listed in the "scope of work" found in the SPR and any additional criteria determined necessary due to the proposed method of installing and testing of the elastomeric flexible element. Furthermore, the flexible element shall satisfy all the size restrictions imposed by the Principal's system requirements including overall dimensions, physical interfaces and extreme loads including cocking and torsional moments.

3.2 EXTREME ANALYSIS

The Principal shall provide the Manufacturer/Supplier with the operating, storm and survival design conditions for both the top and bottom elastomeric flexible element, including information related to:

1. Effective Tension
2. Material Tension
3. Maximum Angle
4. Torsional Moment

The Contractor shall design the elastomeric flexible element as per AP RP 2T for the given extreme conditions and loads. For extreme analysis, the Contractor shall assume that all four loads above are applied simultaneously.

3.3 SERVICE LIFE

All equipment specified herein shall meet the Service Life (SL) required by the project in the SPR. Additionally, fatigue criteria as specified in the following section shall apply. The Contractor shall provide the necessary documentation including the relevant test data to demonstrate that all the elastomeric flexible element components meet the required SL.

3.4 DESIGN CODES AND SAFETY FACTORS

The design criteria for each flexible element shall be based on API RP 2T. The allowable net section and local bending stresses are obtained by using the allowable von Mises stress defined in API RP 2T. The tendons and tendon components are designed for collapse according to API RP 2T.

The stresses given by the finite element analysis results contain peak stresses as well as membrane and membrane plus bending stresses. The finite element mesh shall be refined to verify that peak stresses have been properly captured. The membrane and membrane plus bending stresses shall be obtained by determining the "linearized stresses", defined as the linear, statically-equivalent stress distribution across a section for each stress component. The linearized stresses should be calculated such that the surface bending and average stress for a linear distribution across that section has the same first moment and the same resultant as the actual stress distribution. Linearized component stresses should be used to calculate the linearized principal stresses and von Mises equivalent stresses, which are then used for comparison to the stress categories of primary membrane stress, primary membrane plus bending stress and primary membrane plus bending stress plus secondary stress. The allowable stress for each stress category is shown in the Table 3.1 below. The linearized stress should be checked at a sufficient number of sections to verify that the allowable stresses are not exceeded.

Table 3.1 – Allowable stress

Stress Category ⁽¹⁾	Safety Categories			RP 2T 3 rd ed.
	A	B	S	
Membrane (Net Section Stress) ⁽²⁾	0.67 Sy	0.8 Sy	1.0 Sy	Table 11
Membrane + Local Bending ⁽³⁾	1.0 Sy	1.2 Sy	1.2 Sy	Table 11
Membrane + Local Bending ⁽³⁾ + Secondary	2.0 Sy	2.0 Sy	2.0 Sy	Equation (68)
Range of Primary Membrane + Bending + Secondary + Peak ⁽²⁾	Based on Fatigue Curve			
Average Bearing Stress	1.0 Sy	1.0 Sy	1.0 Sy	Equation (70)
Average Primary Shear Stress ⁽⁴⁾	0.4 Sy	0.4 Sy	0.4 Sy	Equation (69)
Primary Tri-axial Stress (S1 + S2 + S3) ⁽⁵⁾	2.67 Sy	2.67 Sy	2.67 Sy	Riser based

NOTES: Sy = Specified Minimum Yield Strength (SMYS)

S1, S2 and S3 are principal stresses

1. Values pertain to solid-walled metal tendons only. Not applicable to composite tendons or other non-metal construction.
2. Membrane stress shall be computed as the von Mises equivalent stress at midwall. Extreme stresses shall be based on a 50 % probability of exceedance in expected event duration.
3. Membrane + bending stress criterion is based on peak (total) linearized stresses which include stress amplification factors due to discontinuities, contact surfaces, etc. ASME Section VIII Div. 2 includes a 1.5 increase factor above the Membrane stress criterion for stresses defined in a similar fashion. Membrane + bending + secondary criterion is also from ASME Section VIII and includes, for example, localized thermal stresses.
4. Note that ASME Section VIII Div.2, Part AD, Paragraph AD-132.2 places this limit at 0.4 Sy, which is consistent with API RP 2T.
5. Reference ASME Section VIII Div.2, Appendix 4, Paragraph 4-137. This criterion has been adopted here to augment the tendon codes, which do not provide criteria for triaxial stresses.

All necessary calculations shall be performed to demonstrate that the flexible element design meets the requirements of the specifications and regulations, codes and standards. All critical load conditions shall be taken into account, including load conditions encountered during the installation and operational phases.

The design shall be verified by Finite Element Analysis (FEA) and testing where necessary to support and validate FEA. Worst-case analyses shall be run to quantify the effects of fabrication tolerances on component stresses and provide guidance for the Manufacturing Plan and Quality Control Plan. Axi-symmetric modeling shall in general be used. However, three-dimensional modeling shall be used to quantify three-dimensional effects in critically stressed areas where appropriate.

3.5 MATERIALS FATIGUE DESIGN

Prior to starting FEA analysis on the elastomeric flexible element, the Contractor shall request Principal's approval for methodology, parameters, techniques and computer programs used for the FEA and fatigue analysis.

The elastomeric flexible element shall accommodate the conditions specified in the fatigue histograms provided in the SPR for service without failure for a combined fatigue life of project specified SL with a minimum safety factor of 10. The Contractor shall provide, for Principal's approval, the method/basis for combined fatigue life due to various considerations impacting fatigue life.

The Principal shall provide the relevant design data consisting of tension amplitudes (tension minimum, tension maximum and mean tension), angle variations, annual cycles and probabilities. The data shall include the effect of vessel motions, tendon VIV and all other motions.

The Manufacturer/Supplier shall substantiate all assumptions and data used for all analysis, such as the fatigue performance of metals, elastomers, elastomer-metal bond, etc. that will be used in the manufacturing process. Possible material used to substantiate assumptions and data used for analysis are:

- Comparisons of experimental data on stiffness with predictions.
- Data base which supports the fatigue computation rules and procedures, including multiple loading modes, cold temperature effects, elastomeric aging, creep and combined loading.
- Discussion of data, if any, that should be produced to support the design.

The Manufacturer/Supplier is encouraged to use test data from earlier, similar designs as a comparison against fatigue analysis results and thereby substantiate the analysis methodology. In the event that there are insufficient or limited data available the Manufacturer/Supplier shall alert the Principal and provide a plan for further testing and qualification.

Fatigue analysis of all metal components shall be accomplished by the S-N Approach using a power law in conjunction with Miner's rule for cumulative damage (as specified by API RP 2T). Conservatively, BS 7608 B Design curve may be utilized for the inner and outer rings and reinforcement shims with appropriate stress concentration factors. Maximum principal stress shall be used in all fatigue analysis.

The Manufacturer/Supplier shall document all fatigue analysis in a Design Report for the Principal's review and approval.

3.6 FRACTURE MECHANICS OF ALL METAL COMPONENTS

The Contractor shall ensure, through fracture mechanics that the flexible element is fit for purpose and can be proven to be unlikely to fail by fracture.

A fracture assessment shall be performed which establishes the fracture characteristics and fatigue crack growth characteristics of the flexible element inner and outer rings. The life predicted by fracture assessment and fatigue crack growth shall be a minimum of five (5) times the service life, which meets the recommendation for such in API RP 2T. This assessment shall be based on a defect size, proposed by Contractor, which can be reliably detected by Contractor's inspection method and procedures. The fatigue life shall be determined by a fatigue crack growth simulation analysis using Principal approved methods.

The fatigue life of the flexible element load path component with a maximum allowable initial defect size is the time for this defect to grow to the critical size, which triggers brittle fracture under the design extreme (Category "B") loading. The brittle fracture analysis shall be carried out following level 2 or level 3 assessment procedures of BS 7910 with the Contractor selected minimum required CTOD value.

All fracture and fatigue parameters and methodology shall be approved by the Principal. Fracture parameters include, but are not limited to, fatigue crack growth law constants, crack shape assumptions, fracture toughness (CTOD) and the use of a threshold stress intensity factor.

Fracture mechanics fatigue crack growth calculations shall use the general methodology outlined in BS 7910. Crack growth shall assume Paris law behavior, as described in the following equation:

$$\frac{dA}{dN} = \begin{cases} C(\Delta K)^m & \text{when } \Delta K \geq \Delta K_{th} \\ 0 & \text{otherwise} \end{cases}$$

Where dA/dN denotes the incremental crack growth per cycle, ΔK denotes the range in stress intensity and C and m are empirical constants. ΔK_{th} is a threshold value for stress intensity below which crack growth is assumed not to occur. Note that the C and m values do not denote the same empirical constants used for defining S-N curves. Actual material da/dN - ΔK curves with stress concentration correction shall be used. In absence of actual curves, conservative curves recommended in the latest editions API 579-1 and BS 7910 shall be used for da/dN - ΔK approach. Maximum principal stress shall be used in all fatigue analyses.

3.7 ELASTOMER DESIGN AND EVALUATION

Elastomers used in elastomeric flexible element shall meet all the structural strength, fatigue and environmental requirements. Various elastomer properties such as hardness, non-linear shear stress-strain curves for the range of operating temperatures, tensile/shear range, elongation, non-linear bulk modulus, compression versus tension behavior, creep and relaxation, abrasion resistance, tear resistance, low temperature usage, aging, adhesion to metals, etc. shall be characterized by testing the actual elastomer compounds used in the prototype elastomeric flexible element.

The elastomer compound selected shall address the following issues:

1. Due to nonlinear behavior of elastomers, flexible element molding exhibit increased angular stiffness values at low angle oscillations resulting in increased alternating bending stresses in the connecting members. Appropriate elastomers shall be selected to minimize the non-linearity of the elastomeric flexible element cocking stiffness under low angle oscillations.
2. Elastomeric flexible element will be exposed to sea water. Absorption of sea water may reduce the fatigue resistance of elastomer containing compounding ingredients soluble in water (such as antioxidants added to the natural rubber to increase its fatigue resistance) by dissolving these ingredients. Appropriate elastomer compound shall be selected to minimize these concerns.
3. Degradation of material properties is observed in all elastomers due to aging, change of mechanical properties and/or visible changes in the appearance of the elastomer, and the process is accelerated by heat, light and presence of certain metallic impurities. The nature of the changes observed vary considerably depending upon the specified elastomer and the aging conditions to which it is subjected. The net effect on the properties is the resultant of two competing processes of chain scission and cross linking. If chain scission dominates, the elastomer softens and eventually becomes sticky with aging. Most elastomers, however, harden and eventually embrittle as a result of aging (a consequence of cross-linking dominance) thereby increasing the elastomeric flexible element cocking stiffness. Appropriate elastomer shall be selected to minimize the aging effects.
4. Visco-elasticity/visco-plasticity of elastomers vary considerably upon the specified elastomer and affects the long-term performance of an elastomeric flexible element, therefore an appropriate elastomer shall be selected to minimize these effects.

3.7.1 Elastomer strength evaluation

Unlike metals, elastomers are not standardized. Each Manufacturer has their own elastomer formulation. For the elastomer used in the elastomeric flexible element, the

allowable stresses/strains shall be established by material testing in conjunction with non-linear finite element analysis. The criteria for elastomer strength evaluation consists of the following stresses/strains categories.

3.7.1.1 Elastomer tri-axial tensile stress

The maximum tri-axial tensile stress in elastomer is limited to the lesser of 2.5 times the initial shear modulus and 6 times the average shear modulus.

Tri-axial tensile stress is defined as: $\frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3)$, where $\sigma_1, \sigma_2, \sigma_3$ are principal stresses.

Elastomers are commonly found to undergo internal cavitation at tri-axial tension equivalent to 2.5G, where G is the initial shear modulus. The initial shear modulus is several times higher than the average shear modulus used in the design. This phenomenon is a consequence of an elastic instability known as “an unbounded elastic expansion of pre-existing cavities, too small to be readily detected.” The critical stress does not depend on the strength of the elastomer but only on its non-linear shear modulus obtained by testing the actual elastomer.

3.7.1.2 Elastomer tensile strains and shear strains

A typical elastomer layer of an elastomeric flexible element undergoes compression and shear. As the elastomer layer is compressed, the free edges bulge out to maintain a constant volume. As a result of this bulging, localized shear strains and tensile strains are developed at the extreme fiber of the free edges. When the elastomer layer is sheared, a direct shear strain is developed that is inversely proportional to the layer thickness. Thus, there are two types of strains that must be evaluated: 1) direct shear strain due to shearing action and 2) bulge strain due to bulging action.

- Direct Shear Strain: A strain measure for direct shear strain and its allowable value shall be established by the Manufacturer/Supplier and approved by the Principal.
- Bulge Strain: A strain measure for bulge strain and its allowable value shall be established by the Manufacturer/Supplier and approved by the Principal.

3.7.1.3 Elastomer fatigue evaluation

Fatigue analysis of all elastomer components shall be accomplished by methods proposed by the Manufacturer/Supplier and approved by the Principal, in accordance with API RP 2T (3rd edition). Methodology for combining various strains and factors of safety shall be established by the Manufacturer/Supplier and approved by the Principal. The elastomer shall be designed with a safety factor of 10 against fatigue.

3.7.2 Creep in elastomer

It has been determined that an important limit state for the class of elastomers used in flexible elements is creep rupture. This phenomenon is well known as a limit state and is discussed in the literature and textbooks on elastomer design, see (11).

Part of the creep phenomenon is related to the viscoelastic behavior of the material, which is a function of stress and loading rate. Thus, the detailed constitutive behavior of the material shall be defined as a function of these parameters. Further, the limits of the material shall be determined by testing for use in design and life forecasts for the flexible element. Finally, the creep phenomenon damages the material in a manner analogous to cyclic loading (fatigue). Thus, the total damage, due to creep and cyclic (fatigue) loading shall be determined and combined analytically in a rule suitable for design.

3.7.2.1 Requirements

The Manufacturer/Supplier shall demonstrate detailed knowledge of the following, based on test data, correlation with testing and verification in large scale, which also shall be presented for examination:

1. Constitutive behavior of the elastomer accounting for, but not limited to, stress and

loading rate.

2. Creep rupture limits of the elastomer with specific criteria stated for performance limits over the range of parameters expected in design (stress and loading rate, etc.).
3. Design techniques that apply the above to achieve a suitable design for any given instance.
4. Techniques to combine creep and cyclic (fatigue) design for life forecasting over the range of service conditions.

This demonstration shall take the form of a comprehensive report with supplemental information on the specific facets of design, testing and evaluation of creep rupture as it is applied to flexible elements. Supplemental testing shall be required as outlined in the section below.

3.7.2.2 Qualification

If required, to verify that the Manufacturer/Supplier has the knowledge and ability to design a flexible element for creep rupture in combination with cyclic (fatigue) loading, the following testing shall be performed:

- Laboratory testing that demonstrates the understanding of the material constitutive behavior and creep rupture limits by comparing predictions to measurements of critical variables for a selected application. These tests shall be conducted over a range of simulated operating conditions proposed by the Manufacturer/Supplier for approval by the Principal. The proposal shall include acceptance criteria (also subject to Principal Approval).
- Prototype flexible element testing that demonstrates the ability of the analytical tools to predict failure in full sized parts. Details of this test shall be proposed by the Manufacturer/Supplier for approval by the Principal. The proposal shall include acceptance criteria (also subject to Principal Approval).

Successful demonstration and correlation of predictions with measurements, as deemed adequate by the Principal shall constitute qualification with regard to creep and creep rupture limit state.

3.8 METAL TO ELASTOMER BONDS

The Bonding agents used for bonding elastomer and metal components together are highly critical. Elastomer is bonded to metal during vulcanization process and the bonding strength varies considerably upon bonding agents and the type of elastomer bonded. Appropriate bonding agents shall be selected and the bond integrity shall be verified by physical testing in presence of working fluids, including seawater.

3.9 METAL TO ELASTOMER BOND EVALUATION

3.9.1 Average shear stress in elastomer

The average shear stress in elastomer at the interface of metal and elastomer bond shall be established. This includes a proposal of which industry standard will be used to determine this by the Manufacturer/Supplier and shall be approved by the Principal.

3.9.2 Adhesive strength

The adhesive strength of elastomer bonded to steel shall be established. The Manufacturer/Supplier shall propose which industry standard will be used to determine this and shall be approved by the Principal.

3.9.3 Metal to elastomer bond fatigue evaluation

The integrity of the bond shall be evaluated while conducting the testing for elastomer fatigue. Leakage or tearing at the bond line during fatigue testing reflects a weak bond. Measures shall be taken to strengthen the bond so that leakage/tearing occur in the elastomer rather than bond line. The metal to elastomer bond shall have a safety factor of

10 against fatigue. The Manufacturer/Supplier shall propose the bonding method, this includes a proposal of which industry standard will be used to determine this, and shall be approved by the Principal.

3.10 FAILURE MODES

The elastomeric flexible element shall exhibit adequate structural integrity under operating, extreme, test, survival and accidental loads furnished by the Principal in the SPR. The elastomeric flexible element shall accommodate all anticipated loads without gross yielding (of metallic components) or material failures. This capability shall remain intact for the entirety of the planned service life. The capability of elastomeric flexible element under various loadings shall be demonstrated by prototype testing and/or by FEA. The capability check shall verify that elastomeric flexible element components meet the evaluation criteria stated earlier in this section.

The cocking capacity shall be demonstrated by rotating the elastomeric flexible element to its full anticipated cocking angle during the Factory Acceptance Testing (FAT, see (9.2)) and verifying that the elastomeric flexible element sustains no damage to any of its components.

The elastomeric flexible element shall be designed to support the tendon service loads in the event that the elastomer within the elastomeric flexible element fails and/or extrudes.

3.11 SERVICE MAINTENANCE AND INSPECTION

The elastomeric flexible element shall accommodate all the axial, cocking, torsion and radial motions, imposed by a TLP tendon, without failures of any kind and without any lubrication, servicing or post-installation inspection throughout the service life. Furthermore, the Flexible Element shall be maintenance and inspection free throughout the specified SL.

3.12 INSTALLATION

There are at least two tendon installation methods that can be used. The specific project requirements document will have more information regarding the installation method to be used for each project, including the various loading conditions to which the flexible elements will be exposed. At minimum, each elastomeric flexible element shall be designed to accommodate the following considerations relating to installation:

1. Integration of flexible element onto the tendon bottom termination assembly and the tendon top termination assembly.
2. Bolting/connection methods.
3. Maximum angles during the installation offshore.
4. Loading during temporary phases.
5. Installation loading.

3.13 INTEGRATION OF ELASTOMERIC FLEXIBLE ELEMENT IN TENDON END TERMINATIONS

The top elastomeric flexible element will be integrated into the tendon top termination assembly, which attaches the top of the tendon to the tendon porch on the hull. The bottom flexible element is integrated into the tendon bottom termination assembly, which attaches the bottom of the tendon to the receptacle located on the top of the tendon pile. It is critical to the function of the flexible element and associated equipment, to their design and performance and to that of equipment and structures to which they interface, that those interfaces be accounted for in the design of the flexible element. The Contractor shall include interfacing the design of the flexible element equipment with that of equipment and structures to which they interface. Interface checks shall be made at the various interfaces to ensure compatibility, including dimensions, tolerances, handling and assembly methods.

All items of a flexible element shall be designed to be interchangeable between flexible element assemblies of the same size/configuration. Flexible elements shall be interchangeable between the tendon assemblies of a TLP, unless the top and bottom assemblies are of different sizes/configurations. If the tendon top termination assembly and tendon bottom termination assembly require flexible elements of different size/configurations, then the flexible elements for the bottom termination assemblies shall be interchangeable with the other bottom flexible elements, and the flexible elements for the tendon top termination assemblies shall be interchangeable with the other top flexible elements. Selective assembly is not permitted.

3.14 PREVENTION OF TENSION OF ELASTOMER

Under all service conditions (inclusive of in service and temporary phases) the uniform hydrostatic tension (cavitation) stresses in the Elastomer shall not exceed the allowable value. The value for this tension stress and the allowable shall be stated specifically and shall be submitted to the Principal for approval.

The tolerances for the internal dimensions of the elastomeric flexible elements shall be such that the allowable value of hydrostatic tensile stress is not exceeded. Alternately, a fixture shall be designed to prevent deformations that might create unacceptable hydrostatic tensile stress. Other conditions that might result in a hydrostatic tensile stress that exceeds the allowable include handling, or any situation that results in compression.

The Contractor shall demonstrate that procedures are in place to prevent such over-loading and acquire measurements, documenting sizes and tolerances that assure hydrostatic tensile stresses are not exceeded. Alternately, the function of the fixture that avoids such loading shall be tested or demonstrated to the Principal's satisfaction. See (3.7.1.1).

3.15 FASTENERS

DEP 37.81.41.30-Gen. and DEP 37.81.41.33-Gen. shall be used for the selection of bolts.

3.16 EXTERNAL CORROSION PROTECTION

All external metal surfaces of the elastomeric flexible element shall be coated with thermal sprayed aluminum (TSA) per Principal approved DEP 30.48.40.31-Gen. Note that this requirement does not include the reinforcement shims as they are encapsulated by the elastomer to minimize corrosion in the marine environment. For those tendon flexible elements where the SL is greater than 20 years, Manufacturer/Supplier shall incorporate means for supplying Cathodic Protection to the exposed surfaces. This can take the form of anodes (assuming that they can fit within the terminations) or holes for straps for connectivity to other components which are cathodically protected.

3.17 AXIAL AND ROTATIONAL (COCKING) STIFFNESS

Preliminary values of axial rotational stiffness for the tendon elastomeric flexible elements should be provided to the Principal by the Manufacturer/Supplier. Prior to award of contract, the Principal and the selected Manufacturer/Supplier shall agree on more specific stiffness data so that Principal can proceed with the analysis of the tendons, etc. During the very early design phase, and included in the design report, the Manufacturer/Supplier shall provide/confirm stiffness data for all the ranges of operating conditions specified in the SPR. The stiffness values provided with the preliminary design report shall be conservative (higher than the value of the flex element as measured during the FAT). If the value is exceeded, analysis shall be performed to ensure that the higher stiffness can be accommodated in both the tendon flexible element and the components that interact with it.

Temperature variation, aging and stress softening effects on the elastomer shall be included in the estimates of maximum stiffness. Aging of the elastomer may be validated using accelerated aging tests.

The Principal may regenerate the axial and rotational spectrum provided with a Request For Quotation (RFQ) after the Manufacturer/Supplier has established low angle stiffness.