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INDEX OF REVISIONS										
REV	DESCRIPTION AND / OR REVISED SHEETS									
0	ORIGINAL ISSUE									
A	GENERAL REVISION									
B	AMENDS TO INCORPORATE SUGGESTIONS FROM MANUFACTURERS AND CLARIFY SOME ITEMS									
C	RESECTIONING AND AMENDS ON CORROSION RESISTANT MATERIALS, TEST PROCEDURES.									
D	INCLUSION OF FIXED BEND STIFFENER (FBS) AND AMENDS TO INCORPORATE SUGGESTIONS FROM E&P TEAM.									
E	CHANGES IN MINIMUM BEND STIFFENER REQUIREMENTS, DESIGN ACCEPTANCE CRITERIA, BOLT MATERIAL AND DYNAMIC TEST PROCEDURE.									
F	REFERENCES TO NEW SPEC THAT REPLACES N-2409; UPDATE OF REFERENCE TO STANDARDS IN SECTION 12; CORRECTION OF ALLOWABLE CRA HARDNESS IN SECTION 8.3, INCLUSION OF SECTION 10.1 MINIMUM REQUIREMENTS FOR SURFACE FINISHING, INCLUDING ROUGHNESS AND FLAW CRITERIA, INCLUSION OF SECTION 10.2 BOLT TORQUE AND PRE-LOAD PRECISION AND RENUMBERING THROUGHOUT SECTION 10. TREATMENT OF HOT SPOTS IN STRUCTURAL ANALYSIS, REQUIREMENTS FOR SURFACE PROTECTION DURING HANDLING, CHANGES IN TABLE OF MAXIMUM ALLOWABLE STRAIN, INCLUSION OF RESULT REPORTING REQUIREMENTS, REQUIREMENT OF NCR/NCTR AS DOCUMENT DELIVERED TO CLIENT.									
G	CHANGE IN REFERENCE ROUGHNESS FOR CORRECTION FACTOR IN SECTION 7.2 (FROM 0.4 μM TO 1.6 μM) AND SEVERAL CORRECTIONS TO MISTAKEN REFERENCES TO I-ET-3000.00-6500-291-PAZ-038 [1], ALONG WITH ADOPTION OF MANY CONCEPTS AND REFERENCES FROM API RP 17L1 AND API RP 17L2.									
	REV 0	REV A	REV B	REV C	REV D	REV E	REV F	REV G	REV H	
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## GENERAL BEND STIFFENER REQUIREMENTS

## 1 PURPOSE

This Technical Specification (ET) aims to establish minimum requirements for design, material selection, manufacture and qualification of static and dynamic bend stiffeners used to prevent overbending and fatigue of flexible pipes and umbilical cables.

## 2 SCOPE

Requirements, specifications and recommended practices cited hereinafter are applicable for all bend stiffeners for flexible pipes and umbilical cables used offshore Brazil and regulate the minimum requirements which shall be met by manufacturer and Independent Verification Agent (IVA), as defined below. Additional rules and recommended practices may be given in the following regulations and ETs:

- I-ET-3000.00-6500-291-PAZ-038 Flexible Pipe (replacement of Standard N-2409) [1] for PETROBRAS assets only
- I-ET-3500.00-6500-291-PAZ-001 [3]: for nonstandardized prototype qualification tests for PETROBRAS assets only.
- Applicable bellmouth/i-tubing interface specification for sliding, FBS and DCDE bend stiffeners, as well as any other applicable documentation attached to the particular flexible I-RM, including all ETs in format I-ET-3010.xx-1300-279-PPC-0yy [4].
- I-ET-3010.00.1500-960-PPC-012 [5] : for DCDE bend stiffener conceptual design.
- I-ET-3500.00.6500-291-PAZ-026 [6]: for new product or supplier management.
- ET-3500.00-1516-940-PDS-011 [9] (in Portuguese): for cathodic protection of subsea equipment.
- API Recommended Practices 17L1[7] and 17L2[8], where applicable with due changes mentioned herein.

## 3 ABBREVIATIONS AND DEFINITIONS

*Bellmouth*: flared structural component connected to the downmost edge of I-tube, in which sliding, FBS or DCDE bend stiffener is fit.

*Cap*: most external metallic portion of bend stiffener, as shown in figure 3.1 and per API RP 17L2[8].

*Centralizer*: cylindrical part attached to the flexible pipe and fit in the bellmouth as show in figure 3.1.

*CRA*: corrosion resistant alloy.

*DCDE*: sliding dual bend stiffener with dual conical body, as shown in figure 3.1.

*Design methodology*: as per item 5.2 of API 17J:2014[2], extended to the ancillary equipment.

*Dynamic bend stiffener*: bend stiffener designed to undergo cyclic bending over its whole service life.

*End-fitting bend stiffener*: bend stiffener to be fixed onto a rigid support generally by bolting.

*False negative*: supposing that the product, material or concept is, by hypothesis, deemed to be weak or substandard until it passes in the bench tests, the false negative is defined by the lack of evidences of existing weaknesses during the trials, i.e. the survival or success of one or more samples during tests, not exhibiting signals of hazards or deficiencies which actually exist.

*False positive*: the false positive is defined by the incorrect confirmation of some weakness of the product, material or concept during the tests, i.e. the failure of one or more samples during tests which would hardly occur in actual field conditions.

*FAT*: factory acceptance test.

*FBS*: bend stiffener fixed to the flexible pipe (or umbilical) with a metallic cylindrical centralizer.

*FEA*: finite element analysis.



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*FMEA*: failure modes and engineering analysis.

*FMECA*: failure modes and engineering criticality analysis.

*Flared liner*: polymeric sleeve (and its end fitting) which internally coats the ending sleeve, avoiding contact between pipe's external sheath and metallic parts, mentioned as "bend stiffener protective liner" in API RP 17L2[8].

*Flexible manufacturer*: the manufacturer or supplier of the flexible pipe or umbilical.

*FPU*: floating production unit as per API RP 17L2[8].

*FSHR*: free standing hybrid riser.

*Hot spot*: localized area at which stresses substantially exceed neighboring stress values.

*Insert*: bend stiffener's internal reinforcing structure, in general made of steel, which is bonded to or under contact with the surrounding polymeric body.

*Interface structure*: as per API RP 17L2[8].

*Intermediate bend stiffener*: as per API RP 17L2[8]. It is often a static bend stiffener.

*IRC, Independent Review Certificate*: review by which an IVA states that the art, design methodology, design calculations, and manufacturing processes for specific product are in conformity with the applicable product specifications and references.

*I-RM, International Material Request*: documentation issued by PETROBRAS to define the specific requirements of products or equipment to be supplied.

*I-tube*: large-diameter structural conductor in floating production facility through which the top section of the flexible pipe may pass to reach the hang-off support or any other type of topside connection.

*IVA*: Independent Verification Agent.

*LSV*: lay service vessel.

*May*: on course of action.

*MBR*: minimum bending radius, as per API 17J[2], which encompasses the concepts of storage/static minimum bending radius, dynamically-supported minimum bending radius, quasi-dynamic minimum bending radius and dynamic bending radius.

*Minimum bend stiffener*: small bend stiffener, usually for intermediate connections and static service.

*MQP*: manufacturing quality plan.

*NCR*: non-conformity report.

*NCTR*: non-conformity treatment report.

*NC, Non-conformity*: any deviation from documented procedures, break of allowable ranges of controlled parameters, unexpected hazard, defect or damage, disapproval during qualification or FAT, lack of criteria or procedure which could cause a product bad performance, etc.

*NDE*: non-destructive examination.

*NDT*: non-destructive test.

*Pipe supplier*: the manufacturer or supplier of the flexible pipe or umbilical cable.

*Premise*: basis, stated or assumed, on which product conception and engineering are performed and which is consistently followed during design, manufacture, installation and operation.

*Prototype*: as per API 17J[2].

*Purchaser*: PETROBRAS asset, affiliate, partner or sub-contractor in charge of procurement.

*Reinforcement structure*: metallic component, usually toroid of a circular cross-section used to reinforce the polymeric body at its largest section.



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*ROV*: remotely operated vehicle, as per API RP 17L2[8].

*Shall*: mandatory requirement.

*Should*: recommended practice.

*Sliding bend stiffener*: bend stiffener which can slide along the pipe as the dogs which hold it on place are unlocked, usually for installation in bellmouths.

*Static bend stiffener*: bend stiffener design to undergo moderate or high cyclic bending in short time span, though it may be exposed to permanent bending loads with low dynamic content.

*Steelwork*: all metallic parts of the bend stiffener, especially before the polymer moulding process.

*Studbolts*: metallic bolts which link the reinforcement structure to the flange.

*Supplier*: the company which supplies the bend stiffener, usually the flexible pipe supplier.

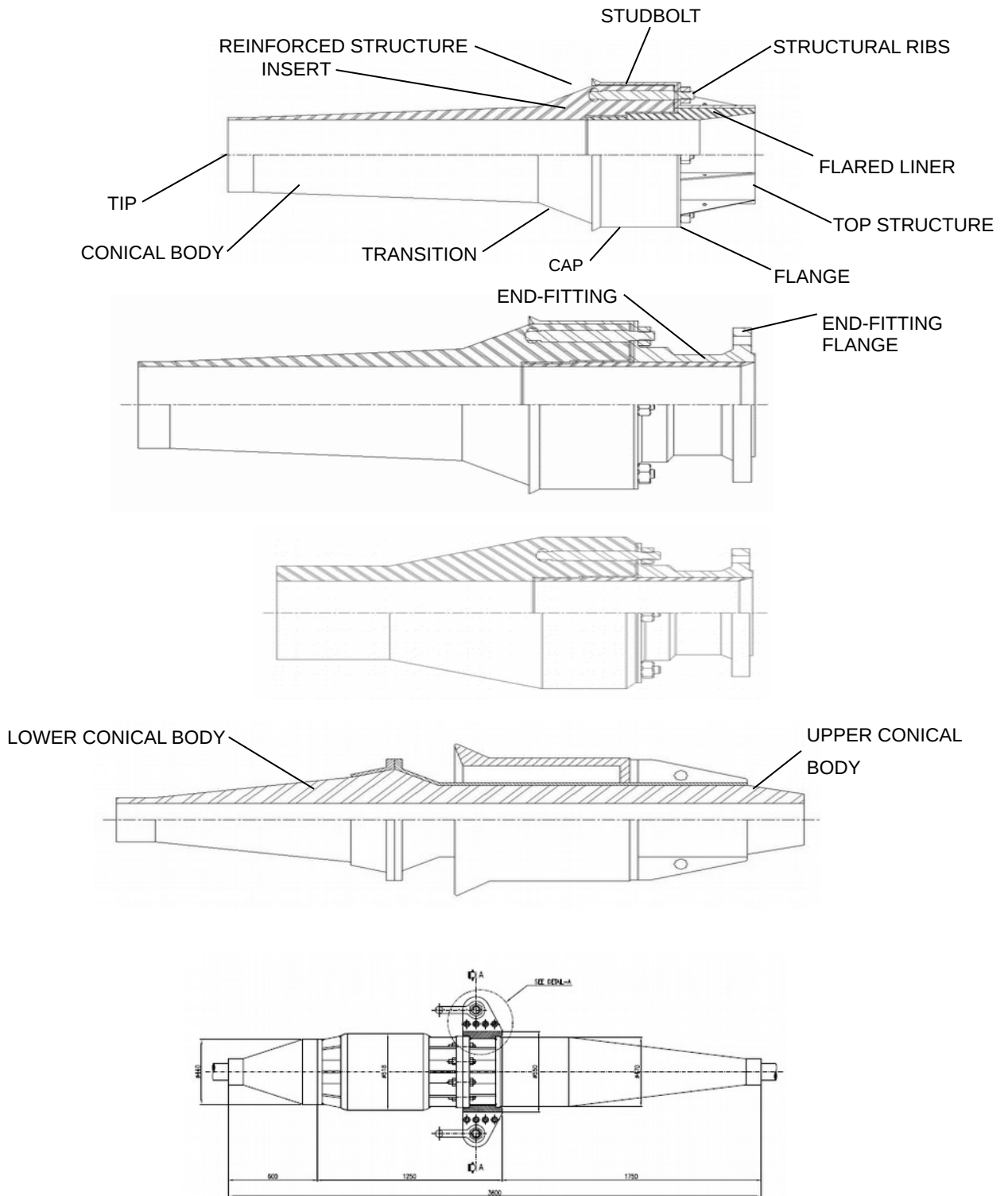
*Tip*: short cylindrical part at the downmost end of polymeric body, mentioned as “bend stiffener tip” in API RP 17L2[8].

*Top structure*: utmost metallic part (in Portuguese called *trombeta*) of a sliding bend stiffener, which cases the pipe and sometimes has a flared shape.

*Type approval*: certificate through which IVA states the range of applications, limits and constraints of design methods, criteria, material data and fabrication processes related to a family of products, based on evidences, provided by the manufacturer, confirming that they are in accordance with the requirements for a safety use and with the rules herein stated.

*UV*: ultraviolet.

*VIV*: vortex induced vibrations.



**Figure 3.1.** From top to bottom: sliding, end-fitting, minimum and DCDE and FBS bend stiffener.



#### 4 RESPONSIBILITIES

- Purchaser:
- (a) issue a detailed I-RM (material requisition document or equivalent) for the whole flexible pipe system and accompanying/referred Specifications, whose embedded information is sufficient for the pipe manufacturer and its suppliers to carry out their engineering tasks and provide the applicable functional requirements for the supply not defined elsewhere, as required per item 4.1 of API 17J[2].
  - (b) review technical documentation issued by Manufacturer and IVA and approve or reprove any design, test acceptance or quality assurance criterion, as well as to accept or to refuse validity to any qualification not previously defined in the specifications, based on the product concept and design philosophy, proposed by manufacturer.
- Manufacturer:
- (a) supply information required for structural analysis or verification and issue all technical documentation.
  - (b) design and supply a product which complies with functional and design requirements mentioned herein, but not limited to them, considering also any other relevant Standard and its own experience, in order to assure the safety use all along its service life. Manufacturer shall comply with ISO-9000/9001/ 9004/19011 [[10],[11],[12],[13]] . Either flexible manufacturer or bend stiffener manufacturer shall provide an IVA review and certification, as well as the validation of design methodologies as per sections 6.2 of [1] or 5.2 of [2], as applicable.
  - (c) guarantee the raw material, the manufacturing procedures and the final product within the bounds accepted by the manufacturing quality programme.
- IVA:
- as per API 17J[2].

#### 5 QUALIFICATION ENVELOP

The manufacturer and IVA shall define the envelop of design and manufacturing parameters within which its materials, design methodologies and manufacturing practices are validated and certified as per item 5.2 of API 17J[2] . Unless properly justified, every new product is deemed to be a prototype. The justification for a non-prototype product shall include:

- (a) envelope of applications for which design and manufacturing methods are validated and certified by IVA results on similarity analyses, comparing the previously qualified product parameters and performance with the characteristics of products. evidences that the product will not meet failure mechanisms beyond the capabilities of the design methodology to predict them, if available.

##### 5.1 SIMPLIFICATION OF QUALIFICATION PROGRAM FOR SMALL DESIGN CHANGES

Even if a product is deemed to be a prototype, the scope of its qualification programme can be simplified provided that following conditions apply:

- (a) manufacturer, purchaser, pipe supplier and IVA agree to do such simplification and on its extent.
- (b) the manufacturer or pipe supplier has successful track records as a PETROBRAS supplier, as well as ISO 9001/9004 certification and certification according to section 5.2 of API 17J[2], applicable to the related product.
- (c) the actual utilization factors for the new product shall be at least the ones of the previously qualified product, for the applicable failure mechanisms.

**GENERAL BEND STIFFENER REQUIREMENTS****6 GENERAL FUNCTIONAL REQUIREMENTS**

According to API 17L1, the purchaser is expected to specify its functional requirements for the ancillary equipment, despite a number of such requirements may be obtained in the standards, Overall functional requirements of sections 4.2.2 and 5.2 of API 17L1[7] apply, with the following extension of regulation for the bend stiffeners under scope of this ET:

- (a) the product shall limit the curvature in the flexible pipe or umbilical to the reciprocal of its dynamic MBR ( $1.5 \times$  storage bending radius or greater as per API 17J[2]) for any accidental or extreme environmental condition predicted as per section 8 of API RP 17B[14] and section 5.3 of API 17J [2] (or whatever design criteria agreed by purchaser), considering the most adverse combinations of temperature, material degradation, creep and other factors present in actual stiffening system.
- (b) under accidental or extreme load conditions, the bend stiffener design shall not be responsible to create bending moments that exceed the strength of the interfacing equipment (bellmouth or whatever).

Note: if applicable, the strength of the interfacing equipment shall be informed in the I-RM, purchasing specification or other technical specification.

- (c) under accidental or extreme load conditions, the bend stiffener shall limit the curvature and the bending moment to values compatible with its own structural strength, considering also foregoing conditions, such as material degradation arising from internal and external environments.
- (d) the bend stiffener shall be effective in reducing the contribution from curvatures on the cumulative fatigue damage in the flexible pipe or umbilical, complying with the regulations in section 5.3 of API 17J[2].
- (e) the visual inspection of the external surface of the polymer body in bend stiffener tip and close to the transition region (near the fastening fit of polymer body in the metallic cap) shall not be obstructed.
- (f) the bend stiffener's metallic parts shall not touch the flexible pipe's (or umbilical's) external sheath during installation, operation, inspection and retrieval.
- (g) bolts, nuts and other fasteners shall be suitably locked after installation, so that they do not get loose by effects of vibrations or corrosion. If belonging to replaceable parts, they shall maintain operational and manipulable (removable by divers, if underwater) over service life.
- (h) the storage or abandonment of pipe or umbilical length and bend stiffeners on seabed – according to purchaser's practices – shall not initiate failure mechanisms.
- (i) in order to comply with section 5.2.9 of API 17L1[7], the number of fasteners to fix the internal steelwork to the bend stiffener flange is expected to be in excess of 1/3 over the minimum required number, to allow for losses (corrosion, loss of nuts, etc).

Note: in case the increased number of fasteners cannot be obtained without enlargement of bend stiffener cap, its compatibility with the bellmouth and i-tube dimensions shall be addressed. If this compatibility cannot be assured, the number of fasteners in excess can be reduced in order to avoid the increase of the bend stiffener cap diameter.

- (j) for sliding and DCDE bend stiffeners, the manufacturer shall supply a stopper to impede the bend stiffener to slide down through the flexible pipe or umbilical if its interface connection fails.

Note: stoppers shall be designed to avoid damage to the surrounding risers in case of collision/interference.

**6.1 FUNCTIONAL REQUIREMENTS FOR SLIDING BEND STIFFENERS.**

Sliding bend stiffeners shall additionally comply with the following requirements:

- (k) the bend stiffener cap's dimensions shall be compatible with the system comprising bellmouth and i-tube as per specific technical specification (in general in format I-ET-3010.xx-1300-279-PPC-0yy [4]).
- (l) the bend stiffener top structure' shape and the gap between the bend stiffener cap and the bellmouth, considering all manufacturing tolerances, shall allow for misalignments and dynamic response during typical pull-in operations. Section 5.2.7 of API 17L2[8] is applicable.

**GENERAL BEND STIFFENER REQUIREMENTS**

- (m) the hole edges across which the pull-in breaking wires pass shall be ground in order to obtain a smooth curvature which avoids premature rupture of those cables. After they are broken, loose pull-in breaking wires shall not damage other components of the system.
- (n) structural ribs shall be tapered to facilitate the top structure alignment in bellmouth entrance during pull-in operation. Their thickness shall be compatible with the contact loads that may exist during that operation.
- (o) misalignment and vibration shall be mitigated by proper adjustment of gap between the bend stiffener cap and the bellmouth or i-tube. Other solutions can also be considered.

Note 1: The assumed manufacturing tolerance of the external diameter of the riser or umbilical should not be less than  $\pm 2.5\%$ .

- (p) the bend stiffener top structure and cap shall withstand extreme contact loads (associated to extreme loads), fatigue and wear over the service life. Other failure mechanisms identified by the manufacturer shall be properly mitigated.
- (q) a protective flared liner shall cover internal metallic surfaces if an integral polymeric body (e.g.: in DCDE bend stiffener) cannot have the role described in item (e). The flared liner should be replaceable as per API Spec 17L1[7] and it shall not have sharp edges which may harm the external sheath when relative motion between them may exist, even if misassembled.

Note 1: The thickness loss (combined effects of material degradation and wear) on the liner should not exceed 50% by the end of product's operational life – if the manufacturer cannot guarantee this, the flared liner shall be replaceable.

Note 2: The water absorption and material ageing shall not render problems for its operation and its replacement by the divers.

**6.2 FUNCTIONAL REQUIREMENTS FOR DCDE BEND STIFFENERS**

DCDE bend stiffeners shall additionally comply with the following requirements:

(j-p) as per section 6.1, with suitable adaptation of nomenclature.

- (r) the polymeric body encapsulated by external steelwork shall not get loose; neither shall it be exposed to excessive pressure, so that the bore radius diminishes substantially (i.e.: more than manufacturing tolerances).

**6.3 FUNCTIONAL REQUIREMENTS FOR FBS BEND STIFFENERS**

FBS bend stiffeners shall additionally comply with the following requirements:

(j-o) as per section 6.1, with suitable adaptation of nomenclature.

- (s) a non-adherent layer made of HDPE shall cover the flexible pipe or umbilical's outer sheath over the length from the FBS to the hang-off in order to avoid surface damage during pull-in.
- (t) the centralizer shall have an appropriate seat for the attachment of a removable overboarding collar, useful for pull-in operations. Whenever possible, this seat shall be located at the top of the centralizer.
- (u) the centralizer shall be as long as possible, considering both the geometry of the particular bellmouth and the minimum distance of  $200 \pm 50$  mm for hang-off installation on the platform deck.
- (v) the supplier shall propose a surface coating protection for the centralizer in order to mitigate wear and corrosion over service life.
- (w) the gap between the centralizer and the bellmouth shall be equal to 3 mm, considering applicable manufacturing practices and parameters.
- (x) corners in centralizer edges shall be filleted. Supplier shall consider two fillet radius in order to mitigate indentation problems.



**GENERAL BEND STIFFENER REQUIREMENTS**

- (y) the distance from end fitting or top armour pot to the FBS bend stiffener shall be properly calculated considering the i-tube design, its fabrication tolerances and the axial stiffness of the pipe or umbilical.
- (z) the top structure of the FBS bend stiffeners shall have a polymeric conical surface in order to ease the entrance of centralizer into bellmouth, mitigating pull-in problems.

**7 GENERAL DESIGN**

The bend stiffener design shall consist of the following engineering tasks, as a minimum:

- (a) material selection.
- (b) interface design.
- (c) thermal analysis, as applicable.
- (d) corrosion analysis and design of protective systems, as applicable.
- (e) complete structural analyses using finite element methods.
- (f) pull-in feasibility study.

Additionally, the following requirements shall be considered, whose fulfilment shall be made available to the purchase on request:

- (g) the theoretical background for engineering design, design premises, calculation procedures, acceptance criteria, engineering tools, software, source and correctness of data shall be verified and certified by an accredited IVA. Sections 4.6.3 and 5.3.2 of API Spec 17L1[7] and 5.2 of API 17J[2] apply.
- (h) possible failure drivers, mechanisms and modes shall be listed in FMEA (or equivalent) submitted to IVA when the design methodology is under evaluation, together with the description of the effectiveness of the design solutions to mitigate them.
- (i) the manufacturer shall keep a track record of its products. When agreed by both purchaser and IVA, a successful track record extending long enough may be accepted as evidence that some failure mechanism is not likely to occur for similar structure under conditions milder than – or similar to - those included in the records.

Note 1: Evidences from successful track records shall be understood as an argument to disregard a specific concern, not a general engineering tool in replacement to analysis, calculation and testing.

Note 2: Track records shall not be accepted if there is no assurance that the manufacturer and IVA are warned on the failure of products included in records.

- (j) the manufacturer shall demonstrate that its design methodology guarantees good adherence between the results from the engineering calculation methods and the experimental results. Furthermore, the concerns on the effects from fabrication defects given in section 5.3.5 of API 17L1[7] apply.
- (k) the bend stiffener shall be compatible with an installation misalignment tolerance (measured from bellmouth's revolution axis) up to 2 degrees in any direction. This tolerance shall be considered in the pull-in feasibility study, as applicable.
- (l) special care shall be taken in the metallic parts in which no inspection is feasible over service life and corrosion is a possible failure driver. The concerns on the effects from fabrication defects given in section 5.3.5 of API 17L1[7] apply.
- (m) cathodic protection or special coatings shall be assured in all metallic materials which are not corrosion resistance alloys (CRA).
- (n) Note 1: the requirements in sections 8.2 and 8.3 shall be met with necessary strictness.
- (o) Note 2: cathodic protection shall meet requirements given in ET 3500.00-1516-940-PDS-011[9] or more severe.
- (p) Note 3: metallic parts on which the cathodic protection may be inefficient or inaccessible (e.g.: occluded parts, etc) shall be protected by selection of corrosion resistant materials.
- (q) if the product integrity and functionality depend on firm adhesion between polymer body and steelwork, the manufacturer shall prove that the adhesion can be kept over the product life. As an alternative, man-



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manufacturer may consider more conservative design premise such as partial debonding. Concerns given in section 5.3.7 of API 17L1[7] apply.

- (r) the ingress of seawater into areas in which bonding shall be kept or into areas in which there is transition of bonded and unbonded surfaces should be avoided.

Note: in the study of possible leak paths, the manufacturer shall account for the water depth at which the flexible pipe and the bend stiffener may be temporarily stored (wet storage), along with the instantaneous curvatures which the bend stiffeners can undergo during pipelay operation for wet storage. Special care shall be taken with leak paths along the threads of nuts and fasteners.

- (s) welds designed by manufacturer, as applicable, shall be in accordance with requirements of section 2 of AWS D.1.1 [15], unless specified otherwise.

- (t) design methodology shall consider conservative assumptions to deal with the effects from degradation agents such as ageing, temperature, UV radiation, water absorption or chemical attack over the material properties, as well as the effects from previous loading (Mullins effect), as applicable.

Note 1: The degree of conservatism in each assumption related to the aforementioned properties can be adjusted to avoid conditions in which no feasible solution exists, provided that the manufacturer can predict the frequency of exposure to the agent, the evolution of the failure mechanism and its criticality.

Note 2: The design shall account for the Mullins effects, acknowledged that the mechanical properties can be significantly different after a number of cycles. If not detailed in the design methodology, the properties shall be acquired from the 20<sup>th</sup> cycle. A cyclic strain of 10% is suggested.

- (u) failure mechanisms which are specific to a certain material shall be studied by manufacturer or raw material supplier in order to include mitigation means in the product design.
- (v) new materials not supported by long enough offshore service may be adopted under purchaser's approval and considering statements in note (4) of item 5.2 of [2].
- (w) changes in flared liner's dimensions and mechanical properties due to water absorption and ageing shall be considered in its design in order to meet applicable functional requirements.
- (x) sharp corners and rapid stiffness transitions in the polymeric body shall be avoided. When rapid stiffness transitions are thoroughly necessary the design shall minimize the maximum strains and the strain variations in the vicinity of these regions.
- (y) when queried by purchaser, the supplier shall prove that minimum bend stiffener cannot be replaced by other equipment with lower cost and similar reliability, such as bend restrictors.
- (z) if the pipe may experience deflections just above the bend stiffener (e.g.: segmented i-tube), the contact forces between it and the flared liner shall be properly distributed to mitigate excessive wear. In addition, the forces transmitted to the flared liner shall be properly withstood by it and its fasteners.
- (aa) bolting should be designed as per section 7.5 of API RP 2D:1998 [16], considering especial requirements for materials given in section 8.

**7.1 DATA TO BE SUPPLIED BY PURCHASER AND/OR PIPE MANUFACTURER**

- (a) service type (e.g.: static or dynamic, temporary or permanent, exposed to sunlight, etc) and other functional requirements in addition to mentioned herein.
- (b) required service life.
- (c) internal diameter and its tolerances.
- (d) maximum external diameter, maximum length and any other constraints related to physical dimensions.
- (e) dynamic and storage minimum bend radius (for umbilicals, the relationship between MBR and effective tension shall be given).
- (f) bending stiffness as function of tension, curvature and internal pressure, as applicable.
- (g) axial stiffness.

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- (h) azimuth and static angle, including allowances for misaligned installation.
- (i) pairs consisting of tension and top angle for every load condition mentioned in functional requirements (section 6, items (a) and (c)).
- (j) temperatures to which the internal bore can be exposed, thermal exchange coefficient, minimum and maximum seawater temperature, minimum and maximum air temperature associated to conditions of storage, transport, installation and service.
- (k) interface requirements specification and pull-in procedures, as applicable.
- (l) allowable bending moment and shear force transmitted to bend stiffener support structure.
- (m) characteristics of the corrosion protection system (e.g.: potential, coverage, printed current, etc).
- (n) description of seabed abandonment and storage practices, as applicable.
- (o) response of pipe stresses as function of tension, curvature and internal pressure, if the manufacturer is in charge of performing fatigue calculation.

**7.2 DESIGN CRITERIA**

In absence of clear acceptance criteria, suitable values can be defined by manufacturer – as part of its design methodology – in agreement with the equipment integrity needs, with the aforementioned functional requirements and other applicable restraints for following design parameters:

- (a) stress components.
- (b) strain components.
- (c) curvature or deflection.
- (d) contact pressure or debonding pressure.
- (e) dimensional interference.
- (f) cumulative fatigue damage.
- (g) temperature.
- (h) abrasion or wear.
- (i) creep.
- (j) material loss or other parameter measuring to corrosion or other degradation mechanisms.
- (k) test of adhesive.

Bend stiffener steelwork and other metallic parts shall be designed to meet permissible utilization factor as per table 7.2.1 or more conservative. For these components, utilization factor is defined by ratio between von-Mises stress and material's yield strength.

The utilization factors given in table 7.2.1 may be locally exceeded at hot spots if both conditions below are met:

- (a) the maximum strain  $\epsilon_{max}$  at the hot spot shall not provide a strain energy that exceeds 1% of the ultimate strain energy:

$$\int_0^{\epsilon_{max}} \sigma d\epsilon \leq 0.01 \int_0^{\epsilon_u} \sigma d\epsilon$$

- (b) the extension of non-compliance with the utilization factor (extension of hot spot) should not exceed 1/4 of the thickness of structural element.

Bend stiffener polymeric body shall be designed to meet the maximum strain criteria given by the product:

$$\epsilon_{max} < \gamma_r \epsilon_{adm}$$



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where:  $\epsilon_{max}$  = characteristic strain;  $\gamma_r$  = correction factor to account for external surface or interface roughness;  $\epsilon_{adm}$  = uncorrected maximum strain criteria. The correction factor  $\gamma_r$  may be taken as 1 if the fatigue data is acquired from samples with the maximum roughness acceptable by the manufacturing quality plan. Elsewhere, the correction factor may be given by:

$$\gamma_r = \sqrt{\frac{1 + 4 Rg_{ref}}{1 + 4 Rg_{qual}}}$$

... where:  $Rg_{ref}$  = average roughness of the samples used to build the  $\epsilon N$  curves in  $\mu m$ ;  $Rg_{qual}$  = roughness on the external surface acceptable by the manufacturing quality plan.

The value of maximum strain criteria shall be set according to the load case and should be based on existing fatigue test data as given in table 7.2.2 (main criteria row).

Note 1: In case the fatigue test data are not available by the design time, the alternative strain criterion stated in table 7.2.2 (alternative criterion) shall be employed. The adoption of this alternative criterion shall not be a reason for any disclaim of the manufacturer's responsibility for the proper design and integrity assurance of its products, thus it shall be employed at the manufacturer's own risk.

Note 2: As for calculation of the correction factor  $\gamma_r$ , if alternative criterion is used,  $Rg_{ref}$  shall be taken as 1.6  $\mu m$ .

The cumulative fatigue damage shall not exceed criteria given in table 7.2.3 or more conservative.

**Table 7.2.1.** Admissible utilization factors for metallic material in bend stiffeners.

Service Conditions			Installation		FAT
Normal operation		Abnormal operation			
Annual, fatigue	Extreme				
Functional and environmental	Functional, environmental and accidental	Functional, environmental and accidental	Functional and environmental	Functional, environmental and accidental	0.91
0.67	0.85	0.85	0.67	0.85	

**Table 7.2.2.** Maximum strain criteria for polymers in bend stiffeners before any correction factor.

	Part	Service conditions			Installation / abandonment on the seabed		FAT
		Normal operation		Abnormal operation			
		Annual, fatigue	Extreme				
Main criterion	general	$\epsilon$ for $N=6 \times 10^5$	$\epsilon$ for $N=1.5 \times 10^5$	$\epsilon$ for $N=5 \times 10^4$	$\epsilon$ for $N=6 \times 10^4$	$\epsilon$ for $N=5 \times 10^4$ cycles	$\epsilon$ for $N=1.5 \times 10^5$
	contact & bonded areas	$\epsilon$ for $N=1.5 \times 10^5$	$\epsilon$ for $N=2.5 \times 10^4$	$\epsilon$ for $N=5 \times 10^3$ cycles	$\epsilon$ for $N=10^4$	$\epsilon$ for $N=5 \times 10^3$ cycles	$\epsilon$ for $N=2.5 \times 10^4$
Alternative criterion	general	0.10 $\epsilon_u$ or 10%, whichever is less	0.15 $\epsilon_u$ or 15%, whichever is less	0.17 $\epsilon_u$ or 17%, whichever is less	0.15 $\epsilon_u$ or 15%, whichever is less	0.20 $\epsilon_u$ or 20%, whichever is less	0.10 $\epsilon_u$ or 10%, whichever is less
	contact & bonded areas	0.15 $\epsilon_u$ or 15%, whichever is less	0.22 $\epsilon_u$ or 22%, whichever is less	0.30 $\epsilon_u$ or 30%, whichever is less	0.22 $\epsilon_u$ or 22%, whichever is less	0.30 $\epsilon_u$ or 30%, whichever is less	0.20 $\epsilon_u$ or 20%, whichever is less

 Note 1:  $\epsilon_u$  = elongation at break at 20-25°C.

Note 2: extraordinary care shall be considered in FAT design in order to avoid damage to the polyurethane. Post-test examination shall be carried out in order to avoid the introduction of damage during the FAT.

**Table 7.2.3.** Admissible cumulative fatigue damage criteria.

application	water injection lines supporting one single well	water injection lines to two or more wells	production/export risers, well production umbilicals
service class as per table 6B of [1]	low	normal	high
parts accessible to visual inspection	1/3	1/6	1/10
parts inaccessible to visual inspection	1/6	1/10	1/10

Note 1: Some third parties in charge of independent review of calculation or design methodology approval do not accept admissible cumulative fatigue damage less than 1/10 for any situation.

**7.3 RISER ANALYSIS USING MODELS FOR BEAMS WITH VARIABLE CROSS-SECTION**

The riser analysis may use simplified models consisting of two-dimensional beams with variable cross-section under tension and shear force. They shall comply with the following requirements:

- (a) methods and tools shall be validated as per requirements in section 6.2 of [1] or section 5.2 of [2].
- (b) the bending stiffness of the equivalent beam shall be iteratively updated over the analysis to take into account the effects from material non-linearity, including the differences in behaviour as the material is under tension or compression.
- (c) if the bend stiffener's neutral position is offset, effects from initial curvature shall be included in the model. If possible, effects from creep should be included too.

Note 1: the design requirement (e) in section 7 shall be considered.

- (d) if the bending stiffness of the straight pipe is of same order of magnitude of the bend stiffener's, the model shall also consider its variation as function of curvature and tension (and internal pressure, as applicable). Such variation may be neglected if the bending stiffness of the flexible pipe is not significant as compared to bend stiffener's or if the variation of such stiffness is small.

Note 1: suitable analytical regressions can be used to represent the bending stiffness of the flexible pipe, provided that they are properly calibrated by experiments or accredited methods of local analysis.

- (e) the methodology shall also verify the fulfilment of requirements on stress components and fatigue given in section 6 of [1].

Note 1: suitable utilization factors as per table 6 in [1].

Note 2: analytical regressions for determining stress components at each layer can be included in the methodology to prevent the need of costly detailed local analysis in this phase, provided that they are properly calibrated by experiments or accredited methods of local analysis.

- (f) whenever analyses concerning the integrity of pipe or umbilical are done by bend stiffener's manufacturer, they shall be checked and, if necessary, redone by the pipe or umbilical supplier, considering its access to more detailed information thereof.

In order to check preliminary design feasibility and to support the bellmouth design, the following data shall be calculated:

- (a) maximum pipe curvature.
- (b) maximum stress components at pipe or umbilical.
- (c) maximum strain at bend stiffener conical body.
- (d) maximum loads (shear force and bending moment) at conical body's root, as well as the distance to be considered in estimation of loads transferred to bellmouth or end-fitting, as applicable.

**7.4 INTERFACE DESIGN**

The interface to production vessel or platform shall be design as per purchaser specification. Bolted connections shall be designed for diver-assisted make-up or for diverless operation using either mechanical or hydraulic tools. Diver-assisted make-up shall be carefully studied in terms of ergonomics, because misdone assembly is a common failure driver for this equipment. Visual inspection should be feasible as possible.

The guidelines for sliding bend stiffener cap's dimensions are given in specific ET such as I-ET-3010.xx-1300-279-PPC-yyy [4]. Whenever applicable, the structural ribs of the ending sleeve shall be aligned to the cap cylindrical surface or a smooth transition shall be made to avoid teeth which may hinder the pull-in operation. The gap between bend stiffener cap and the bellmouth shall be optimized in view of:



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- (a) manufacturing tolerances.
- (b) efficient force transmission.
- (c) mitigation of vibration and misalignment problems.
- (d) pull-in feasibility as per conclusions of analysis described in section 7.7.
- (e) interface design shall consider, as well, drawings supplied in the related I-RM.
- (f) concerns given in sections 5.2.6 and 5.2.7 of API 17L2[8].

The cap shell thickness shall be designed to withstand the forces and the moments during pull-in (maximum efforts can be in the beginning of the pull-in operation, refer to item (p) of section 6.1) and, as applicable, to avoid its collapse in the abandonment condition.

### 7.5 THERMAL ANALYSIS

When required, the manufacturer shall perform thermal analysis as per section 5.4.2 of API 17L2[8]. This analysis should be performed using FEM, taking into account most important parameters such as air and seawater temperature and their convective actions, insulating effects, air and water-filled gaps, sunlight and heat generated from internal flow temperature, etc. Allowable temperature criteria for constitutive materials and adhesives (as applicable) shall be defined as design premises.

### 7.6 STRUCTURAL ANALYSIS

The manufacturer shall verify the compliance of applicable functional and design criteria using accredited methods, in agreement with general requirements of section 5.3 of API 17L1[7] and other requirements stated herein. Preferential method of structural analysis is FEM. In general, the structural analyses performed in this phase generally profit from results obtained in preceding analyses and simplifications are acceptable, provided that all applicable criteria are checked and data for additional analysis are suitably produced.

Under the scope of validation of design methodologies, the following rules apply on the structural analysis of components:

- (a)-(c) as per requirements of section 7.3 of this ET.
- (g) FE software, if used, shall be validated using widely accepted benchmark tests such as NAFEMS [17].
- (h) the analyst shall be warned that FE method is not good at calculation of peak stresses at holes, fillets and other stress raisers (see COOK [18]), thus the straightforward use of extreme FE-predicted stresses as hot spot stresses is discouraged, alternative stress extrapolation methods – e.g.: method described in DNV RP C203 [19] – shall be made available.
- (i) in addition to the foregoing warning, the concept of stress concentration factor (SCF) shall also be used with care, since its definition is often ambiguous and non-adherent to experimental evidences, especially in the fatigue performance assessment (see ROUSSIE [20]).

In general, structural analysis treated herein comprises the following verifications:

- (a) bend stiffener body design (see section 5.3.5 of API 17L1[7]), including determination of maximum stress and strain criteria in welds, steelwork and polymeric body.

Note 1: the verification of static strength and fatigue of fasteners can be performed using accredited analytical methods instead of FEA.

Note 2: if the local effects from contact between flexible pipe and bend stiffener are negligible, instead of incorporating the pipe into the model and enforcing that contact pair, the analyst may replace it by pressure fields on the internal bore, standing for contact forces between pipe and bend stiffener. The pressure fields may be found from distributed forces calculated as per section 7.3. The method for extrapolation of pressure fields from distributed forces shall be validated by IVA.



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Note 3: if the aforementioned distributed loads are not used in replacement for pipe, special care shall be taken to embody the conflicting stiffness properties in the model of flexible pipe: very high radial stiffness, high axial stiffness and low bend stiffness. The analyst shall verify if resulting bend stiffness is not erroneously high due to improper modelling effects (e.g.: pipe as stiff fibre displaced from neutral axis).

- (b) interface structural design (see section 5.3.5 of API 17L1[7]), including determination of shear loads, bending moments, loads transferred to dogs, etc.
- (c) cumulative fatigue design in all parts made of polymer and steel.

- (d) bond design, as per section 5.3.7 of API 17L1[7].

- (e) creep associated to steady curvature, including the concerns given in 5.3.10 of API 17L1[7] for static bend stiffeners.

Note 1: analysis shall consider items (e) of section 7, (h) of section 7.1 and (c) of section 7.3.

- (f) adhesion assurance in bonded interfaces, where applicable.

Note 1: whenever possible, the manufacturer shall assess the effects from partial debonding.

Note 2: the manufacturer shall propose a model for evaluating the debonding mechanism in terms of extreme loads and cumulative effects.

- (g) waterproofing (sealability) in areas not deemed to be able to undergo wet conditions (in accordance to design premises).

Note 1: in general, most critical case is the seabed storage: high external pressure combined to pure bending. If the manufacturer cannot assess the storage curvature, MBR shall be taken.

- (h) performance sensitivity studies, in view of variations of manufacturing tolerances and material properties within allowable limits, along with subsidiary information for engineering criticality analyses.

Note 1: this study obtains information necessary to compose the manufacturing quality report.

- (i) corrosion protection.

## 7.7 PULL-IN FEASIBILITY STUDY

When required by the purchaser in the due I-RM, the pipe or umbilical supplier shall carry out computational simulations of the pull-in operation using virtual prototypes. Pull forces, self-weight, tensions in pull-in break wires (and their actual application points), bend stiffener, pulling head, bellmouth and i-tube's geometry - including adverse combinations of tolerances - and misalignments shall be included into the simulation.

## 8 MATERIALS

The constitutive materials shall be compatible with bend stiffener's functional and design requirements. Material qualification for service shall be done using applicable requirements of section 7.2 of [1] and section 6 and 7 of ISO 13628-2 [21]. The manufacturer is responsible for material selection, hence the identification of particular failure mechanisms from which each material can suffer and their mitigation are under its scope of work.

Material properties shall be obtained by trials whenever possible. Exceptionally, if conditions like those cited in section 5.1 are met, other sources of information can be used, provided that they are accredited and certified by IVA. Test shall be performed in accordance with documented practices and, as applicable, within standard test procedures. If test methods are not specified by purchaser and/or no international standard test procedure is available, the manufacturer may use its own methods and criteria or other developed by the raw material supplier. Material tests should be redone when:

- (a) new prototype is obtained by change of materials.



- (b) the raw material supplier is changed.
- (c) any doubt arises on the quality of a representative lot of material.

Material tests shall be certified by an IVA; the test records and certificates shall be kept on file for the predicted product's service time.

Test samples shall be extracted from processed material, instead of raw material. In absence of statistically representative number of tests, the most unfavourable test results shall be considered. Formal acceptance and rejection criteria shall be proposed by manufacturer and approved by an Independent Verification Agent (IVA), provided its correlation to the design requirements.

**8.1 REQUIREMENTS FOR POLYMERS**

The information on physical, chemical and mechanical properties of polymers shall be collected at the operational temperature range. The following properties shall be acquired and documented:

- (a) stress-strain curves gauged at 200%-strain per minute rate and ranging from -20- to 20%-strain.  
Note 1: curves gauged at 100%-strain per minute rate can be accepted under PETROBRAS agreement.
- (b) ultimate strength and elongation at break.
- (c) Young's modulus at 5- or 6%-strain.
- (d) admissible range of temperature.
- (e) creep parameters.
- (f) fatigue data or criteria.
- (g) density.
- (h) abrasion against the material of the flexible pipe or umbilical's external sheath.

- (i) list of chemical products, which may be found during handling or operation, which are harmful.

Besides those, the following information on materials shall be acquired and considered in design:

- (j) variation of mechanical properties due to temperature and Mullins' effect.
- (k) manufacturing limitations and requirements.
- (l) resistance to exposition to hydraulic oil, diesel oil, grease, solvents, lubricant and petroleum, as applicable.

This information shall be submitted to IVA and kept accessible to purchaser's personnel.

When not subject of special agreement between purchaser, IVA and manufacturer, test procedures for polymers shall follow procedures referred in table 8.1.1.

**Table 8.1.1.** Test procedures for polymeric materials

Tests	ASTM	DIN	ISO
Density	D-792[22]		1183[23]
Hardness	D-2583[24] or D-2240		868[26]
Tear strength	D-624[27]		34-1[28]
Tensile properties	D-638[29]	53504[30]	527-1 or 527-2[31] or 37[32]
Compression set	D-695[33]		815[34]



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Tests	ASTM	DIN	ISO
Rotating drum abrader	D-5932[36]		
Rubber reel test	G-65[38]		
Oil and solvent resistance	D-471[39]	53428[40]	
Hydrolytic stability	D-3137[41]		2440[42]
Water absorption	D-570[43]		62
Heat ageing	D-573[45]	53508[46]	188[47]

**8.2 REQUIREMENTS FOR METALLIC MATERIALS**

The bend stiffener manufacturer shall acquire and record the following mechanical properties:

- (a) yield and ultimate strength.
- (b) elongation at break.
- (c) Young's modulus.
- (d) stress-strain curves.
- (e) hardness and impact strength.
- (f) fatigue data, preferentially SN curves for representative values of mean stress.
- (g) manufacturing limitations.

**8.3 CORROSION RESISTANT ALLOYS**

Under the scope of this ET, the metallic materials considered as CRA are:

- (a) Alloy 625 (UNS N06625, as per ASTM B443, B444 or B446, whichever is applicable)

Exceptionally, the following alloys can be accepted for bend stiffeners used in umbilical and water injection lines supporting one single well:

- (a) Alloy C-276 (UNS N10276, as per ASTM B564, B574, F468 and F467, whichever is applicable)
- (b) Alloy 718 (UNS N07718), only if the requirements of API 6A/ISO 10423[48] are met.

Provisions in DNV RP B-401 [49] shall be fulfilled for abovementioned materials.

CRA materials shall be used in the cases foreseen in section 5.2.8 of API 17L2[8], which includes:

- (a) components with complex or occluded geometry, including the reinforcement structures (torus), their respective stud bolts and fasteners.
- (b) regions where cathodic protection may not work properly or is not available (such as internal areas of components, etc.).

The hardness of CRA materials shall be limited to 32 HRC or equivalent. The microstructure of CRA materials for stud bolts, screws, nuts and related items shall be controlled in order to assure that their mechanical strength is similar to conventional materials, as given by ASTM A193 [50] for bolts and ASTM A194 [51] for nuts.

The electrochemical compatibility between CRA material and other metals shall be verified by the manufacturer and confirmed by the IVA; design solutions shall be afforded to avoid galvanic corrosion.



Instead of CRAs, coatings such as interdiffused electroless nickel (9-13% phosphorous) and epoxy coating on surface of carbon or low alloy steels may be applied, under purchaser and IVA approval:

- (a) in parts where cathodic protection alone might be less effective, with the additional restriction that the anodes shall be specified to give full corrosion protection for the entire component's life, considering predicted coating breakdown factor over coating life.

The efficiency of aforementioned coatings shall be established by accelerated corrosion trials (bench tests) in addition to successful track records (in-field tests), witnessed and certified by IVA.

#### 8.4 REQUIREMENTS FOR ADHESIVE MATERIALS

The specification of the adhesive product shall consider possible coatings on the metal surfaces (if applicable), extreme debonding forces, ageing, dynamic loads and operational and temperature. Favourable bonding interface condition shall be guaranteed by manufacturing process and quality control to avoid rust and unsuitable surface conditions.

In agreement with the design premises, if the adhesion is assumed to be critical for the good operation and integrity of the bend stiffener, then the manufacturer shall offer evidences that it will keep effective all the design life long. Test procedures should be run as per ISO 4624 [52], ASTM D4521[53], ASTM D3528 or any other reasonable methods agreed by manufacturer and IVA.

#### 9 GENERAL PROTOTYPE TESTING

The prototype qualification programme shall be established by the pipe or umbilical supplier and submitted to purchaser. This programme shall encompass all relevant characteristics of design and manufacture such as, but not limited to, design loads, temperature and materials. General guidelines given in section 5.5 of API 17L2[8] apply.

The prototype qualification shall consist, at least, of an alternate (dynamic) bending test in real scale. Static bending tests may also be specified in I-RM or technical specification of product development.

Typically, the functional limits of flexible pipe or umbilical define the design envelope, therefore the bend stiffener prototype tests are usually performed in conjunction with the prototype tests of pipe or umbilical.

#### 9.1 STATIC BENDING TEST

The purposes of the static bending test are to check:

- (a) if the bend stiffener's deflections have good correlation with those predicted at design stage;
- (b) if the bend stiffener meets certain functional requirements herein mentioned, especially those related to the flexible pipe's integrity.

The bending test is not a bending-on-sheave test; the test configuration is similar to dynamic fatigue test. Instead of dynamic fatigue, however, combinations of tension and bending moment are applied in order to track conditions in which the pipe achieves the dynamic MBR, provided that other design bounds are not exceeded.

The test rig should preferentially be able to simulate the effects misalignment and dimensional tolerances given in the design premises report.

Photographs of the deformed structure against a referential frame or ruler shall be taken whenever possible. The data acquisition system shall continuously log and store the following gauges:

- (a) deflection at a minimum of 3 points.
- (b) pulling load at pipe edge.
- (c) rotary table rotation, if the test rig can allow for the angle tolerance as stated in the section 7, item (f).



- (d) temperature.
- (e) pipe or umbilical's free curvature.

The acceptance criteria for the static bending test shall be proposed by the manufacturer, based on the compliance of aforementioned functional and design requirements.

## 9.2 DYNAMIC FATIGUE TEST AND DISSECTION AFTER TESTING

The manufacturer shall execute these trials as per the specific I-RM or, in lack of specific reference, as per non-standardized test specification I-ET-3500.00-6500-291-PAZ-001 [3] for risers and I-ET-3000.00-1500-29B-PAZ-006 [54] for umbilical cables. Whenever the dynamic fatigue test also aims at qualifying some flexible pipe prototype, the adherence to [3] or [54] shall be duly assured. If it aims at qualifying the bend stiffener prototype only, the following modifications may be agreed between PETROBRAS, the manufacturer and the IVA, as applicable:

- (a) review of any manufacturing reports of the bend stiffener and flexible pipe samples in order to know about extreme deviations and non-conformity treatments that might influence the test results or that might be matter of future justification of insufficient performance.
- (b) fine-tuning of polyurethane superficial roughness at critical bend stiffener section to the extreme of the acceptance criteria as per manufacturer's quality management system.
- (c) reduction of the number of cycles to 1,000,000 cycles or less, if the condition (d) below is met.

**Note 1:** the engineer in charge of test planning should assess pipe fatigue life in order to mitigate the risk of a pipe failure during the test execution. Although the pipe failure may be acceptable when the dynamic fatigue test focuses on the bend stiffener prototype, it usually hinders the test execution and arises doubts about the effectiveness of the bend stiffener.

- (d) inclusion of extreme angles and forces (usually related to extreme and accidental load conditions), taking number of cycles exceeding 10.

**Note 1:** if the assessment of extreme and accidental loads for actual application is not made available by the time of test execution, tests should be planned considering the extreme values of pipe curvature and polymer strain as per design methodology.

**Note 2:** the extreme loads should preferentially be applied before the fatigue blocks.

**Note 3:** the availability of test rigs shall be verified beforehand, in order to avoid excessive limitation of options.

- (e) inclusion of pipe centreline transverse displacement (at 4 points) and transverse bending load (force at hydraulic actuator) into the list of data to be monitored.

**Note:** the transverse displacements shall be predicted in the phase of test planning and shall be informed to the technicians in charge of test rig control and test witnessing. If the measured displacements deviate from the predicted displacements very much, the involved parts shall decide if the fatigue load parcels have to be reassessed before going further testing, acknowledged that the actual curvatures and damage contributions from each parcel wouldn't be within the planned values.

- (f) visual inspection at end of every fatigue parcel and at every 20,000 cycles during test.

**Note:** the photography of surface of the most critical polyurethane sections and of visible metallic parts susceptible to crack propagation is recommended.

Formal acceptance and rejection criteria for the dynamic test and the dissection shall be proposed by the manufacturer or supplier and shall be approved by the IVA and purchaser.

The presence of internal voids or inclusions in the polymeric body, cracks in the steelwork, unbonded areas which should be bonded (according to design premises) and other non-conformities which could not be found by other non-destructive methods shall be carefully investigated during dissection. The dissection plan shall contemplate the areas where these defects are most probable to occur and where their existence is more hazardous.



**9.3 PULL-IN TEST**

The pulling test shall be performed if required within the scope of I-RM. Its main purpose is to verify the bend stiffener performance in the pull-in operation, especially in the bend stiffener cap insertion into the bellmouth, as well as its suitable locking at the position and easy removal.

**10 MANUFACTURING PROCESSES**

All processes of manufacture and related work instructions shall be documented in a manufacturing quality plan (MQP) or similar, as per ISO 9000 standards. Concerns of section 4.5.3 of API 17TL1[7] apply. Specific I-RM should establish requirements for manufacturing processes which replace those given herein. In lack of more precise specifications in proper documentation, the regulations in this section apply.

MQP shall include, at least:

- (a) requirements on raw materials, statements of applicable scope and processing limits, acceptance criteria and inspection techniques.
- (b) sequence and description of processes of manufacture.
- (c) applicable machinery adjustments.
- (d) specification and procedures for mould preparation, moisture of constituents, injection into mould, curing, mould removal and finishing of the polymeric body.
- (e) inspection techniques and acceptance criteria for dimensions, surface roughness, coating thickness, surface or internal defects and other quality assurance parameters for each part of the bend stiffener.
- (f) specification for adhesive, its preparation (including surface treatments, as applicable) and application.
- (g) welding procedure specifications (WPS), welding personnel qualification requirements, specifications of non-destructive examination (NDE) and heat treatment.
- (h) procedures for attachment of anodes for cathodic protection, as applicable.
- (i) repair procedures, as applicable.
- (j) description of factory acceptance tests and their acceptance criteria.
- (k) requirements on handling and storage.
- (l) needs for marking, documentation and traceability of raw material, specifications, records and other sources of information.
- (m) non-conformity treatment procedures.
- (n) inspection points and policy.
- (o) description of staff responsibilities.

Criteria and requirements in MQP shall be practicable and in harmony with design assumptions. Information therein included are mostly manufacturer's proprietary knowledge, but a comprehensive MQP abstract shall be available, on purchaser's request, to document:

- (a) the solidness of the manufacturing quality procedures.
- (b) manufacturing parameters to be verified by sample dissection after qualification tests.

Manufacturing allowances shall be specified on statistical foundations by the manufacturer's technical staff. Adverse combinations of parameters within allowed ranges shall not initiate failure mechanisms undetectable by factory acceptance tests (FATs). The MQP shall also consider ergonomic and geometrical constraints, especially if the adhesive between polyurethane and steelwork is applied manually or by spray.



Dimensional tolerances for all dimensions, as per item (f) of this section, shall be included in engineering drawings. These tolerances shall be verified in the design process to be acceptable, such that the functional requirements are unaffected by variations within the specified tolerances.

Main steps in the manufacturing process shall be subject to inspection. The manufacturer shall record every verified non-conformity. The manufacturing plan shall prevent long period of time between inspection and following manufacturing phases, especially if the metallic surfaces are exposed to atmospheric or pitting corrosion.

Considerations should be given to applying a suitable fixing method onto the bolt, in order to prevent from loosening due to vibrations.

The constituent raw materials for polymers shall be mixed in ratios specified in the MQP. When mixing polymeric material components, care shall be taken on the resulting temperatures from exothermic reactions. They shall not cause damaging residual stresses which may result in functional requirements not being satisfied. For each mix of polymeric material, a sample of material shall be retained and tested to check if it is consistent with the properties measured in the qualification tests. The following properties shall be tested as a minimum:

- (a) tensile strength.
- (b) hardness.
- (c) stress-strain curve for the strain range considered in the design (tension and compression).

### 10.1 INSPECTIONS AND MINIMUM REQUIREMENTS FOR SURFACE FINISHING

For the purpose of inspection, some type of classification of the importance of the local surface finishing in the global structural integrity is strongly recommended, acknowledged that flaws or increased roughness at sections undergoing excessive strains cannot be acceptable, whereas some certain amount of flaws can exist at sections undergoing low strains with no major consequence to the equipment endurance. In order to provide such classification herein, the following classes of surface finishing are given:

- M1: metallic surfaces that may get in contact with polyurethane, free of adhesives, by which load transfer is expected to occur and at which the local components of strain in the neighbouring polyurethane can exceed 3% in any fatigue condition or 10% in extreme or accidental conditions.
- M2: metallic surfaces that may get in contact with polyurethane, free of adhesives, by which load transfer is expected to occur and and at which the local components of strain in the neighbouring polyurethane are not expected to exceed 3% in any fatigue condition nor 10% in extreme or accidental conditions.
- M3: metallic surfaces in general.
- P1: polyurethane surfaces where any component of strain exceeds 3% in fatigue conditions or 10% in extreme/accidental conditions.
- P2: external polyurethane surfaces where any component of strain is not expected to exceed 1% in fatigue conditions nor 3% in extreme/accidental conditions.
- P3: general polyurethane surfaces (i.e.: bore).

**Note:** for intermediate bend stiffeners, under agreement of PETROBRAS and IVA, regions which would normally be classified as M1 and P1 can be downgraded to M2 and P2 or even M3 and P3.

The bend stiffener designer shall inform the due classification of the surfaces in the manufacturing drawings delivered to the bend stiffener manufacturer.

The surface of metallic components shall be visually examined for flaws, including dents, cracks, scratches, shavings, gouges, corrosion and discolouration. Criteria for such defects shall be stated in the MQP, based on due requirements for mitigation of failure on areas such as blurring, scorching, staining, except



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discolouration at welds. NDT of welds shall be performed in accordance with the MQP compatible with suitable international standard.

Before application of adhesive to metallic parts, the manufacturer shall ensure that surfaces are clean, with due roughness and free from dust or dirt and are prepared properly. When handling a metallic part which has been coated by adhesive, care shall be taken to avoid damaging this coating. The manufacturer shall find out the maximum time for which the metallic parts with adhesive can be stored before moulding, considering a time in which bonding efficiency is not affected substantially. The manufacture shall comply with this time limit.

The surface of polyurethane body shall also be visually examined for flaws. Requirements for inspections of surfaces within the class P1 shall be matter of tighter criteria defined in the MQP. When finishing the surface of bend stiffener body, i.e. by activities such as grinding of bubbles or taking flash off, extreme care shall be taken not to leave cuts or punctures on surfaces, which might initiate a failure in the bend stiffener body.

The surface roughness shall not exceed the following criteria:

- 4 µm for surfaces classified as M1 and P1.
- 6 µm for surfaces classified as M2 and P2.
- 15 µm for surfaces classified as M3 and P3.

The occurrence of bubbles in polyurethane is subjected to the following criteria:

- No bubble exceeding 3 mm is acceptable on surfaces classified as P1.
- No bubble exceeding 6 mm is acceptable on surfaces classified as P2.
- The equivalent bubble – evaluated from the sum of diameters of two neighbouring bubbles – shall not exceed 150% of the allowable diameter. Two bubbles are considered to be neighbours if the distance between them is less than the diameter of the largest bubble. Bubbles with diameter of less than 0,7 mm can be disregarded for application of this criterion.

## 10.2 BOLT TORQUE AND PRE-LOAD PRECISION

The manufacturer shall provide studies on the uncertainty that may exist in the bolt pre-load and torque. No concern is necessary when the bolt pre-load is given by hydraulic tensionner. When conventional torquimeter is used, the uncertainty can raise up to ±20% or more, thus the design shall account for both lack and excess in preload, by due assumptions in the structural analyses. If the analysis results point risk of premature failure, proper control means shall be proposed, such as the use of hydraulic tensionner to make the assembly at the safest level of preload. When more reliable sources are unavailable, the table below (extracted from Machinery's Handbook[55]) shall be used.

**Table 10.2.1. Accuracy of bolt preload application methods (from Machinery's Handbook [55]).**

Method	Accuracy	Method	Accuracy
By feel	±35%	Computer-controlled wrench	
Torque wrench	±25%	below yield (turn-of-nut)	±15%
Turn-of-nut	±15%	yield-point sensing	±8%
Preload indicating washer	±10%	Bolt elongation	±3–5%
Strain gages	±1%	Ultrasonic sensing	±1%



**10.3 NON-CONFORMITY REPORT (NCR) AND NON-CONFORMITY TREATMENT REPORT (NCTR)**

NCRs and NCTRs shall be prepared under conditions given in specific I-RM. In lack of proper specification, the regulations in this section apply.

Non-conformity report (NCR) shall be prepared shortly after any non-conformity is found and a non-conformity treatment report (NCTR) shall be prepared after the careful investigation of causes and effective actions to mitigate the repetition of the non-conformity are suggested. Non-conformity reports (NCRs) shall be generated when one of the following occurrences is found, at least:

- (a) a divergence between the documented procedures and the actual practices.
- (b) the break of documented allowable limits for material properties, dimensions and other fabrication and mounting parameters.
- (c) any unexpected hazard or defect, which can influence the material or bend stiffener's integrity and performance, is found during fabrication or mounting.
- (d) the product is not approved during qualification or factory acceptance tests.
- (e) the product experiences damage during transportation, installation or operation.

NCR shall include detailed information about the non-conformity, the detection method and proper subsidies for the identification of its causes and its driver mechanisms.

NCTR shall include the conclusions about the cause of non-conformity, the description of its driver mechanisms, the possible consequences, the frequency of occurrence of similar non-conformities in the manufacturer's plant, the suggested actions to mitigate future occurrences and the actions which are implemented by the date of emission of the NCTR.

The list of identified non-conformities, indexes to the NCRs and NCTRs and quality indicators shall be communicated to purchaser before the delivery of the product. Copies of the NCRs and NCTRs shall be delivered to the final client as part of the product documentation. When IVA is engaged in the prototype certification, it shall be allowed to access the NCRs and NCTRs pertaining to similar products, in order to check if the operational practices of the manufacturers are compatible with the needs.

**10.4 FAT**

Factory acceptance tests (FATs) consist, at least, of:

- (a) visual and dimensional inspection: the surface of finished polymeric parts shall be visually examined for any obvious flaws such as warping, cracks, scratches, bubbles, discoloration or indentations. Any flaws verified to exceed allowable limits stated in the manufacturer documented procedures shall be treated as per MQP. Dimensional FAT tests shall verify that the bend stiffener is in accordance with engineering drawings. Special care shall be taken with the measurement of surface roughness in critical areas, which shall never exceed the criteria given in section 10.1.
- (b) tests of polymer samples mentioned in the last paragraphs of section 10.

**10.5 REPAIRS**

Repairs will be accepted only in case a previous certified procedure, considering all concerns related to the product use, in special those regarding fatigue, and when defined limits for repairable defects, is available. Average surface roughness in repaired areas is exceptionally tolerated to exceed the aforementioned bounds, but should not exceed the value given by:



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$$Rg_{max} = \min \left[ \frac{58}{(\Delta \epsilon_{\%, \text{fatigue}})^2}, \frac{234}{(\Delta \epsilon_{\%, \text{extreme}})^2} \right] - 0.25$$

... where:  $Rg_{max}$  = maximum allowable roughness in  $\mu\text{m}$ ;  $\Delta \epsilon_{\%}$  = maximum amplitude (maximum minus minimum, considering fatigue and extreme load conditions) of strain at location, in percent strain (informed by bend stiffener designer).

Note: the surface roughness proposed above is straightforwardly related to a proposed  $\epsilon N$  curve given by  $N = 9.9 \cdot [1.649 \log(1 + 4 R_g) + 3.47 \log \epsilon]$ .

**10.6 MARKING**

The marking on bend stiffener shall include the following, as a minimum:

- (a) Manufacturer name.
- (b) Manufacturer serial number for product.
- (c) Fabrication date.
- (d) Project/application title or tracking number.

The marking shall not vanish over service life. The marking on the bend stiffener shall be enough to direct purchaser personnel to all related documentation straightforwardly.

**10.7 HANDLING, STORAGE, TRANSPORTATION AND INSTALLATION**

General concerns of section 4.7.5 and 4.8 of API 17TL2[8] apply. The manufacturer shall document the storage requirements, respecting purchaser's practices, which shall include the following items:

- (a) allowable storage temperature.
- (b) list of chemicals that may be found during storage, transportation and installation and are especially harmful if exposed to.

The procedures for the installation of the bend stiffener shall encompass, at least:

- (a) equipment required.
- (b) fastening forces for fasteners and straps.
- (c) identification of which particular fasteners are to be used for securing a particular component.
- (d) step by step installation procedures.

Bend stiffener locations where the maximum strains occur shall be specially protected during handling, storage, transportation and installation in order to avoid any contact or friction that may harm the surface or increase its roughness from the output of manufacturing plant to the final installation site.

**10.8 FINAL INSPECTION**

The inspections mentioned in item (e) of Manufacturing Quality Plan (see section 10) shall be duly carried out.

**11 INTEGRITY MANAGEMENT**

General requirements of section 4.9 of API 17TL2[8] and specific requirements of resolution ANP-41-2015[56] apply.



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**12 DOCUMENTATION**

Bend stiffener documentation shall be in accordance with the principles and regulations for documentation of flexible pipes, umbilicals and related ancillary equipment. Additional requirements for specific documents are herein mentioned. If not properly declared in the specific I-RM, the bend stiffener supplier shall submit or make available the following documents at the delivery of the product:

- (a) installation procedure report as per section 10.7.
- (b) MQP abstract, excluding proprietary information unnecessary to attest the product's quality.
- (c) raw material test records or certificates.
- (d) non-conformity treatment reports, as applicable, excluding proprietary information which shall not be disclosed.
- (e) factory acceptance test (FAT) reports.
- (f) handling and storage recommendations as per section 10.7 of this ET.

**12.1 MINIMUM DATA SHEET**

The tables below clarify the minimum information to be included in technical proposal.

<b>1 - GENERAL DATA</b>	
Bend stiffener identification	
Associated flexible pipe structure identification (ref. Section 9.1, [1])	
Reference to specification of interface to fitting devices	
Reference to project or technical proposal	
Maximum design temperature (°C)	
Total length (m)	
Material used in polymer conical body and its hardness Shore at 23° C	
Tip length (m)	
Effective length of the conical polymeric body (m)	
Internal bore diameter (mm)	
External diameter at tip section (mm)	
Effective external diameter at root section of the conical body (mm)	
Specification of metallic material used in cap	
Cap's external diameter (mm)	
Cap's length (m)	
Total weight in air (kgf)	
Total weight in sea water (kgf)	

<b>2 - TECHNICAL DATA</b>	
Minimum bending radius (or curvature) for storage (m)	
Minimum bending radius (or curvature) for laying (m)	
Design curves for extreme top angle and tension (kN and degrees)	



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**3- MODULUS OF ELASTICITY (YOUNG'S MODULUS)/TEMPERATURE CURVE**

**4- SKETCH OF BEND STIFFENER**

**12.2 DESIGN PREMISES REPORT**

The design premise shall contain the parameters as specified in table 15 of ISO 13628-2[21]. If the manufacturer has made assumptions on any of the parameters of the table, then it shall be specified in the design premise that the values are assumed. The design premise shall include all technical requirements and recommendations given in this technical specification and in [1].

Besides that, the design premises report shall contain:

- (a) conceptual description of load cases.
- (b) requirements for the project.
- (c) relevant assumptions to be employed in analysis procedures and design.
- (d) design criteria: required safety margins and structural capacities for each bend stiffener component.
- (e) environmental limitations: limits for external temperature, pipe's internal fluid temperature, sunlight exposition, water depth, etc.
- (f) possible failure modes, mechanisms and drivers: detailed description of failure modes, mechanisms and drivers to which the bend stiffener is susceptible shall be presented. The design solution to mitigate them shall be specified by the manufacturer in this section.

**12.3 DESIGN REPORT**

The design report shall contain, at least:

- (a) material properties: data mentioned in the sections 8, 8.1, 8.2, 8.3 and 8.4.
- (b) detailed description of bend stiffener: drawings; design data; structural properties and variations due to temperature, pressure and other effects; stiffness; weight (in air and in water); storage and dynamic minimum bending radius (MBR); end fitting/support structure dimensions and tolerances; interface requirements (termination devices, corrosion protection systems, static offset angles); support point maximum bending moment; and geometrical restrictions.
- (c) bending stiffener performance against loading (if the product is a prototype): details on calculation procedures which are not covered in (a) and (b); documented basis for stress concentration factors; stress/strain analysis; calculations demonstrating that design satisfies functional requirements accounting for variations within manufacturing tolerance envelopes; estimation of volumetric contraction; maximum contact pressure; identification of the weak (limiting) sections.

In order to facilitate the interpretation of the results, the report should contain a summarized table as per the example below.



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Performance parameter		Load condition x		
		Maximum	Criterion	Ratio
Stress [MPa] – tensile side	Steelwork welds			
	Plain steelwork			
	Bolts and fasteners			
	Surface debonding/shear at polymer-metal interface			
Stress [MPa] compressive side	Steelwork welds			
	Plain steelwork			
	Bolts and fasteners			
	Surface debonding/shear at polymer-metal interface			
Strain at PU – plain body	Maximum tensile			
	Maximum compressive			
Strain at PU – contact/ bonded areas	Maximum tensile			
	Maximum compressive			
Damage by the service life	Steelwork welds			
	Bolts and fasteners			
	Polyurethane			

**12.4 TECHNICAL PROPOSAL OF BEND STIFFENER**

When required, the technical proposal comprises the following information:

- (a) minimum bend stiffener data sheet as per section 12.1.
- (b) justification of product not being a prototype, as applicable.
- (c) if product is minimum bend stiffener, analysis report comparing performance of proposed product and cheaper engineering solutions as per item (p) of section 7.
- (d) tables comprising results found by riser analysis (see section 7.3) for each extreme/accidental load case, including: maximum pipe curvature and associated location, maximum strain at polymer and associated location, bending moment and shear forces at the root section of conical body.
- (e) assessment of maximum strain at polymer and cumulative damage in the bend stiffener's steelwork and flexible pipe structure, as applicable, for fatigue load cases.

**12.5 INSPECTION AND TEST REPORT**

An Inspection Plan shall be submitted to the approval of the purchaser including all relevant operations during manufacturing, its descriptions, inspections, hold points, etc. The inspection and test report shall include, as a minimum, the requirements of [1].



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