Rules for the Classification of Tension Leg Platforms (TLP)

July 2012

Rule Note
NR 578 DT R00 E

Marine Division
92571 Neuilly sur Seine Cedex – France
Tel: + 33 (0)1 55 24 70 00 – Fax: + 33 (0)1 55 24 70 25
Marine website: http://www.veristar.com
Email: veristarinfo@bureauveritas.com

MARINE DIVISION
GENERAL CONDITIONS

ARTICLE 1

1.1. - BUREAU VERITAS is a Society the purpose of whose Marine Division (the "Society") is the classification (" Classification ") of any ship or vessel or structure of any type or part of it or system therein collectively hereinafter referred to as a "Unit" whether linked to shore, river bed or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as well head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

The Society:

- prepares and publishes Rules for classification, Guidance Notes and other documents ("Rules");
- issues Certificates, Attestations and Reports following its interventions ("Certificates");
- publishes Registers.

1.2. - The Society also participates in the application of National and International Regulations or Standards, in particular by delegation from different Governments. Those activities are hereafter collectively referred to as " Certification ".

1.3. - The Society can also provide services related to Classification and Certification such as ship and company safety management certification; ship and port security certification, training activities; all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

1.4. - The interventions mentioned in 1.1., 1.2. and 1.3. are referred to as " Services ". The party and/or its representative requesting the services is hereinafter referred to as the " Client ". **The Services are prepared and carried out on the assumption that the Clients are aware of the International Maritime and/or Offshore Industry (the "Industry") practices.**

1.5. - The Society is neither and may not be considered as an Underwriter, Broker in ship's sale or chartering, Expert in Unit's valuation, Consulting Engineer, Controller, Naval Architect, Manufacturer, Shipbuilder, Repair yard, Charterer or Shipowner who are not relieved of any of their expressed or implied obligations by the interventions of the Society.

ARTICLE 2

2.1. - Classification is the appraisement given by the Society for its Client, at a certain date, following surveys by its Surveyors along the lines specified in Articles 3 and 4 hereafter on the level of compliance of a Unit to its Rules or part of them. This appraisement is represented by a class entered on the Certificates and periodically transcribed in the Society's Register.

2.2. - Certification is carried out by the Society along the same lines as set out in Articles 3 and 4 hereafter and with reference to the applicable National and International Regulations or Standards.

2.3. - **It is incumbent upon the Client to maintain the condition of the Unit after surveys, to present the Unit for surveys and to inform the Society without delay of circumstances which may affect the given appraisement or cause to modify its scope.**

2.4. - The Client is to give to the Society all access and information necessary for the safe and efficient performance of the requested Services. The Client is the sole responsible for the conditions of presentation of the Unit for tests, trials and surveys and the conditions under which tests and trials are carried out.

ARTICLE 3

3.1. - **The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical knowledge of the Industry. They are not a standard or a code of construction neither a guide for maintenance, a safety handbook or a guide of professional practices, all of which are assumed to be known in detail and carefully followed at all times by the Client.**

Committees consisting of personalities from the Industry contribute to the development of those documents.

3.2. - The Society only is qualified to apply its Rules and to interpret them. Any reference to them has no effect unless it involves the Society's intervention.

3.3. - The Services of the Society are carried out by professional Surveyors according to the applicable Rules and to the Code of Ethics of the Society. Surveyors have authority to decide locally on matters related to classification and certification of the Units, unless the Rules provide otherwise.

3.4. - **The operations of the Society in providing its Services are exclusively conducted by way of random inspections and do not in any circumstances involve monitoring or exhaustive verification.**

ARTICLE 4

4.1. - The Society, acting by reference to its Rules:

- reviews the construction arrangements of the Units as shown on the documents presented by the Client;
- conducts surveys at the place of their construction;
- classes Units and enters their class in its Register;
- surveys periodically the Units in service to note that the requirements for the maintenance of class are met.

The Client is to inform the Society without delay of circumstances which may cause the date or the extent of the surveys to be changed.

ARTICLE 5

5.1. - The Society acts as a provider of services. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty.

5.2. - The certificates issued by the Society pursuant to 5.1. here above are a statement on the level of compliance of the Unit to its Rules or to the documents of reference for the Services provided for.

In particular, the Society does not engage in any work relating to the design, building, production or repair checks, neither in the operation of the Units or in their trade, neither in any advisory services, and cannot be held liable on those accounts. Its certificates cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

5.3. - The Society does not declare the acceptance or commissioning of a Unit, nor of its construction in conformity with its design, that being the exclusive responsibility of its owner or builder, respectively.

5.4. - The Services of the Society cannot create any obligation bearing on the Society or constitute any warranty of proper operation, beyond any representation set forth in the Rules, of any Unit, equipment or machinery, computer software of any sort or other comparable concepts that has been subject to any survey by the Society.

ARTICLE 6

6.1. - The Society accepts no responsibility for the use of information related to its Services which was not provided for the purpose by the Society or with its assistance.

6.2. - If the Services of the Society cause to the Client a damage which is proved to be the direct and reasonably foreseeable consequence of an error or omission of the Society, its liability towards the Client is limited to ten times the amount of fee paid for the Service having caused the damage, provided however that this limit shall be subject to a minimum of eight thousand (8,000) Euro, and to a maximum which is the greater of eight hundred thousand (800,000) Euro and one and a half times the above mentioned fee.

The Society bears no liability for indirect or consequential loss such as e.g. loss of revenue, loss of profit, loss of production, loss relative to other contracts and indemnities for termination of other agreements.

6.3. - All claims are to be presented to the Society in writing within three months of the date when the Services were supplied or (if later) the date when the events which are relied on of were first known to the Client, and any claim which is not so presented shall be deemed waived and absolutely barred. Time is to be interrupted thereafter with the same periodicity.

ARTICLE 7

7.1. - Requests for Services are to be in writing.

7.2. - **Either the Client or the Society can terminate as of right the requested Services after giving the other party thirty days' written notice, for convenience, and without prejudice to the provisions in Article 8 hereunder.**

7.3. - The class granted to the concerned Units and the previously issued certificates remain valid until the date of effect of the notice issued according to 7.2. here above subject to compliance with 2.3. here above and Article 8 hereunder.

7.4. - The contract for classification and/or certification of a Unit cannot be transferred neither assigned.

ARTICLE 8

8.1. - The Services of the Society, whether completed or not, involve, for the part carried out, the payment of fee upon receipt of the invoice and the reimbursement of the expenses incurred.

8.2. Overdue amounts are increased as of right by interest in accordance with the applicable legislation.

8.3. - The class of a Unit may be suspended in the event of non-payment of fee after a first unfruitful notification to pay.

ARTICLE 9

9.1. - The documents and data provided to or prepared by the Society for its Services, and the information available to the Society, are treated as confidential. However:

- clients have access to the data they have provided to the Society and, during the period of classification of the Unit for them, to the **classification file** consisting of survey reports and certificates which have been prepared at any time by the Society for the classification of the Unit;
- copy of the documents made available for the classification of the Unit and of available survey reports can be handed over to another Classification Society, where appropriate, in case of the Unit's transfer of class;
- the data relative to the evolution of the Register, to the class suspension and to the survey status of the Units, as well as general technical information related to hull and equipment damages, are passed on to IACS (International Association of Classification Societies) according to the association working rules;
- the certificates, documents and information relative to the Units classed with the Society may be reviewed during certificating bodies audits and are disclosed upon order of the concerned governmental or inter-governmental authorities or of a Court having jurisdiction.

The documents and data are subject to a file management plan.

ARTICLE 10

10.1. - Any delay or shortcoming in the performance of its Services by the Society arising from an event not reasonably foreseeable by or beyond the control of the Society shall be deemed not to be a breach of contract.

ARTICLE 11

11.1. - In case of diverging opinions during surveys between the Client and the Society's surveyor, the Society may designate another of its surveyors at the request of the Client.

11.2. - Disagreements of a technical nature between the Client and the Society can be submitted by the Society to the advice of its Marine Advisory Committee.

ARTICLE 12

12.1. - Disputes over the Services carried out by delegation of Governments are assessed within the framework of the applicable agreements with the States, international Conventions and national rules.

12.2. - Disputes arising out of the payment of the Society's invoices by the Client are submitted to the Court of Nanterre, France.

12.3. - **Other disputes over the present General Conditions or over the Services of the Society are exclusively submitted to arbitration, by three arbitrators, in London according to the Arbitration Act 1996 or any statutory modification or re-enactment thereof. The contract between the Society and the Client shall be governed by English law.**

ARTICLE 13

13.1. - **These General Conditions constitute the sole contractual obligations binding together the Society and the Client, to the exclusion of all other representation, statements, terms, conditions whether express or implied. They may be varied in writing by mutual agreement.**

13.2. - The invalidity of one or more stipulations of the present General Conditions does not affect the validity of the remaining provisions.

13.3. - The definitions herein take precedence over any definitions serving the same purpose which may appear in other documents issued by the Society.

RULE NOTE NR 578

NR 578

Rules for the Classification of Tension Leg Platforms (TLP)

July 2012

Section 5 Hull Scantlings

SECTION 1 GENERAL

1 General

1.1 Application

1.1.1 The present Note provides requirements for the classification of Tension Leg Platforms (TLP) intended for various offshore services.

1.1.2 The requirements of the present Note apply only for units intended to be granted the class notations specified in [1.2].

1.1.3 The requirements of the present Note are complementary to provisions of the Offshore Rules, Pt A, Pt B and Pt C, which remains applicable, except where otherwise specified in the present Note.

1.1.4 The requirements of the present Section are consistent with the recommendations of API RP 2T. The Society may refer to this standard when deemed necessary, in order to define minimum criteria for classification purpose.

Interpretations of API RP 2T and additional requirements are given in the present Note.

1.1.5 When relevant requirements of IMO MODU Code, as amended, applicable for column stabilized units, are referenced in the present Note, these requirements are adopted as minimum criteria for classification purpose.

1.2 Class notations

1.2.1 Structural type notation

The provisions of the present Note apply to floating units intended to be granted the structural type notation **offshore TLP**, as defined in Pt A, Ch 1, Sec 2 of the Offshore Rules.

1.2.2 Service notations

Units covered by the present Note may be granted relevant service notations defined in Pt A, Ch 1, Sec 2, [4.2] of the Offshore Rules. Usual service notations for TLP are given in Tab 1.

Table 1 : Usual service notations for TLP

Service notation	Description
production	For units intended to oil production and fitted with production plant
gas production	For units intended to gas production and fitted with gas production plant
drilling	For units intended to drilling activities and fitted with drilling equipment
accommodation	For units intended to accommodate offshore personnel
special service (dry wellhead support)	For units intended to provide offshore support of dry wellheads

1.2.3 Additional service features

The additional service features given in Tab 2, and defined in Pt A, Ch 1, Sec 2, [7] of the Offshore Rules are mandatory for units covered by the present Note.

Table 2 : Additional service features

Additional service feature	Items covered
AUTO	Automated installations enabling periodically unattended operations of machinery spaces
HEL	Helideck fitted onboard the unit

1.2.4 Additional features TLS and TLS PLUS

One of the additional features **TLS** or **TLS PLUS** is mandatory for units covered by the present Note.

The additional feature **TLS** covers the classification of tendon legs system, including tendons and their components, top and bottom connectors and foundations. Specific requirements for this additional feature are given in Sec 6 of the present Note. In principle, additional feature **TLS** adopts the same level of safety as API RP 2T.

The additional feature **TLS PLUS** may replace **TLS** upon the request of the party applying for classification. In addition to the requirements applicable for **TLS**, **TLS PLUS** requires the verification of tension legs system under loading conditions more severe than API RP 2T, as follows:

- tendon removal condition under 100 years environment
- broken tendon condition
- flooded tendon condition.

Further requirements are given in Sec 4 and Sec 6 of the present Note.

Requirements for foundations are given in Sec 7.

1.2.5 Site, transit and navigation notations

Site and transit notations are to be granted in accordance with the provisions of Pt A, Ch 1, Sec 2, [5] of the Offshore Rules. Navigation notations are not relevant for classification of TLP.

For towing/transit phase, TLP are to be granted with the notation **transit-specific criteria**. Criteria for the assessment in towing/transit phase are based on data and assumptions specified by the party applying for classification, and stated in the Design Criteria Statement.

1.2.6 Additional class notations

The additional class notations stated in Tab 3 may be granted to units covered by the present Note. Other additional class notation as given by the Offshore Rules may be granted on a case-by-case basis.

Table 3 : Additional class notations

Additional class notation	Description	Reference for definition
ALM	Lifting and deck appliances	Pt A, Ch 1, Sec 2, [6.2.2] of the Offshore Rules
COMF HEALTH-NOISE-g	Comfort and health requirements relating to noise level	Pt A, Ch 1, Sec 2, [6.2.11] of the Offshore Rules
COMF HEALTH-VIB-g	Comfort and health requirements relating to vibration level	Pt A, Ch 1, Sec 2, [6.2.11] of the Offshore Rules
HIPS	High integrity protection systems	Pt A, Ch 1, Sec 2, [6.2.12] of the Offshore Rules
LSA	Life saving appliances	Pt A, Ch 1, Sec 2, [6.2.7] of the Offshore Rules
Spectral Fatigue	Fatigue check through spectral fatigue techniques	Pt A, Ch 1, Sec 2, [6.2.13] of the Offshore Rules NI 539 Spectral Fatigue Analysis Methodology for Ships and Offshore Units
STI **(1)**	Specific thickness increments	Pt A, Ch 1, Sec 2, [6.2.10] of the Offshore Rules
DRILL	Requirements for the classification of drilling equipment and installations	NR570 Classification of Drilling Equipment
PROC	Process plant on production units	Pt A, Ch 1, Sec 2, [6.2.5] of the Offshore Rules NR459 Process Systems on board Offshore Units and Installations.
RIPRO	Risers	Pt A, Ch 1, Sec 2, [6.2.6] of the Offshore Rules
RBVS-xxx	Classed units for which the Society provides risk based verification services	NI 567 Risk Based Verification of Offshore Units
IVBS	Classed units for which the Society provides independent verification services, acting as Independent Verification Body	NI 567 Risk Based Verification of Offshore Units
RBA	Units for which the classification process is carried out through a risk analysis approach	NR568 Classification of Offshore Units - Risk Based Approach

(1) The additional class notation **STI** defined in Pt A of the Offshore Rules may be granted to units covered by the present Note taking into account the requirements of Sec 3, [6.2].

1.3 Society involvement

1.3.1 Scope of classification

The scope of classification for units listed above is based on an appraisal of the integrated unit covering in general:

a) Hull, accommodation, helideck and hull attachments and appurtenances including:
- tendon supporting structure
- foundations for the support of topsides equipment and the hull mounted equipment
- support structure for life saving appliances
- passive fire protection and cathodic protection

b) Tendon legs system, including tendons and components, top and bottom connectors and foundations, within the scope of additional feature **TLS** or **TLS PLUS**.

c) Moonpool arrangement

d) Intact and damage stability, in pre-service and operating conditions

e) Marine equipment (with foundations) pertaining to the offloading facilities, if any

f) Accommodation quarters

g) Lifting appliances (in case of the additional class notation **ALM**)

h) Drilling equipment and installations (in case of additional class notation **DRILL**)

i) Process plant and components (in case of additional class notation **PROC**)

j) Rigid or flexible risers, as relevant (in case of additional class notation **RIPRO**)

k) High integrity pressure protecting systems, in case of additional class notation **HIPS**)

l) Equipment and systems necessary for the safe operation of the hull and to the safety of personnel on board as defined in the Rules for the Classification of Offshore Units and related applicable Rules (taking into account the additional service features **AUTO**, and the additional class notation **LSA**)

m) Equipment and systems installed in the hull, the failure of which may jeopardise the safety of the floating unit

n) The fire and gas detection system for the hull as well as the definition of the hazardous areas of the hull

o) The fire water and foam system for the protection of the hull.

1.3.2 Detailed boundaries for classification

For each project, the detailed boundaries for the classification of units covered by the present Note are defined by the Society on case-by-case basis and with reference to the requested structural type and service notations, additional class notations and additional service features.

As a rule, any foundation, support or stool, and any structural part which is welded to the hull are within the scope of the classification, independently of the additional class notations.

1.4 Design Criteria Statement

1.4.1 Classification is based upon the design data or assumptions specified by the party applying for classification. A Design Criteria Statement is to list the services performed by the unit and the design conditions and other assumptions on the basis of which class is assigned to the unit.

The Design Criteria Statement is to be issued by the Society, based on the information provided by the party applying for classification.

1.4.2 The Design Criteria Statement is to be referred to on the unit's Classification Certificates.

1.4.3 The Design Criteria Statement is to be incorporated in the Operating Manual, as stated in Pt A, Ch 1, Sec 1, [3.4] of the Offshore Rules.

1.4.4 Additional details about the Design Criteria Statement are given in Pt A, Ch 1, Sec 1, [1.6] of the Offshore Rules.

1.5 Design life

1.5.1 The requirements about "Service Life", "Design life", unit modifications and unit re-assessment are given in Pt A, Ch 1, Sec 1, [1.7] of the Offshore Rules.

1.6 Statutory requirements

1.6.1 Project specification

Prior to commencement of the review of drawings, the complete list of Rules, Codes and Statutory Requirements to be complied with must be submitted for information. This list is to detail the requirements to be complied with:

- International Rules
- Flag state requirements
- Coastal state requirements
- Owner standards and procedures
- Industry standards
- Classification notations.

The project specification is also to specify the list of Owner requested statutory certificates.

1.6.2 Conflict of Rules

In case of conflict between the Classification Rules and any Statutory Requirements as given by Flag state or Coastal State, the latter ones are to take precedence over the requirements of the present Rules.

1.6.3 IMO MODU Code

Compliance with IMO MODU Code may be required by Owner, Flag and/or Coastal State.

The Society reserves the right to refer to the requirements in IMO MODU Code, when deemed necessary.

2 Definitions

2.1 Referenced documents

2.1.1 Offshore Rules

Offshore Rules means Bureau Veritas Rules for the Classification of Offshore Units (NR445). When reference is made to the Offshore Rules, the latest version of these ones is applicable.

2.1.2 Ship Rules

Ship Rules means Bureau Veritas Rules for the Classification of Steel Ships (NR467). When reference is made to the Ship Rules, the latest version of these ones is applicable.

2.1.3 API RP 2T

API RP 2T means the recommended practice published by American Petroleum Institute "Planning, Designing and Constructing Tension Leg Platforms". When reference is made to API RP 2T, the third edition of the document, from July 2010 is concerned.

2.1.4 API 2A WSD

API 2A WSD means the standard published by American Petroleum Institute "Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms - Working Stress Design" - latest edition.

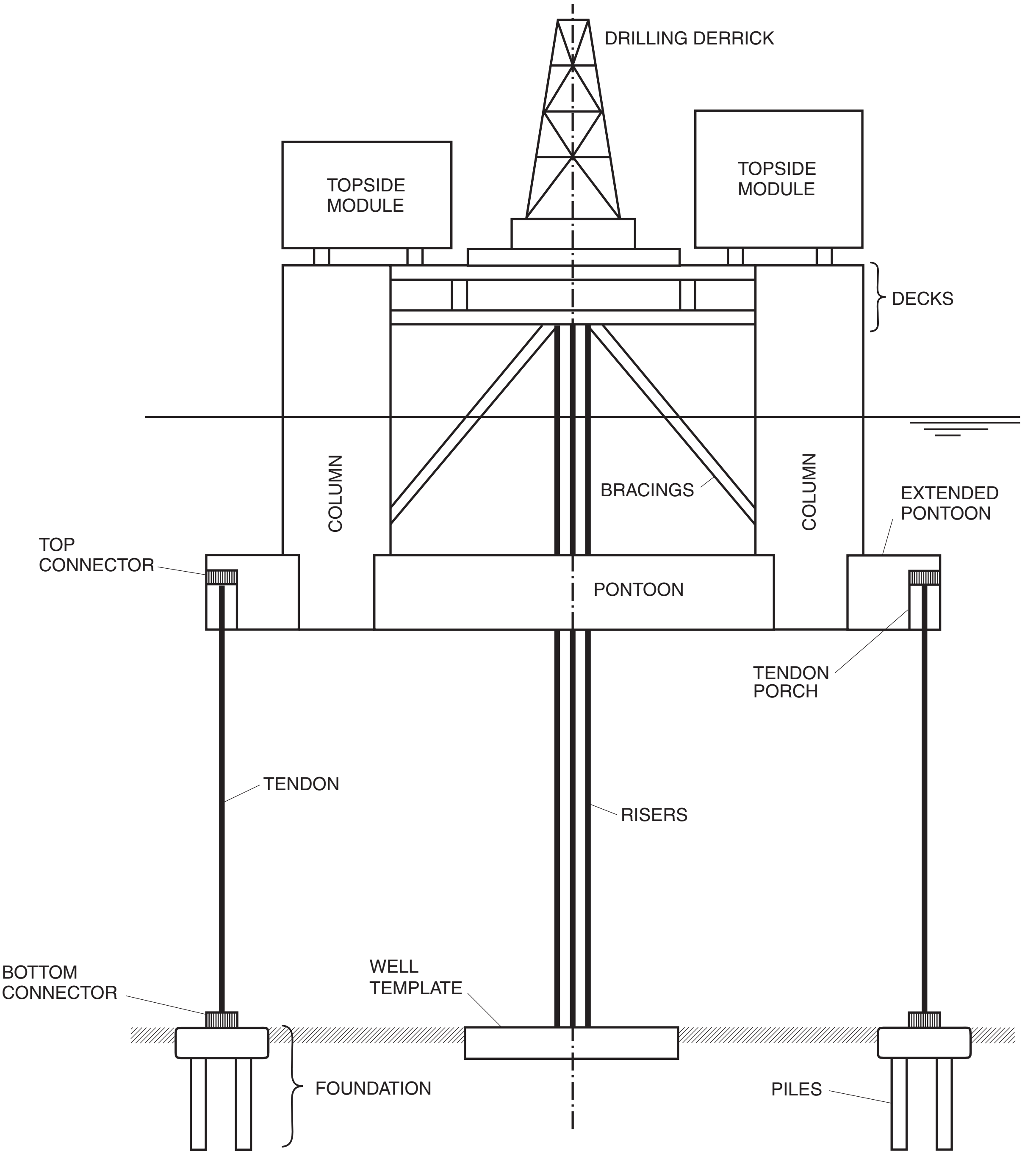
2.2 Technical definitions

2.2.1 Tension leg platforms (TLP)

Tension leg platforms are floating offshore units connected to the seabed through a tendon legs system (TLS). The TLS ensure the station keeping and restrains the motion of the unit due to wind, waves, current and tidal effects within specified limits (see Fig 1).

Tendons are pre-tensioned. Generally very stiff in axial direction, the tendons limit heave, pitch and roll responses to very small amplitudes.

Figure 1 : Example of Tension Leg Platform (TLP)



2.2.2 TLP hull

TLP hulls may be of various structural types; the most usual are as follows:

- conventional TLP, designed generally on the principle of column stabilized units with four columns, and having top tendon connectors inside the structure of columns or on tendon porches attached to the columns
- extended TLP, with smaller columns located inboard and extended pontoons; the tendons are connected at the extremities of extended pontoons
- seastar TLP, generally with one central column and at least three extended pontoons for connection of tendon legs system
- TLP designed by mixing the principles of extended and seastar TLP.

2.2.3 Tendon legs system (TLS)

Tendon legs system includes tendons, top and bottom connectors, foundations to the seabed, load measurement systems and inspection or monitoring apparatus.

Tendons may be of various types. Examples include:

- tubular members with connectors; the members may be void, partially void or flooded
- tubular or solid rod members with welded connections
- fabricated from small diameter high tensile strength wire or fiber strands, formed into bundles.

2.2.4 TLS Foundations

TLS foundations are installations at the seabed or in the seabed serving as anchoring of tendons and providing the transfer of tendons loads to soil.

2.2.5 Squeeze-pry effect

Squeeze and pry load effects are typical for column stabilized hulls under wave loads.

Squeeze effect occur when lateral loads on columns due to waves are maximum inward toward the center of the TLP, "squeezing" the columns toward each other. Prying is the opposite effect, when the lateral load is outward away from the platform center.

Squeeze and pry load effects may be determinant for the connection between columns and pontoons and for the interconnection between the hull and decks.

2.2.6 Hydrodynamic global behaviour analysis

Hydrodynamic global behavior analysis defines all hydrodynamic calculations and tests aimed to determine the effects of environmental loads on the TLP coupled with tendons and risers. Further details are given in App 1.

2.3 Other definitions

2.3.1 Definitions given in the Offshore Rules are to be considered for the purpose of the present Note.

2.3.2 Reference is also made to relevant definitions of API RP 2T.

3 Documents to be submitted

3.1 General

3.1.1 Required documentation for classification purpose is given in Pt A, Ch 1, Sec 4 of the Offshore Rules.

3.1.2 The following information is to be provided as background data, at initial stage of classification:

- environmental design data (wind, wave, current, earthquake, etc.)
- soil data
- overall architecture of the installation
- functional specification of the installation.

3.2 Additional features TLS and TLS PLUS

3.2.1 The party applying for classification is to submit to the Society all relevant drawings, available certificates and calculation reports relating to the components of tension legs system within the scope of classification, as stated in Sec 6.

The Society is to be consulted for each project in order to define the list of documents that will be subject of approval.

SECTION 2 STABILITY, WEIGHT CONTROL, WATERTIGHTNESS AND WEATHERTIGHTNESS

1 General

1.1 Application

1.1.1 The requirements of the present Section are applicable for all units covered by the present Note, as stated in Sec 1.

1.1.2 The present Section provides requirements for intact and damage stability of TLP covering pre-service conditions and operations on the intended site.

Requirements relating to weight control, inclining tests or equivalent procedures are given in [3].

Specific requirements relating to watertight and weatertight integrity of TLP are given in [4].

1.2 Documentation to be submitted

1.2.1 General

A stability file is to be submitted by the Owner or its representative. It has to include line plans, capacity plans, justification of lightweight characteristics, definition of loading conditions, trim and stability booklet, damage stability booklet, damage control plan, damage control booklet.

1.3 Operational procedures

1.3.1 General

Adequate instructions and information related to the stability, watertightness and weathertightness of the unit are to be provided by the Owner and included in the Operating Manual. In accordance with Pt A, Ch 1 of the Offshore Rules, the procedures and operating instructions do not fall into the scope of classification and need not to be approved by the Society.

1.3.2 Operating Manual

The results of the inclining test, or deadweight survey, or inclining test adjusted for weight differences when relevant, are to be indicated in the Operating Manual.

The lightweight particulars are to include the detailed list of the equipment (cranes, accommodation, features...) located on the unit when the test has been carried out.

A record of all changes to machinery, structure, outfitting and equipment that affect the lightweight data, are to be maintained in the Operating Manual or a in a lightweight data alterations log and is to be taken into account in daily operations.

A record of correlations between calculated and measured tendon tension is to be maintained in the Operating Manual and taken into account for daily operations.

Specific procedures relating to loading instrument (see [1.3.3] are to be included in the operating manual.

1.3.3 Loading instruments

Appropriate loading instruments/load management tools are to be provided onboard TLP during operations on the intended site in order to facilitate safe management of weight and center of gravity control and tendon tensions during service. Clear procedures for the use of loading instruments and management of its parameters are to be included in the Operating manual.

2 Stability

2.1 Pre-service conditions

2.1.1 Intact and damaged stability of units covered by the present Note during pre-service conditions, while afloat, are to comply with the requirements of Pt B, Ch 1 of the Offshore Rules, applicable for column-stabilized units.

2.1.2 The references to the Offshore Rules which are to be considered for classification of TLP are given in Tab 1.

2.1.3 For damage stability purpose, the extent of damage to be taken into account is the one assumed in [2.3].

Table 1 : References for stability requirements in pre-service conditions

Item	Reference
Stability calculations	Pt B, Ch 1, Sec 2 of the Offshore Rules
Intact stability criteria	Pt B, Ch 1, Sec 3, [1] of the Offshore Rules
Damage stability	Pt B, Ch 1, Sec 3, [3.1] and [3.3] of the Offshore Rules

2.2 On-site conditions

2.2.1 Stability of TLP for on-site condition, with tendon legs system connected is not governed by a metacentric approach. The stability is typically provided by the pretension and stiffness of the tendon system, rather than by waterplan area and moments.

2.2.2 Stability analysis of TLP for on-site conditions is to show that the system is sufficiently constrained by tendon legs system to avoid overturning. Stability checks are implicit through minimum and maximum tendon tension criteria as defined in Sec 6.

2.2.3 It is to be checked that weight changes and center of gravity shifts during the most relevant operational phases and for design loading conditions defined in Sec 4 will generate tendon tensions within the allowable minimum and maximum limits defined in Sec 6.

2.3 Extent of damage

2.3.1 In assessing the damage stability of TLP, the following extent of damage is to be assumed:

a) Only those columns, underwater hulls and braces on the periphery of the unit are to be assumed to be damaged and the damage is to be assumed in the exposed outer portions of columns, underwater hulls and braces.

Note 1: The outer portions of a member are defined as portions located outboard of a line drawn through the centres of the peripheral columns of the unit; special consideration is to be given to units of particular design and to units provided with efficient fendering.

b) Columns and braces are to be assumed to be flooded by damage having a vertical extent of 3 m occurring at any level between 5 m above and 3 m below the considered waterline.

Note 2: The waterline of a TLP is affected by tidal effects, storm surge, and mainly by the setdown due to environmental conditions. The vertical extent of damage is to be adjusted accordingly.

Where a watertight flat is located within this region, the damage is to be assumed to have occurred in both compartments above and below the watertight flat in question.

Lesser distances above or below the draughts may be applied to the satisfaction of the Society, taking into account the actual conditions of operation. However, in all cases, the required damage region is to extend at least 1,5 m above and below the draught specified in the Operating Manual.

c) No vertical bulkhead fitted in columns is to be assumed to be damaged, except where bulkheads are spaced closer than a distance of one eighth of the column perimeter, at the draught under consideration, measured at the periphery, in which case one or more of the bulkheads are to be disregarded.

d) Horizontal penetration of a member damage is to be assumed to be 1,5 m, measured at right angle to the shell of the member.

e) Underwater hull or pontoons are to be assumed to be damaged when the unit is in a towing condition in the same manner as indicated in items a), b), d) and either item c) or item f), having regard to their shape.

f) All piping, ventilation systems, trunks, etc., within the extent of damage are to be assumed to be damaged; positive means of closure are to be provided, in accordance with Pt B, Ch 1, Sec 4 of the Offshore Rules, at watertight boundaries to preclude the progressive flooding of other spaces which are intended to be intact.

3 Weight control

3.1 General

3.1.1 Weight control procedure includes:

- a detailed breakdown of components and modules estimates during design phase
- weight measures or equivalent acceptable calculations of components during construction
- tracking of weights during assembly and commissioning
- inclining test.

Relevant reports and calculations are to be submitted to the Society. An inclining test is to be performed, when possible, as required in [3.2]. Alternative requirements of [3.3] are also to be considered.

3.2 Inclining test

3.2.1 An inclining test is to be carried out on each unit at the time of construction or following substantial modification during pre-service conditions, to determine accurately the lightweight data (weight and position of centre of gravity).

3.2.2 The inclining test is to take place, when the unit is as near as possible to completion, in the presence and to the satisfaction of the attending Surveyor. The test procedure is to be submitted to the Society for examination prior to being carried out.

3.2.3 The results of the inclining test are to be submitted to the Society for review.

3.3 Alternative

3.3.1 For special configurations of TLP or special installation procedures, for which an inclining test on the complete structure cannot be performed, alternative methods for determining the TLP weight and center of gravity may be accepted.

Alternative methods may include weighing of TLP or components using certified load cells. The procedures to assemble the final weight and center of gravity of the unit are to be documented to the satisfaction of the Society.

4 Watertightness and weathertightness

4.1 General

4.1.1 Units covered by the present Note are to comply with the relevant requirements of Pt B, Ch 1, Sec 4 of the Offshore Rules, applicable for column stabilized units.

4.1.2 A plan identifying the location of all watertight and weathertight closures and all non-protected openings and identifying the position open/closed of all non-automatic closing devices is to be submitted to the Society for review. This plan will be included in the Operating Manual.

4.1.3 External openings having lower edges below the levels to which weathertighness is requested are to be provided with weathertight closing appliances. Closing appliances are to effectively resist to ingress of water due to intermittent immersion.

SECTION 3 STRUCTURAL DESIGN REQUIREMENTS

1 General

1.1 Scope

1.1.1 The present Section provides general requirements relating to the design and construction of TLPs.

1.1.2 Units covered by the present Note are to comply with the relevant requirements of Pt B of the Offshore Rules, applicable for columns stabilized units, except when otherwise specified in the present Note.

1.1.3 Relevant requirements of IMO MODU Code Ch 2, applicable for column stabilized units, are adopted through the present Rules and are to be considered as minimum requirements for classification purpose.

1.2 General design principles

1.2.1 Generally, units covered by the present Note are designed to sustain all loads liable to occur during pre-service conditions and during operations. For the purpose of classification, design loading condition for which checks are required are given in Sec 4.

1.2.2 The design submitted for classification is to take into account operating tolerances regarding important design parameters, such as tendon and riser tension or ballast and weight distribution. The most unfavorable operating tolerances are to be specified by the Designer.

1.3 Structural categorization

1.3.1 Definition of categories

Structural elements in welded steel are classed into three categories: second, first and special categories as listed:

- Second category: Second category elements are structural elements of minor importance, the failure of which might induce only localised effects.
- First category: First category elements are main load carrying elements essential to the overall structural integrity of the unit.
- Special category: Special category elements are parts of first category elements located in way or at the vicinity of critical load transmission areas and of stress concentration locations.

1.3.2 Structural categorization

Structural categories, as defined in [1.3.1], are to be indicated on drawings submitted to the Society for approval.

The Society may, when deemed necessary, upgrade any structural element to account for particular considerations such as novel design features or restrictions regarding access for quality control and in-service inspections.

1.3.3 Guidance for structural categorization

Structural categories specified in Tab 1 for various elements are given as guidance for the application of [1.3.2].

2 Materials for construction

2.1 Design temperature

2.1.1 Design temperature of structural elements is to be taken as follows:

- for the emerged part of the structure (in general, above the lowest astronomical tide), the design temperature is the air temperature defined in [2.1.3]
- for the immersed part of the structure (in general, below the lowest astronomical tide), the design temperature is the water temperature defined in [2.1.4].

2.1.2 The Society may accept values of design temperature obtained through direct calculation, provided that:

- the calculations are based on air temperature and water temperature as defined in [2.1.3] and [2.1.4]
- the calculations provide a design temperature corresponding to the worst condition of the unit in pre-service conditions and during operations
- a complete calculation report, including a documentation of methods and software, is submitted to the Society.

2.1.3 Air temperature requested by [2.1.1] is to be taken as the mean air temperature of the coldest day (24 h) of the year for any anticipated area of operation.

Where no particular value is specified, classification is to be based upon the following air temperature:

- 0°C for units not intended to operate in cold areas
- −10°C for units intended to operate in cold areas.

2.1.4 Water temperature requested by [2.1.1] is to be taken as the water temperature of the coldest day (24 h) of the year for any anticipated area of operation.

Where no particular value is specified, classification is to be based upon 0°C water temperature.

Table 1 : Guidance for structural categorization

Category	Structural element
Special	• Tendon and tendon connectors • Hull shell in way of intersections between columns, topside deck, pontoons and tendon porch; the extension is to be taken at least 1 m in all directions from the intersection • Highly stressed supports of cranes pedestals and flare booms • Derrick supporting structure • In general, supports and stools of equipment designed without soft-toe brackets
First	• Hull shell of columns, decks and pontoons other than special category • In general, supports of equipment designed with soft toe brackets • Structural elements providing reinforcement and structural continuity at intersections, other than special category • Diagonal bracings on deck • Helideck supporting structure • Main supporting structure of heavy substructures and equipment
Secondary	• Other structures than special and first • Substructure of laydown areas • Outfitting features • Stair towers and their substructure • Rest support structures for handling equipment • Reinforcing stiffeners, girders or bulkheads sustaining a low or moderate level of stress and easily available for inspection

2.2 Material requirements

2.2.1 Steels and products used for the construction of structural elements of TLPs are to meet the applicable requirements of NR 216 Materials and Welding.

Steels and products manufactured to other specifications may be accepted in specific cases provided that such specifications gives reasonable equivalence to the requirements referenced above.

2.2.2 Structural elements are to comply with the requirements relating to materials for construction given in Pt B, Ch 3, Sec 2 of the Offshore Rules, taking into consideration the structural categories defined in [1.3].

2.3 Steels with specified through thickness properties

2.3.1 The designer is to evaluate the risk of any lamellar tearing, i.e. shrinkage stresses of the weld during cooling, clamping of the structure close to a joint, thickness of material, any rolling defects at mid-thickness and importance of the weld runs.

2.3.2 The maximum allowable stress through thickness is 50% of the allowable yield stress. For Z-grade plates a maximum stress of 75% of allowable yield stress can be accepted as through thickness stress.

Special attention to the welding of Z-grade plates is to be paid by the designer. The Society may require ultrasonic inspection before and after welding of the plate.

3 Inspections and checks

3.1 General

3.1.1 Materials, workmanship, structures and welded connections are to be subjected, at the beginning of the work, during construction and after completion, to inspections by the Shipyard suitable to check compliance with the applicable requirements, approved plans and standards.

3.1.2 The manufacturer is to make available to the attending Surveyor a list of the manual welders and welding operators and their respective qualifications.

3.1.3 The manufacturer's internal organisation is responsible for ensuring that welders and operators are not employed under improper conditions or beyond the limits of their respective qualifications and that welding procedures are adopted within the approved limits and under the appropriate operating conditions.

3.1.4 The manufacturer is responsible for ensuring that the operating conditions, welding procedures and work schedule are in accordance with the applicable requirements, approved plans and recognized good welding practice.

3.2 Inspection requirements

3.2.1 Requirements of Section 6 of NR426 "Construction Survey of Steel Structures of Offshore Units and Installations" are to be complied with.

3.2.2 The Society reserves the right to increase the number of non destructive examinations due to complexity of the structure and with particular attention to the intended service.

4 Access

4.1 General

4.1.1 Access arrangement is to comply with the relevant requirements of IMO MODU Code, Ch 2.

4.2 Means of access

4.2.1 Each space within the unit is to be provided with at least one permanent means of access to enable, throughout the life of the unit, overall and close-up inspections and thickness measurements.

4.2.2 For the access to horizontal openings, hatches or manholes, the dimensions are to be sufficient to allow a person wearing a self-contained air-breathing apparatus and protective equipment to ascend or descend any ladder without obstruction and also to provide a clear opening to facilitate the hoisting of an injured person from the bottom of a confined space. The minimum clear opening is not to be less than 600 x 600 mm. When access to a hold is arranged through a flush manhole in the deck or a hatch, the top of the ladder is to be placed as close as possible to the deck or the hatch coaming. Access hatch coamings having a height greater than 900 mm are to be provided with steps on the outside in conjunction with the ladder.

4.2.3 For access to vertical openings or manholes in swash bulkheads, girders and web frames providing passage through the length and breath of the space, the minimum opening is to be not less than 600 x 800 mm at a height not more than 600 mm from the lower shell plate unless gratings or other footholds are provided.

4.2.4 Where a permanent means of access may be susceptible to damage during normal operations or where it is impracticable to fit permanent means of access, the Society may accept, on a case-by-case basis, the provision of movable or portable means of access, provided that the means of attaching, rigging, suspending or supporting the portable means of access forms a permanent part of the unit's structure. All portable equipment is to be capable of being readily erected or deployed by unit's personnel.

4.2.5 Equipment on deck is to be arranged such as to allow inspections of deck structure and to avoid permanent concentration of dust, mud and remaining water.

4.3 Access manual

4.3.1 An access manual is to be incorporated in the operating manual of the unit. The access manual is to describe unit's means of access to carry out overall and close-up inspections and thickness measurements.

4.3.2 The access manual is to be up-dated as necessary, and an up-dated copy is to be maintained onboard.

4.3.3 The access manual is to include, for each space, the following information:

- plans showing the means of access to the space, with appropriate technical specifications and dimensions
- plans showing the means of access within each space to enable an overall inspection to be carried out, with appropriate technical specifications and dimensions; the plans are to indicate from where each area in the space can be inspected
- plans showing the means of access within each space to enable close-up inspection to be carried out, with appropriate technical specifications and dimensions; the plans are to indicate the position of structural critical areas, whether the means of access are permanent or portable and from where each area can be inspected

Note 1: Critical structural areas are locations identified from calculations to require monitoring, or, from the service history of similar or sister units, to be sensitive to cracking, buckling, deformation or corrosion which would impair the structural integrity of the unit.

- instructions for inspecting and maintaining the structural strength of all means of access and means of attachment, taking into account any corrosive atmosphere that may be within the space
- instructions for safety guidance when rafting is used for close-up inspections and thickness measurements
- instructions for the rigging and use of any portable means of access in a safe manner
- an inventory of all portable means of access
- records of periodical inspections and maintenance of the unit's means of access.

5 Net scantling approach

5.1 Principle

5.1.1 Except when otherwise specified, the scantlings obtained by applying the criteria specified in this Note are net scantlings.

5.1.2 Net thickness of plating is to be obtained by deducting the rule corrosion addition from the gross thickness indicated by the Designer. The requirement of [5.1.3] is to be considered.

5.1.3 For all finite element models, the net thickness of plating is to be obtained by deducting half of the rule corrosion addition from the gross thickness indicated by the Designer.

5.2 Corrosion addition

5.2.1 The values of rule corrosion additions are given in Tab 2. If the party applying for classification specifies values of corrosion additions greater than those defined in Tab 2, these values are to be taken into account for calculations and stated in the Design Criteria Statement.

Table 2 : Rule corrosion additions, in mm, for each exposed side

Compartment type	Rule corrosion addition (mm)
Outside sea and air	0,50
Ballast	1,00
Hydrocarbon products and fuel oil	0,75
Drilling mud, drilling brines	1,25
Dry holds	0,50
Void spaces	0,50
Other compartments	0,50

5.2.2 In general, the corrosion addition to be considered for plating forming the boundary between two compartments of different types is equal to:

- for plating with a gross thickness greater than 10 mm, the sum of the values specified for one side exposure to each compartment
- for plating with a gross thickness less than or equal to 10 mm, the smallest of the following values:
  - 20 % of the gross thickness of the plating
  - sum of the values specified for one side exposure to each compartment.

For an internal member within a given compartment, or for plating forming the boundary between two compartments of the same type, the corrosion addition to be considered is twice the value specified for one side exposure to that compartment.

5.2.3 For structural members made of stainless steel, the corrosion addition is to be taken equal to 0.

6 Corrosion protection

6.1 General reference

6.1.1 The requirements of Pt B, Ch 3, Sec 5, [1] and [2] of the Offshore Rules, relating to corrosion protection methods and design of corrosion protection systems, are to be complied with. These requirements refer to NR423 Corrosion Protection of Steel Offshore Units and Installations.

6.1.2 Reference is also made to the recommendations of API RP 2T [13] relating to corrosion protection of hull, tendon legs system and foundations.

6.2 Thickness increments and additional class notation STI

6.2.1 A thickness increment of platings and, where relevant, of stiffeners may be added to the gross thickness in special areas subject to mechanical wastage due to abrasion or in areas of difficult maintenance.

$t_{net} = t_{gross} - t_c$

$t_{gross} = t_{as\text{-}built} - t_i$

where:

t_i : Thickness increment

t_c : Corrosion addition as defined in [5.2]

t_{net} : Net thickness

t_{gross} : Gross thickness.

The gross thickness plus the thickness increment is equal to the as-built thickness.

6.2.2 For the checking criteria specified in the present Note the thickness increments are not to be considered.

6.2.3 Notation STI requested

When the unit has the additional class notation **STI**, the thickness increments may be defined by the Owner or by the Society, as follows:

a) When the Owner specifies its own thickness increments, it is to be notified to the Society where thickness increments are provided. Thickness increments are to be stated in the Design Criteria Statement.

b) When the Owner does not provide its own thickness increments, the values to be generally considered are defined as follows:
   - 1 mm for all decks
   - 1 mm for the outer shell, except the splash zone
   - 5 mm for shell located in the splash zone
   - 1 mm for elements other than mentioned above.

Adequate indications (location, value of thickness increments) are to be given in the relevant structural drawings.

6.2.4 Notation STI not requested

When the additional class notation **STI** is not assigned to the unit, the thickness increments are to be taken equal to zero.

7 Hull structural design

7.1 Deck clearance/air gap

7.1.1 Unless the deck structures are designed to withstand wave impact loading, the underside of deck is to be clear of passing wave crests under all design loading conditions.

When wave impacts are permitted to occur on the underside of topside deck, it must be demonstrated that the safety of personnel is not significantly impaired.

7.1.2 The following clearances are to be maintained between the undeside of the topside deck and the wave crest:

- 1,5 m for all design loading conditions defined in Sec 4, that are not involving Survival Environment
- positive air gap for design loading conditions involving Survival Environment.

Deck clearances are to be checked at various points on the underside of the topside deck.

7.1.3 Deck clearances are normally determined by appropriate model tests. Detailed hydrodynamic analysis are accepted, provided that the following items are taken into account:

- relative motions between the TLP and waves
- nonlinearities of wave profile
- maximum and minimum draughts (set down, tidal effects, storm surge, subsistence)
- offset due to wave, wind and currents
- various environmental headings.

7.2 Columns and pontoons

7.2.1 Columns and pontoons may be designed as either framed or unframed shells. In either cases, framing, ring stiffeners, bulkheads or diaphragms are to be sufficient to maintain shape and stiffness under all the anticipated loadings.

Portlights or windows, including those of non-opening type, or other similar openings, are not to be fitted in columns.

7.2.2 Scantlings of columns and pontoons designed with stiffened platings are to be not less than those corresponding to watertight bulkheads, taking into account an immersion not less than maximum damaged waterline. For all areas subject to wave immersion, a minimum head of 6 m is to be considered.

7.2.3 Internal structure of columns in way of bracings is to be capable to sustain the axial strength of the bracing.

7.2.4 Special attention is to be given to structural design of columns in way of intersections with deck structures, in order to ensure smooth load redistribution.

7.3 Overall strength

7.3.1 Pontoons, columns, bracings and primary deck members are to be designed for all load cases defined in Sec 4.

When assessing overall environmental loads due to waves, due attention is to be given to the sensitivity of the structural response to direction and period of waves.

Besides, when, in the opinion of the Society, the overall arrangement of bracings does not provide for load redistribution in case of unexpected structural failure, the consideration of specific damaged situation may be required.

7.3.2 Due consideration is to be given to the fatigue strength of primary structural members, in particular in way of connections between pontoons, columns and bracings.

7.4 Local strength

7.4.1 Pontoons and columns are to be designed taking into account pressure loadings and other relevant local loads in all applicable design loading conditions defined in Sec 4.

Particular attention is to be paid to the structural details in areas subject to high local loadings resulting from, for example, wave slam, partially filled tanks or possible external damages.

7.4.2 The upper structure is to be designed taking into account the loadings indicated in the deck loading plan.

7.4.3 Bracings are normally to be watertight and are to be suitably designed to resist local forces: external hydrostatic pressure, wave and current loads. Particular consideration is to be given to the wave impact loads sustained during transit.

Where fitted for operational or structural protection purposes equipment penetration, housing and attachment are to be adequately designed and the bracing, if necessary, reinforced to restore the required strength particularly with respect to fatigue loading.

When bracing members are of tubular section, ring frames may be required to maintain stiffness and roundness of shape.

Adequate access for inspection of the bracings is to be provided. Local or remote leak detection devices are to be fitted to the satisfaction of the Society.

7.4.4 Local structures in way of fairleads, winches, etc., forming part of the mooring system are to be designed to the breaking strength of the mooring line.

7.5 Structural redundancy

7.5.1 Unit's structure is to be able to withstand the loss of any bracing member without overall collapse.

7.5.2 The structural arrangement of the upper hull is to be considered with regard to the structural integrity of the unit after the failure of any primary girder.

7.6 Local reinforcements

7.6.1 Special attention is to be given to the structural design of tendon supporting structures, in order to ensure smooth redistribution of tendon concentrated loads through the hull without causing unacceptable stress concentrations.

7.6.2 Adequate reinforcements are to be provided in way of the structural foundations of items such as:

- machineries
- fairleads, winches and other towing, mooring and anchoring equipment
- equipment corresponding to the particular service of the unit, such as the drilling equipment, crane foundations, and other concentrated loads.

Sufficient strength and stiffness are to be provided in these areas, in order to withstand the loads induced in all the conditions of operation, and avoid vibration that could lead to damage of the structure.

8 Requirements for tendon legs system

8.1 General

8.1.1 Tendon legs system is a critical element for safe operation of TLPs. Tendon legs system is designed such that a possible failure or removal of a tendon will not cause progressive tendon failure or excessive damage to the hull or foundation. Specific requirements for tendon legs system are given in Sec 6.

8.1.2 Requirements relating to tendon legs system are given under the scope of additional feature **TLS**, which is mandatory for units covered by the present Note, as stated in Sec 1.

9 Welding and weld connections

9.1 General

9.1.1 The requirements stipulated in NR426 Construction Survey of Steel Structure of Offshore Units and Installations are to be applied for welding of structural elements.

9.1.2 Reference is made to relevant structural requirements of AWS D1.1 Structural Welding Code Steel - the latest edition, which is a recognized standard for classification purpose.

SECTION 4 DESIGN CONDITIONS AND LOAD CASES

1 General

1.1 Principles

1.1.1 Scope

The present Section provides requirements for design loads applied for structural assessment of TLP floater and tendon legs system.

Loads cases considered for fatigue assessment are not included in the present Section. Relevant requirements are given in Sec 5 and Sec 6.

1.1.2 General procedure

The set-up of loads for the assessment of hull and tendon legs system follows generally the steps given in Tab 1.

Table 1 : General procedure for set-up of loads

Step	Description
1	Definition of loading conditions, taking into account the requirements stated in [2].
2	Performance of hydrodynamic global behavior analysis in order to determine relevant responses of TLP under environmental conditions. This analysis is to cover all loading condition, in accordance with the requirements of [3].
3	Definition and selection of load cases based on the requirements given in [4]. Several load cases are defined for each loading condition. Load cases are defined differently for hull and for tendon legs system.
4	Calculation of design loads and their combination for each load case. The requirements of [5] are to be complied with.

1.1.3 Loading manual

A loading manual of the unit is to be submitted for the approval of the Society.

Loading manual is a document which describes:

- all loading conditions on which the design of the unit, including the floater and tendon legs system, has been based
- all permissible limits and operational limits applied for the design
- all allowable local loadings for the hull, decks and foundations.

1.1.4 Direct calculations and model tests

Direct calculations are to be carried out, as required in the present Rule Note. Direct calculations may be calibrated based on model tests. In such a case, testing procedures and method used for the extrapolation of model tests to full scale data are to be at the satisfaction of the Society. Preferably, the procedure should be reviewed and agreed before the test is performed.

Attendance of a Surveyor to model tests will be decided at the convenience of the Society.

1.1.5 References

The requirements of the present Section are consistent with the recommendations of API RP 2T. The Society may refer to this standard when deemed necessary, in order to define minimum criteria for classification purpose.

Interpretations of API RP 2T and additional requirements are given in this Section.

2 Loading conditions

2.1 General

2.1.1 Loading conditions on the basis of which the structural checks are performed cover all stages of TLP life entering under the scope of the classification. Various severities of environmental loads are also considered.

The categories of loading conditions mentioned in the present Note are given in [2.2].

2.2 Categories

2.2.1 Pre-service conditions

Pre-service conditions includes:

- loadout
- wet transit/towing, when relevant
- dry transit, when relevant
- deck and topside modules installation
- pre-installation of tendons, when relevant
- free-standing condition of tendons at the operating site, when relevant
- tendons and risers connection with the TLP.

The present Note provides specific requirements for the towing of the floater from the shipyard to the intended operating site or for field transit, which is within the scope of classification.

Dry transit, when relevant, and other pre-service conditions stated above are to be documented. Relevant procedures and calculation reports, including the definition of loads and the assessment of hull parts and tendon legs system are to be submitted to the Society for information.

Attendance of a Surveyor during pre-service conditions not covered by the present Note will be decided at the convenience of the Society, in order to ensure that the hull and systems are in good condition after installation or transportation stages, without significant damage.

2.2.2 Normal operational conditions

The structures of the TLP and systems are checked against normal operational conditions covering normal operations of the TLP on the intended site. Limiting operational parameters (maximum wave height and period, maximum roll and pitch, maximum offset, etc.) may be specified for services such as drilling, by the party applying for classification.

The acceptability of deflections and vibrations are to be considered under normal operating conditions.

2.2.3 Extreme conditions

The structures of the TLP and systems are checked against extreme conditions in order to determine their serviceability strength. The structure will be designed to survive extreme conditions without significant probability of compromising its serviceability.

As a rule, extreme conditions correspond to:

- extreme design environments, as defined in [2.3.3]
- reduced design environments (see [2.3.5]) combined with hull damage or one tendon removed.

2.2.4 Survival conditions

The structures of the TLP and systems are checked against survival conditions in order to determine the reserve strength to overloads. The structure will be designed to survive without damage to environment, loss of life or total loss of the TLP.

As a rule, survival conditions correspond to:

- survival design environments, as defined in [2.3.4]
- extreme or reduced environments combined with hull damage, one tendon removal or loss of one tendon.

Survival conditions are generally applicable for the assessment of tension legs system. Hull structural strength checks are not mandatory, but may be required by the Society on a case-by-case basis.

2.3 Design environments

2.3.1 General

Design environments are associated to design loading conditions defined in [2.5].

Design environments are generally defined in terms of wind, wave and current loads and may take into account other relevant parameters influencing on sea level such as tidal effects and storm surge.

In the present Note, design environments are characterized by return periods.

2.3.2 Normal environments

Normal environments are expected to occur frequently during unit's life and are used for the checks of TLP in normal operating conditions.

When no limiting parameters are specified by the Designer for various operations of the TLP, the normal environments are to be associated with a typical return period of 1 year.

2.3.3 Extreme environments

Extreme environments have a low probability of being exceeded during the life of the unit. The structure is designed to withstand extreme environments in a safe operable condition.

For the purpose of the present Note, extreme environments are associated with a return period of 100 years.

2.3.4 Survival environments

Survival environments have a very low probability of being exceeded during the life of the unit.

For the purpose of the present Note, survival environments are associated with a return period of 1000 years.

2.3.5 Reduced environments

Reduced environments combined with hull damage, tendon removal or loss of tendon are used in order to define extreme conditions and survival conditions.

For the purpose of the present Note, reduced environments are associated with a return period of 10 years.

2.4 System condition

2.4.1 General

Design loading conditions defined in [2.5] take into consideration the following conditions of TLP and systems:

- intact hull and tendon legs system
- hull damage, as defined in [2.4.2].
- tendon removed, as defined in [2.4.3]
- loss of tendon, as defined in [2.4.4].

2.4.2 Hull damage

As a minimum, hull damage is to include the following flooding scenarios:

- any single compartment adjacent to the sea
- any two adjacent compartments at the waterline
- any horizontal flats located in the zone of damage extent, as defined below
- any compartment containing ballast pumps or machinery cooled by seawater.

Loading conditions taking into account hull damage are to be considered through the following cases (see Tab 2)

- hull damage with compensation by ballast adjustment, in order to maximize performance in damaged condition
- hull damage with no compensation by ballast, occurring mainly during extreme and survival conditions.

The extent of hull damage is to be taken as required in Sec 2 for damage stability calculations.

Special consideration will be given to the size of the supply vessels and other collision scenarios, before establishing the extent of hull damage.

2.4.3 Tendon removed

Tendon removed condition involves that one tendon is removed for inspection, maintenance or replacement. This condition is a planned one, and is to be considered with compensation by ballast adjustment in order to maximize performance.

2.4.4 Loss of tendon

Loss of tendon involves that one tendon is broken or disconnected accidentally. This condition is not a planned one, and is to be considered without compensation by ballast.

As stated in Tab 2, loss of tendon will be considered only within the scope of the additional feature **TLS PLUS**, as defined in Sec 1.

2.4.5 Tendon flooded

Tendon flooded condition is applied for tubular tendons, considering that the internal volume of the member is completely flooded. This condition impact on mass distribution and buoyancy of the tendon as well as on its vibration responses. Hydrostatic pressure on the tendon will take into account water in the flooded space.

Tendon flooded is not a planned condition and is to be considered without compensation by ballast.

As stated in Tab 2, tendon flooded will be considered only within the scope of the additional feature **TLS PLUS**, as defined in Sec 1.

2.5 Design loading conditions

2.5.1 Design loading conditions specified in [2.5.3] are to be considered for the assessment of hull and tendon legs system.

When some of loading conditions shown in [2.5.3] are not included in the loading manual, it must be indicated on drawings and in the loading manual that these loading conditions are not allowed. In addition, it should be demonstrated that these conditions will never happen during the life of the unit.

When loading conditions shown in [2.5.3] are foreseen in the loading manual, the analysis is to be carried out taking into account the associated draught as indicated in the loading manual.

2.5.2 In addition to [2.5.3] the Society may require to consider other conditions from the loading manual as design loading condition for structural check, when considered that these conditions are expected to be critical for structural elements of hull or tendon leg systems. The selection will be done on a case-by-case basis, taking into account design and operational specificities of the unit.

2.5.3 Design loading conditions to be considered as a minimum are given in Tab 2.

2.6 Accidental conditions

2.6.1 General

In addition to the design loading conditions defined in [2.5], the TLP is to be assessed through relevant accidental situations, on the basis of the requirements given in Pt B, Ch 2, Sec 1, [4.3] of the Offshore Rules.

Hull structure as well as tendon legs system and foundations are to be investigated.

Accidental scenarios are defined on a case-by-case basis, taking into account the specificities of TLP design, pre-service conditions and operations.

2.6.2 Accidental situations for hull and deck

The following accidental situations are generally considered for the assessment of hull and deck:

- collisions with supply vessels or other relevant collision scenarios
- dropped objects taking into account all equipment susceptible to drop on the hull or decks during pre-service conditions and operations
- relevant fire scenarios
- relevant explosion scenarios.

Guidelines for the analysis of accidental scenarios and applicable criteria are provided in Pt D, Ch 1, Sec 9 of the Offshore Rules.

The Society may require appropriate risk analysis to be submitted, in order to determine applicable loads and the probabilities of occurrence of various events considered through above accidental scenarios.

2.6.3 Accidental situations for tendon legs system

In addition to the design loading conditions defined in [2.5], the investigation of other tendon failure scenarios may be requested by the Society, taking into account the specificities of design and installation of tendon legs system. These scenarios will be selected on a case-by-case basis.

The investigation of the effect of tendon failure on surrounding structure, considering the release of elastic energy stored in the tendon, is requested except when it is proven that the probability of tendon failure is sufficiently low, at the satisfaction of the Society.

When tendon connectors with the hull and foundations are exposed to dropped objects events, the Society may require additional investigation of such events. The installation of appropriate shielding on connectors may be required.

When tendon top connector is dry, due consideration will be given to connector strength to fire and explosions which may occur on or close to the TLP.

2.6.4 Accidental situations for foundations

As a minimum, accidental situations for foundations are to include those considered for tendon legs system.

2.7 Earthquake conditions

2.7.1 For units intended to operate on sites where earthquakes are a concern, the assessment of tendon legs system and foundations in earthquake conditions is requested for the purpose of classification.

Table 2 : Design loading conditions

Category **(1)**	System condition **(1)**	Environment to be considered **(1)** **(5)**	Assessment target	Basic allowable stress factor α **(6)**
Towing	Intact	10 years return period or specified limiting parameters **(2)**	Hull	0,8
	Hull damage - no compensation	10 years return period or specified limiting parameters **(2)**	Hull	1,0
Normal operational condition	Intact	1 year return period or specified limiting parameters **(2)**	Hull and tendon legs system	0,6
Extreme conditions	Intact	100 years return period	Hull and tendon legs system	0,8
	Hull damage - no compensation	1 year return period	Hull and tendon legs system	0,8
	Hull damage - compensation	10 years return period	Hull and tendon legs system	0,8
	Intact - tendon removed **(4)**	10 years return period	Tendon legs system **(7)**	0,8
	Intact - tendon removed **(3)**	100 years return period	Tendon legs system **(7)**	0,8
Survival conditions	Intact	1000 years return period	Tendon legs system **(7)**	1,0
	Hull damage - no compensation	10 years return period	Tendon legs system **(7)**	1,0
	Hull damage - compensation	100 years return period	Tendon legs system **(7)**	1,0
	Intact - tendon removed **(4)**	100 years return period	Tendon legs system **(7)**	1,0
	Intact - loss of tendon **(3)**	100 years return period	Tendon legs system **(7)**	1,0
	Intact - tendon flooded **(3)**	100 years return period	Tendon legs system **(7)**	1,0

(1) Further information is given in [2.2] to [2.4].
(2) When limiting environmental parameters are specified by the party applying for classification for the related loading condition, they are to be used for structural checks instead of the return periods specified in the table. Such limiting environmental parameters will be stated in the Design Criteria Statement.
(3) This loading condition is required only if the additional feature **TLS PLUS**, as defined in Sec 1, is intended to be granted.
(4) This loading condition is not requested for units intended to receive the additional feature **TLS PLUS**, as defined in Sec 1.
(5) Lower return periods may be accepted by the Society upon Owner request, provided that an appropriate risk analysis justify a shorter recurrence interval.
(6) The basic allowable stress factor is defined in Pt B, Ch 3, Sec 3 [5.4.2] of the Offshore Rules. This factor is given in this table as an indication of safety level for each design loading condition. Its values are specified for each structural criteria in Sec 5, Sec 6 and Sec 7, respectively.
(7) These loading conditions may also be requested by the Society for the assessment of local hull scantlings or connections between hull parts, on a case-by-case basis.

2.7.2 Earthquake conditions are to take into account the level of vertical and horizontal earthquake accelerations and ground motions which has a reasonable probability of not being exceeded during the life of the unit, at the satisfaction of the Society.

For tendon tension responses, vertical accelerations and ground motions are determinant and horizontal accelerations may be neglected.

For foundations, both horizontal and vertical accelerations and motions are to be considered.

2.7.3 Recommendations and requirements relating to Strength Level event (SLE) and Ductility Level event (DLE) criteria given in API 2A WSD and applicable for fixed offshore platforms are adopted as minimum requirements for classification purpose.

SLE and DLE criteria are developed using a probabilistic seismic hazard assessment (PSHA) consistent with the seismic risk at the intended operation site.

3 Hydrodynamic global behavior analysis

3.1 General

3.1.1 Hydrodynamic global behavior analysis of the TLP is mandatory for the classification purpose. This analysis is to be performed on the basis of recommendations and requirements given in App 1.

Other methodologies which are consistent with the provisions of API RP 2T may be accepted by the Society provided that relevant documentation is submitted.

3.1.2 The purpose of hydrodynamic global behavior analysis is to determine relevant load parameters requested for the definition of load cases and design loads. Examples of such parameters are given below:

- maximum offset and setdown of the floater
- maximum yaw motions
- maximum and minimum tensions in tendons
- deck clearance and wave run-up
- maximum accelerations and motions under environmental conditions
- internal pressures and sea pressures relevant for investigated loading conditions
- specific hull effects such as squeeze-pry.

4 Load cases

4.1 General

4.1.1 Load cases consist in a combination of design loads and load parameters applicable for a specified loading condition.

As a rule, load cases are defined in order to maximize or minimize a loading effect relevant for the hull or tendon legs system.

4.1.2 For each design loading condition defined in [2.5], load cases are to be defined based on the requirements of the present Article [4].

4.1.3 As a rule, the definition of load cases covering operations on the intended site, is based on the steps defined in Tab 3.

4.1.4 Load cases for towing conditions are to be defined based on the provisions of [4.5] and [4.6].

Table 3 : Definition of load cases

Step	Description
1	Analysis of initial mean position in stillwater (see [4.2])
2	Analysis in zero offset position (see [4.3])
3	Mean response analysis for determining mean offset and setdown (see [4.4.2])
4	Calculation of maximum offset (see [4.4])
5	Wave response analysis for determining structural responses, with maximization of one loading effect (see [4.5])

4.1.5 Load cases checked for classification purpose will be selected on a case-by-case basis, taking into account the specificities of unit's design and operations. The selection of load cases is subjected to the approval of the Society.

4.2 Initial mean position in stillwater

4.2.1 The purpose of analysis of initial mean position in stillwater is to determine relevant water draughts for load cases definition. The analysis is to take into account vertical fixed and operational loads that are relevant for the investigated loading condition. Equilibrium is to be achieved taking into account pre-tension in tendons and risers (when relevant).

When various riser configuration are expected during the life of the unit, at least minimum and maximum riser configurations are to be taken into account.

4.2.2 The analysis of initial mean position in stillwater is to take into account all relevant initial water draughts that may occur within the investigated loading condition, according to the Loading Manual. Effects of tidal and surge effects on the water draughts are to be taken into account.

Through the combination of initial draughts and tidal effects, separate cases will be defined in order to maximize and minimize the tensions in tendons.

4.3 Zero offset position

4.3.1 Load cases are to be defined for the analysis of zero offset position, for water draughts defined as per [4.2].

4.3.2 In general, load cases defined for zero offset position are to take into account only the environmental loads due to wave.

4.4 Maximum offset/setdown

4.4.1 General

Guidelines for the calculation of maximum offset/setdown of the floater are given in Appendix 1. Relevant recommendations of API RP 2T are also to be considered.

The calculation of the maximum offset is to take into account the following items:

- mean offset of TLP
- low frequency response
- wave response.

4.4.2 Mean response analysis

Generally, a mean response analysis is to be performed in order to determine the mean offset and corresponding setdown of the floater.

Mean response analysis is to consider the lateral one minute mean wind, mean wave drift and current load.

4.4.3 Load cases

Specific load cases maximizing tendon tension and its effects on hull structure are to be defined in relation with maximum offset of TLP.

4.5 Wave response analysis

4.5.1 Individual load cases are to be defined for the maximization of each relevant loading effect of hull and tendon legs system.

Loading effects which are to be considered as a minimum for classification are given in [4.6] and [4.7].

4.5.2 The maximization of various loading effects for hull and tendon legs system, taking into account the simultaneity of the responses, is realized through a wave response analysis.

App 1 provide guidelines for such analysis based on equivalent design wave approach. Other spectral approaches may be accepted by the Society.

4.6 Load cases for hull assessment

4.6.1 Hull assessment is performed on a limited number of load cases. Envelope load cases, maximizing load effects for various hull parts will be selected based on the results of hydrodynamic global behavior analysis.

The selection of load cases for hull assessment is subjected to the approval of the Society.

4.6.2 As a minimum, load cases for hull assessment are to be defined for the maximization of the following loading effects:

- squeeze-pry effect between TLP's columns, when relevant
- torsional moments about horizontal axes
- longitudinal shear forces between the pontoons
- longitudinal acceleration of deck mass
- transverse acceleration of deck mass
- vertical acceleration of deck mass
- vertical wave bending moments of the pontoons.

Additional guidelines for the definition of associated equivalent design waves are given in API RP 2T [8].

4.7 Load cases for tendon legs system

4.7.1 Load cases considered as a minimum for the check of tension legs system are to be defined for the following loading effects:

- maximum tension in tendons
- minimum tension in tendons
- maximum flex element angle in top and bottom connectors
- maximum loading of specific components (joints, connectors parts), defined on a case-by-case basis.

5 Design loads

5.1 General

5.1.1 Design loads are, in general, defined in Pt B, Ch 2 of the Offshore Rules. Specific requirements and guidelines relating to design loads relevant for TLP design are given in the present Note.

5.1.2 Reference is also made to the recommendations of API RP 2T relating to the evaluation of design loads.

5.1.3 The following categories of loads are considered, with reference to Pt B, Ch 2 of the Offshore Rules:

- fixed loads
- operational loads
- environmental loads
- accidental loads
- earthquakes
- testing loads
- temporary construction loads.

5.1.4 Appropriate factors are to be applied for preliminary design stages, in order to take into account the uncertainties in estimation of fixed loads and operational loads and their locations.

5.2 Fixed loads

5.2.1 Fixed load or lightweight is the weight of the complete unit with all permanently attached machineries, equipment and other items of outfit.

The light weight of the unit includes the weights, to their normal working level, of all permanent ballast and other liquids such as lubricating oil and water in the boilers, but excludes the weight of liquids or other fluids contained in supply, reserve or storage tanks.

5.2.2 Fixed loads are to comply with the applicable requirements of Pt B, Ch 2, Sec 3, [2] of the Offshore Rules.

5.3 Operational loads

5.3.1 Operational loads are loads associated with the operation of the unit and include:

- the weights of all moving equipment and machinery
- the weight of drill string and related pieces of equipment
- variable loads of consumable supplies weights
- storage of cuttings from drilling, when relevant
- seawage, dirty oil and water tanks
- other storage loads
- hydrostatic loads (buoyancy)
- liquids in tanks
- ballast loads
- riser tensioner forces, when relevant
- pre-tension of tendons
- loads resulting from lifting appliances in operation
- forces induced by production plant, when relevant.

Dynamic loads induced by equipment in operation are to be considered as operational loads.

5.3.2 Operational loads are to comply with the applicable requirements of Pt B, Ch 2, Sec 3, [2] of the Offshore Rules.

5.4 Environmental loads

5.4.1 General

Environmental loads are loads resulting from the action of the environment and include loads resulting from:

- wind
- waves
- current
- ice and snow accumulation, where relevant
- ice loads due to iceflow or icebergs, when relevant
- tidal and storm surge effects
- marine growth
- scouring and other seabed instabilities.

5.4.2 Environmental data

Environmental data for the intended sites of operation are to be specified for the purpose of design load definition.

The environmental data are to comply with the requirements of Pt B, Ch 2, Sec 2 of the Offshore Rules.

5.4.3 Wind loads

Wind pressures and forces acting on structural elements are to be calculated based on sustained and gust wind velocities. The following methods are referenced:

- Pt B, Ch 1, Sec 2, [4.2] of the Offshore Rules
- recommendations and requirements of API RP 2T
- additional recommendations and requirements given in App 1.

5.4.4 Wave loads

Wave loads are to be defined in accordance with the requirements of Pt B, Ch 2, Sec 3, [3.3] of the Offshore Rules.

Design waves used for wave loads definition are to be described by wave energy spectra or deterministic waves having appropriate shape and size. Consideration is to be given to waves of lesser height, where, due to their period, the effect on structural elements may be greater.

Appropriate hydrodynamic analysis and model tests are mandatory for the assessment of wave loads. Additional recommendations and requirements are given in App 1.

5.4.5 Current loads

Current loads are to be calculated in compliance with the requirements given in Pt B, Ch 2, Sec 2, [4] of the Offshore Rules and Pt B, Ch 2, Sec 3, [3.4] of the Offshore Rules. Additional recommendations and requirements are given in App 1.

5.4.6 Specific wave and current effects for TLP

The following wave and current effect are to be considered for the purpose of the classification, with reference to the recommendations of App 1 and relevant recommendations of API RP 2T:

- vortex induced vibrations (VIV) and vortex induced motions (VIM) on tendons and slender members
- slamming and shock pressure
- wave diffraction and radiation
- mean drift forces
- higher order non-linear wave loads, including ringing and springing effects.

5.4.7 Inertial loads

Maximum accelerations applied on structure and equipment are to be obtained from the hydrodynamic global behavior analysis (see [3]).

Inertial internal pressures in liquid compartments may be calculated using the method given in Pt D, Ch 1, Sec 5 of the Offshore Rules, using accelerations as defined in the present Section.

Depending on the shape and dimensions of tanks, the Society may require to assess sloshing motions and pressures based on appropriate calculations.

5.4.8 Sea pressures

Sea pressure applied on hull are to be calculated taking into account relevant draughts. Generally, sea pressures are obtained from hydrodynamic analysis (see App 1).

Simplified methods including hypothesis on pressure distribution may be accepted by the Society provided that relevant documentation justifying these methods is submitted.

5.4.9 Ice and snow

The requirements of Pt B, Ch 2, Sec 3, [3.7] of the Offshore Rules are to be complied with.

5.4.10 Scouring

Scour is the removal of seabed soils due to currents and waves. The scour may induce an overstress of foundation elements due to the removal of its vertical and lateral support.

For sites where the scour is a concern, scouring effects are to be taken into account by the Designer. Appropriate documentation is to be submitted to the Society.

5.5 Accidental loads

5.5.1 Accidental loads are defined taking into account the definition of relevant accidental condition. The requirements of [2.6] are to be taken into account.

5.6 Earthquakes loads

5.6.1 Earthquake loads are defined in terms of vertical and horizontal accelerations and motions. They are to be taken into account for the assessment of tendon legs systems and foundations, under relevant earthquake conditions defined in [2.7].

5.7 Testing loads

5.7.1 Testing loads are loads sustained by the structure during testing phases of tanks or equipment.

5.8 Temporary construction loads

5.8.1 In accordance with the provisions of Pt A, Ch 1 of the Offshore Rules, temporary construction loads not resulting from the tests required to be performed by the applicable Rules requirements are not subject to review by the Society unless a specific request is made. The attention of the Builder is however called upon the provisions of Pt B, Ch 3 of the Offshore Rules concerning construction procedures liable to affect, for instance by prestressing, the strength of the unit.

5.9 Design loads combination

5.9.1 The design loads are to be realistically combined to produce the maximum effect upon each component of the structure of the unit.

5.9.2 When a load combination liable to occur within the set of design specifications or at the specified site of operation is not considered for the design of the unit, adequate instructions are to be stated in the Operating Manual and/or appropriate procedures provided to prevent such combination from occurring.

The present requirement particularly relates to the distribution of operational loads.

5.9.3 For the purpose of load combinations, the environmental elements (wind, wave and current) are to be assumed to act simultaneously in the same direction, unless combinations of environmental elements with different directions might be more severe and liable to occur.

The most unfavourable direction, or combination of directions, for each component of the structure is to be considered.

5.9.4 For each direction, the environmental elements (wind, waves and current) are to be combined with their design values or associated design values.

For wave loads, the most unfavourable combination of wave height, wave period and water level when relevant, is to be retained.

For wind loads, the one minute sustained velocity is to be used in combination with other environmental elements for the design of the primary structure of the unit.

5.9.5 Where spectral design procedures are used, wave height and period relate to the significant height and reference period of sea state, and direction relates to the direction of highest energy density.

Then design loads and stresses are to be taken as the maximum values over a 3 h period.

5.9.6 When this is possible, the extreme environmental loads and stresses may be evaluated through long term statistics, using suitable techniques, to the satisfaction of the Society.

SECTION 5 HULL SCANTLINGS

1 General

1.1 Principle

1.1.1 Application

The hull scantling is to comply with the requirement of the present Section. The following Industry standards may be considered applicable on a case by case basis:

- API 2A WSD: Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms - Working Stress Design - latest edition
- API 2U: Bulletin on Stability Design of Cylindrical Shells - latest edition
- API 2V: Design of Flat Plate Structures - latest edition
- AISC 360-05: Specifications for Structural Steel buildings - latest edition.

1.1.2 In case of conflict between the Offshore Rules and the present Note, this latter is to take precedence.

1.1.3 Net thickness

All thickness are net, i.e. they do not include any corrosion addition. The applicable corrosion additions are those specified in Sec 3.

2 Basic allowable stress factor

2.1 General

2.1.1 For structural strength calculation of hull elements, the basic allowable stress factor, as defined in the Offshore Rules, Pt B, Ch 3, Sec 3, [5.4], is to be taken as defined in Sec 4, Tab 2.

Hull elements constituting watertight boundaries are also checked under testing conditions. For testing conditions, the basic allowable stress factor is to be taken 0,9.

A summary of basic allowable stress factor values is given in Tab 1.

Table 1 : Summary for basic allowable stress factor

Design loading condition	Basic allowable stress factor α
Towing intact	0,8
Towing damage	1,0
Normal operational conditions	0,6
Extreme conditions	0,8
Survival conditions	1,0
Testing conditions	0,9
Note 1: The basic allowable strength for normal operational conditions is increased by one-third and two-third for respectively extreme and survival conditions. The same principle is to be applied when strength assessment is requested to be checked according to industry standards mentioned in [1.1.1].	

3 Global Finite Element Model

3.1 Structural modelling

3.1.1 General

The unit is to be modelled through a full unit finite element model.

The structural model is to represent the primary supporting members with the plating to which they are connected.

Ordinary stiffeners are also to be taken into account in the model in order to reproduce the stiffness and the inertia of the actual hull girder structure.

3.1.2 The structural analysis on fine mesh models is to be carried out by applying one of the following procedures:

- an analysis of the whole three dimensional model based on a coarse mesh model, as defined in [3.4.2], from which the nodal displacement and forces are used as boundary conditions for analyses based on fine mesh sub-models. The minimum extent of fine mesh submodels is to comply with the relevant requirements of [3.4.3]
- an analysis of the whole three dimensional model based on a fine mesh model, as defined in [3.4.3].

3.1.3 When the three dimensional model is based on coarse mesh models, the following areas are to be investigated based on fine mesh models, as defined in [3.4.3]:

- typical pontoon structure
- column structure
- deck structure
- connection of pontoon with column
- connection of column with deck
- Tendon supporting structure
- typical topsides stools or supports
- risers supporting structure ends, when relevant.

Other areas may be required to be analyzed through fine mesh models, when deemed necessary by the Society, depending on unit's structural arrangement and loading conditions, as well as on the results of the coarse mesh analysis.

3.2 Model construction

3.2.1 Net scantlings

All structural elements are to be modelled with their net scantlings obtained by deducing half of the corrosion addition specified in Sec 3.

3.2.2 Elements

Finite elements used in the structural model are to comply with the requirements given in [3.4], for the relevant type of finite element model.

3.3 Model extension

3.3.1 General

The complete structure of the unit is to be modelled to properly take into account the following effects in the structural analysis:

- effect of the global loads
- effects of sea pressures and pressures in internal capacities
- global and local deformations of structural items
- effects of local loads.

3.3.2 Hull structure

Finite element model of unit's hull is to include the following primary supporting members forming the pontoons, columns and deck structure:

- outer shell, longitudinal and transverse bulkhead plating
- horizontal stringers
- web frames.

3.3.3 Topside supports

Topsides supporting structure is to be modelled in order to input mass and/or forces coming from topsides equipment.

3.3.4 Mass of topsides

The mass of topside equipment is to be taken into account in the model, at the satisfaction of the Society, in order to reproduce the correct lightweight distribution and inertial loads on topside supports.

3.3.5 Deckhouses and superstructures

Deckhouses and main superstructures connected to the main deck are to be included in the structural model. Their modelling is to correctly represent their weights and local effects on hull girder stiffness and deck behavior.

3.3.6 Tendon supporting structure

The tendon supporting structure is to be modelled, in order to evaluate the interaction with the hull and the tendon.

3.4 Finite element models

3.4.1 General

Finite element models are generally to be based on linear assumptions. The mesh is to be executed using membrane or shell elements, with or without mid-side nodes.

Meshing is to be carried out following uniformity criteria among the different elements.

In general, the quadrilateral elements are to be such that the ratio between the longer side length and the shorter side length doe not exceed 4 and, in any case, is less than 2 for most elements. Their angles are to be greater than 60° and less than 120°. The triangular element angles are to be greater than 30° and less than 120°.

3.4.2 Coarse mesh

The number of nodes and elements is to be such that the stiffness and the inertia of the model represent properly those of the actual hull structure, and the distribution of loads among the various load carrying members is correctly taken into account.

To this end, the structural model is to be built on the basis of the following criteria:

- ordinary stiffeners contributing to the global strength and which are not individually represented in the model are to be modelled by rod elements and grouped at regular intervals
- webs of primary supporting members may be modelled with only one element on their height
- face plates may be modelled with bars having the same cross-section
- the plating between two primary supporting members may be modelled with one element stripe
- holes for the passage of ordinary stiffeners or small pipes may be disregarded
- Manholes (and similar discontinuities) in the webs of primary supporting members may be disregarded, but the element thickness is to be reduced in proportion to the hole height and the web height ratio.

In some specific cases, some of the above simplifications may not be deemed acceptable by the Society in relation to the type of structural model and the analysis performed.

3.4.3 Fine Mesh

The unit's structure may be considered as finely meshed when each longitudinal secondary stiffener is modelled; as a consequence, the standard size of the finite elements used is based on the spacing of ordinary stiffeners.

The structural model is to be built on the basis of the following criteria:

- webs of primary members are to be modelled with at least three elements on their height
- the plating between two primary supporting members is to be modelled with at least two element stripes
- the ratio between the longer side and the shorter side of the elements is to be less than 3 in the areas expected to be highly stressed
- holes for the passage of ordinary stiffeners may be disregarded.

When fine mesh analysis is performed through sub-models, as stated in [3.1.2], the minimum extent of the sub-model is to be such that its boundaries correspond to locations where the deformations of the global model are accurately calculated, at the satisfaction of the Society. In general, it corresponds either to the adjacent or to the second adjacent primary supporting member.

3.5 Boundary conditions of the model

3.5.1 Boundary conditions are to be applied in order to prevent rigid body motions of the overall model, at the satisfaction of the Society. In general, boundary conditions are to respect the following requirements:

- constraints are to be applied on at least three nodes
- transverse and vertical translations are to be fixed at two nodes, and longitudinal translation at the remaining node
- all nodal rotations are to be kept free.

3.6 Load model

3.6.1 Loading condition

The loading conditions for which the structural analysis is carried out are to comply with the requirements of Sec 4.

Following the specificities of the design and/or operation of the considered unit, the Society may require the investigation of additional loading conditions considered relevant for structural check. In such a case, the additional loading conditions are to be stated in the Design Criteria Statement.

3.6.2 Loads and load combination

Loads are to be assessed and combined according the Sec 4.

3.6.3 Loading procedure

Applicable loading conditions are to be analyzed through:

- the computation of the characteristics of the finite element model under still water
- the selection of the load cases critical for the strength of the structural members. Each critical load case maximizes the value of one of the load effects specified in Sec 4 and having a dominant influence on the strength of some parts of the structure.

When equivalent design wave approach is adopted, the determination of the design wave characteristics for each load case is to be based on relevant requirements and recommendations stipulated in App 1.

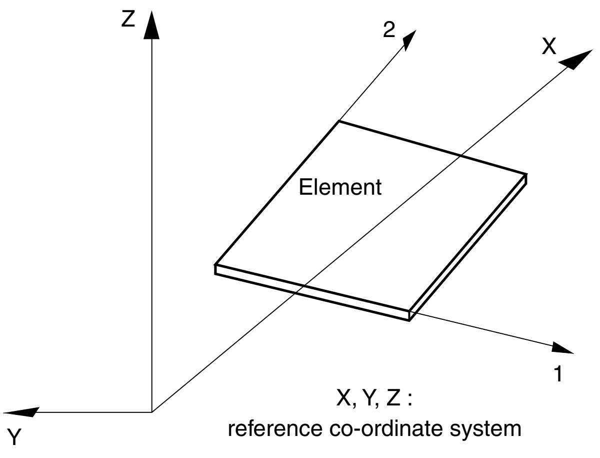
3.6.4 For each loading condition, the convergence of the displacement, trim and vertical bending moment is deemed satisfactory within the following tolerances:

- 2% of the displacement
- 0,1 degree of the trim angle.

3.7 Stress calculation

3.7.1 Stress components are generally identified with respect to the element co-ordinate system, as shown, by way of example, in Fig 1.

Figure 1 : Reference and element co-ordinate systems



3.7.2 The following stress components are to be calculated at the centroid of each element from global finite element model:

- the normal stresses σ_1 and σ_2 in the directions of element co-ordinate system axes
- the shear stress τ_{12} with respect to the element co-ordinate system axes
- the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2 + 3\tau_{12}^2}$$

3.7.3 Stress for elementary plate panel

Where an elementary plate panel is meshed by several finite plate elements, the stresses of the elementary plate panel are obtained by the following methodology:

- For each finite element, the element stresses expressed in the element co-ordinate system are projected in the co-ordinate system of the panel.
- The elementary plate panel stresses are calculated as weighted average of projected element stresses, with weighting by element areas.

3.7.4 Stress for ordinary stiffener

The global stress σ_x to be considered for the yielding and buckling check of stiffeners is to be obtained from the maximum stress between adjacent elementary plate, as defined in [3.7.3] along the direction of the considered stiffeners.

4 Local pressure assessment

4.1 General

4.1.1 The local pressure, including static and dynamic pressure if any, for the strength assessment of plating and ordinary stiffeners is to be evaluated according to [4.2] and [4.3].

In addition, the requirements of Sec 3, [7.2.2] are to be taken into account.

4.1.2 Load point

Lateral pressure is to be calculated at the lower edge of the elementary plate panel and at midspan of the ordinary stiffener considered.

4.2 Design loading conditions

4.2.1 The pressure considered for design loading conditions specified in Sec 4 is to be evaluated from the Global Finite Element model at the location defined in [4.1.2] for the considered elementary plate panel or ordinary stiffener.

4.3 Testing conditions

4.3.1 Testing pressure for tanks intended to be water tested is to be evaluated according to Offshore Rules Pt B, Ch 3, Sec 7.

5 Plating

5.1 Net scantlings

5.1.1 The net thickness is to be obtained by deducing the corrosion addition specified in Sec 4 from the gross scantling.

5.2 Yielding strength

5.2.1 The net thickness of laterally loaded plate panels subjected to in-plane normal stress acting on the shorter sides is to be not less than the value obtained, in mm, from the following formula:

$$t = 14,9 c_a c_r s \sqrt{\frac{P}{\lambda_L R_Y \alpha}}$$

where:

c_a : Aspect ratio of the plate panel:

$$c_a = 1,21\sqrt{1 + 0,33\left(\frac{s}{\ell}\right)^2} - 0,69\frac{s}{\ell}$$

c_r : Coefficient of curvature of the panel:

$c_r = 1 - 0,5\ s / r$

r : Radius curvature, in mm

λ_L : Parameter equal:

- Design loading conditions:

$$\lambda_L = \sqrt{1 - 0,95\left(\frac{\sigma_x}{R_y}\right)^2} - 0,225\frac{\sigma_x}{R_y}$$

- Testing conditions

$\lambda_L = 1$

P : Pressure applying on the elementary plate panel, kN/m², as defined in [4]

s : Spacing of the elementary plate panel, in m

ℓ : Span of the elementary plate panel, in m

R_y : Minimum yield stress, in N/mm², of the material, to be taken equal to 235/k

σ_x : Stress along the short edge of the panel, in N/mm², as specified in [3.7.3]

α : Basic allowable stress factor is to be taken according to [2.1.1].

6 Ordinary stiffeners

6.1 Net scantlings

6.1.1 The net thickness is to be obtained by deducing the corrosion addition specified in Sec 4 from the gross scantling. The net shear areas and section modulus are obtained from the net thickness of the considered ordinary stiffeners.

6.2 Single span ordinary stiffeners subjected to lateral pressure and global stresses

6.2.1 The net section modulus w, in cm³, and the net shear sectional area A_{Sh} , in cm², of ordinary stiffeners subjected to lateral pressure and global stresses are to be not less than the values obtained from the following formulae:

$$w = \frac{P}{12 \cdot 1,1 \cdot \alpha(R_y - \sigma_x)} s l^2$$

$$A_{Sh} = 10\frac{P}{1,1\alpha R}\left(1 - \frac{s}{2l}\right) s l$$

where:

P : Pressure applying on the ordinary stiffener, in kN/m², as defined in [4]

s : Spacing of stiffeners, in m

l : Stiffener span, in m

R_y : Minimum yield stress, in N/mm², of the material, to be taken equal to 235/k

σ_x : Stress of ordinary stiffener, in N/mm², as specified in [3.7.4]

α : Basic allowable stress factor to be taken according to [2.1.1].

6.3 Single span ordinary stiffeners in testing conditions or subjected to lateral pressure only

6.3.1 The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of longitudinal or transverse ordinary stiffeners subjected to lateral pressure are to be not less than the values obtained from the following formulae:

$$w = \frac{P}{12 \cdot 1,1 \cdot \alpha R_y} s l^2$$

$$A_{Sh} = 10\frac{P}{1,1\alpha R}\left(1 - \frac{s}{2l}\right) s l$$

where:

P : Testing pressure applying on the ordinary stiffener, in kN/m², as defined in [4]

s : Spacing of stiffeners, in m

l : Stiffener span, in m

R_y : Minimum yield stress, in N/mm², of the material, to be taken equal to 235/k

σ_x : Stress of ordinary stiffener, in N/mm², as specified in [3.7.4]

α : Basic allowable stress factor to be taken according to [2.1.1].

6.4 Multi span ordinary stiffeners

6.4.1 The maximum normal stress σ and shear stress τ in a multispan ordinary stiffener are to be determined by a direct calculation taking into account:

- the distribution of still water and wave pressure and forces, to be determined on the basis of the global finite element model as stipulated in [4]
- The global stress as defined in [3.7.4]
- the number and position of intermediate supports (decks, girders, etc.)
- the condition of fixity at the ends of the stiffener and at intermediate supports
- the geometrical characteristics of the stiffener on the intermediate spans.

6.4.2 Checking criteria

It is to be checked that the normal stress σ and the shear stress τ calculated according to [6.4.1], are in compliance with the following formulae:

$\sigma \leq 1,1\ \alpha R_y$

$\tau \leq 1,1\alpha R_y / 2$

where:

R_y : Minimum yield stress, in N/mm², of the material, to be taken equal to 235/k

α : Basic allowable stress factor to be taken according to [2.1.1].

6.5 Buckling check

6.5.1 The buckling check of ordinary stiffener is to be performed in accordance with Pt B, Ch 7, Sec 2, [4] of the Ship Rules taking into account the requirements of [6.5.2]. The critical buckling stress σ_c is to be obtained from the formulae given in Pt B, Ch 7, Sec 2, [4.3] of Ship Rules.

6.5.2 The critical buckling stress of the ordinary stiffener is to comply with the following formula:

$|\sigma_b| \leq \alpha\sigma_c$

where:

σ_c : Critical buckling stress, in N/mm², as calculated in [6.5.1]

σ_b : Global compression stress σx, in N/mm², in the stiffener, as calculated in [3.7.4].

7 Primary supporting members

7.1 Yielding strength

7.1.1 Yielding criteria for coarse and fine mesh analysis

For coarse mesh analysis and fine mesh analysis, it is to be checked that the equivalent stress σ_{VM} , in N/mm², calculated according to the present section is in compliance with the criteria defined in Offshore Rules Pt B, Ch 3, Sec 3.

The basic allowable stress factor is to be taken according to [2.1.1].

7.1.2 Yielding criteria for face plates of primary supporting members and openings

For fine mesh analysis, face plates of primary supporting members and openings may be modelled by shell elements or by beam/bar elements.

When shell elements are used, the requirements of [7.1.1] are to be complied with.

When beam/bar elements are used, it is to be checked that the beam/bar element's axial stress σ_{ax}, in N/mm², is in compliance with the criteria defined in Pt B, Ch 3, Sec 3 of the Offshore Rules.

The basic allowable stress factor is to be taken according to [2.1.1].

7.2 Buckling check

7.2.1 The buckling check of plating is to be performed in accordance with Pt B, Ch 7, Sec 1, [5] of the Ship Rules taking into account the requirements of [7.2.2] and the checking criteria defined in [7.2.5]. The critical buckling stress is to be obtained from the formulae given in Pt B, Ch 7, Sec 1, [5.3] of the Ship Rules.

7.2.2 The compression stresses to be taken into account for the checking criteria given in [7.2.5] are given as follows:

a) Compression and bending:

The compression stress σ_b, in N/mm², acting on side "b" of the plate panel, is to be calculated as specified in [7.2.3]

b) Shear:

The shear stress, in N/mm², acting on the plate panel is to be calculated as specified in [7.2.4]

c) Compression, bending and shear:

The compression stresses $\sigma 1$ and $\sigma 2$, in N/mm², are to be calculated as specified in [7.2.3]

The shear stress τ, in N/mm2, is to be calculated as specified in [7.2.4]

d) Bi-axial compression, taking account of shear stress:

The compression stresses σ_1 and σ_2 , in N/mm², are to be calculated as specified in [7.2.3]

The shear stress τ, in N/mm², is to be calculated as specified in [7.2.4].

7.2.3 Combined in-plane global and local compression normal stresses

The combined in-plane compression normal stresses to be considered for the buckling check of plating are to take into account global stresses and the local stresses resulting from the bending of the primary supporting members. These local stresses are to be obtained from a direct structural analysis as specified in [3.7.3].

7.2.4 Combined in-plane global and local shear stresses.

The combined in-plane shear stresses to be considered for the buckling check of plating are to take into account the global stresses and the local stresses resulting from the bending of the primary supporting members. These local stresses are to be obtained from a direct structural analysis as specified in [3.7.3].

7.2.5 Checking criteria: Acceptance of results

Criteria defined in Pt B, Ch 7, Sec 1, [5.4] of the Ship Rules are to be complied with. When applying these criteria, partial safety factors defined in the Ship Rules are to be disregarded and the basic allowable stress factor α, as defined in [2.1.1] is to be applied on critical stress.

8 Fatigue check of structural details

8.1 General

8.1.1 Fatigue analysis is to be performed to ensure adequate strength against fatigue failure during TLP design life, as defined in [8.3].

8.1.2 For units intended to receive the additional class notation **Spectral Fatigue**, reference is made to the relevant requirements of NI 539 Spectral Fatigue Analysis Methodology for Ships and Offshore Units.

8.1.3 Fatigue evaluations are to be carried out according to recognized methods to the satisfaction of the Society, such as:

- general methodology given in Pt B, Ch 3 of the Offshore Rules, that the requirements are undertaken by the present Section
- relevant recommendations of API RP 2T applicable for fatigue assessment of hull
- relevant recommendations given in App 1.

Other methods may be accepted by the Society on a case-by-case basis.

8.1.4 Structural elements for which fatigue is a probable mode of failure are to be adequately designed to resist the effects of cumulative damage caused by repeated application of fluctuating stresses.

The predominant cause of fluctuating stresses leading to crack propagation and fatigue failure is normally wave loading. However, other sources of cyclic loads such as wind, rotating machinery or cranes may also induce significant fatigue loadings and are to be given due consideration where relevant.

8.2 Load cases for fatigue evaluation

8.2.1 For fatigue evaluation a sufficient number of load cases is to be considered to correctly model loads acting on the unit during its whole life, giving due consideration to:

- the various design conditions of operation of the unit
- the direction and the intensity of environmental actions, as resulting from the long term distributions of relevant environmental parameters with possible limitations corresponding to each of these conditions.

The effect of springing and ringing resonant responses and VIV effects, when relevant, are to be considered for fatigue analysis.

8.3 Fatigue life

8.3.1 The design of primary structural elements is to take into account the service life of the unit and for all of its conditions of operation. The design life of the structure is to be specified by the party applying for classification. It is normally to be taken not less than 20 years.

The design service life of the structure is to be indicated in the Design Criteria Statement.

8.3.2 A further increase in the design fatigue life is to be considered for elements in uninspectable areas or areas where repair within the expected life time is not possible or practical.

8.4 Structural details for fatigue analysis

8.4.1 General

Structural details for fatigue analysis will be selected on a case-by-case basis, at the satisfaction of the Society. Typically, the following items are included:

- intersection of stiffeners with bulkheads and primary supporting members
- end brackets
- flanges of primary members in way of brackets
- typical details of pontoon-to-column intersections
- typical details of decks-to-column intersections
- connections of bracings, when relevant
- tubular joints
- tendon porches
- topside connections with decks
- details at corner of moonpool arrangements, when relevant
- riser supporting structure
- foundation of riser tensioning systems, when relevant
- crane pedestals.

8.5 Design

8.5.1 The design of structural details is to comply with relevant requirements of API RP 2T [8.6]. Theses requirements include:

- tubular joints
- pontoon-to-column and deck-to-column joints
- transition joints and stiffened plate intersections.

The design of beam brackets and intersection of local stiffeners with primary supporting members are to be based on the principles of Ship Rules.

8.5.2 Design of tendon porches is to be based on the requirements and recommendations of API RP 2T, taking into account the Appendix B of the above referenced document.

8.5.3 The level of fluctuating stress is to be adequately limited.

A suitable fatigue life is best achieved by adequate joint detail design and fabrication quality control. Joint detail design is to avoid, as possible, joint eccentricities introducing secondary stresses and local restraints, abrupt section changes, re-entrant corners, notches and other stress raisers.

In fatigue sensitive areas, improved joint performance is to be achieved through, as necessary, a combination of reduction in nominal stresses, obtained by increased thicknesses, improved detailing, providing smooth transitions and suitable shape of weld joints.

8.5.4 Fatigue strength is also affected by fabrication induced (residual) stresses and by stress raisers caused by inherent weld defects, particularly surface defects.

This is normally accounted for by joint classifications, provided however that standard quality control procedures are adequately implemented.

8.5.5 Where it is not possible to improve fatigue life by another method, the Society will examine, in each separate case, weld profile improvement techniques such as grinding, shot blasting, TIG dressing and other post-welding treatments.

Where a joint performance depends upon particular fabrication and quality control requirements, adequate procedures are to be drawn up providing the necessary specifications concerning workmanship and inspection.

8.5.6 Due attention is to be given to attachment of fittings onto primary structural members. Unavoidable cut-outs or openings are to be, as far as possible, located outside high stress areas and superposition of notches is to be avoided.

8.6 Fatigue analysis

8.6.1 The long term distribution of fluctuating stresses is to be obtained from an overall structural analysis, for the relevant load cases, in accordance with [8.2].

Spectral analysis is generally to be used. Time domain analysis is to be preferred when both non linearities and dynamic effects are significant. Deterministic analysis may be used when appropriate.

8.6.2 Geometrical stress concentrations result from openings, transitions in properties or geometry of members, end connections and other discontinuities. When not modelled in the overall analysis, such geometrical stress concentrations may be accounted for by appropriate Stress Concentration Factors (SCF).

Proposed SCF's are to be duly documented to the satisfaction of the Society. SCF's may be obtained from analytical solutions, in some cases, or from adequately calibrated parametric equations or by direct stress analysis. The Society reserves the right to call for such analysis if found necessary.

8.6.3 Local effects, resulting from residual stresses and from weld surface defects, are to be accounted for through joint classification.

8.6.4 The cumulative fatigue damage at each spot is to be calculated using the Palgren-Miner Rule and an appropriate S-N curve, taking into account joint classification, thickness effect and the degree of corrosion protection.

8.6.5 Fracture mechanics methods may also be used for fatigue analysis subject to adequate consideration of the stress history, of the joint geometric configuration and of the following, to the satisfaction of the Society:

- selection of initial crack geometry and size
- crack propagation rate, taking into account corrosion factors
- toughness parameters governing final crack instability for which a verification by appropriate fracture mechanics testing may be required.

8.7 Checking criteria

8.7.1 For the spectral fatigue analysis, the fatigue damage ratio is to be not greater than those given in Tab 2.

Table 2 : Damage ratio for spectral fatigue analysis

Consequence of failure	Degree of accessibility for inspection, maintenance and repair		
	Not accessible **(2)**	Underwater inspection **(3)**	Dry inspection
Critical **(1)**	0,1	0.25	0,5
Non-critical	0,2	0,5	1,0

(1) Critical damage as per risk analysis including loss of life, uncontrolled pollution, collision, other major damage to the installations and major production losses. When risk analysis report categorizing structural elements as critical or non-critical is not available, all structural elements are to considered as critical.
(2) Includes areas that can be inspected in dry or underwater conditions but require heavy works for repair.
(3) Includes areas that can be inspected in dry conditions but with extensive preparation and heavy impact on operation.

SECTION 6 TENDON LEGS SYSTEM (TLS)

1 General

1.1 Application

1.1.1 The present Section provides requirements for the classification of tendon legs system (TLS), within the scope of additional features **TLS** and **TLS PLUS**. Specific requirements for the assessment of foundations are given in Sec 7.

1.1.2 The requirements of the present Section are consistent with the recommendations of API RP 2T. The Society may refer to this standard when deemed necessary, in order to define minimum criteria for classification purpose.

Interpretations of API RP 2T and additional requirements are given in the present Note.

1.1.3 The requirements of the present Section are directly applicable for tendons made of steel tubular members. Other forms of tendon such as solid rod, bars, wire ropes and tendons made of other materials will be given special consideration.

1.2 Scope of additional features TLS and TLS PLUS

1.2.1 Additional features **TLS** and **TLS PLUS**, include in general the following items within the scope of classification:

- top connector and elements ensuring the interface between the tendon and the TLP, including flex elements
- tendon member, including intermediate connections, when relevant
- bottom connector and elements ensuring the interface between the tendon and the foundation, including flex elements
- foundations, including templates, piles or other relevant elements ensuring the transfer of tendon loads to soil.

Other components such as buoyancy devices, instrumentation for monitoring the performance and condition of tendons, intermediate connectors with watertight bulkheads, etc., may be included within the scope of classification when relevant.

Exact limits of classification will be defined for each project on a case-by-case basis. The Society is to be consulted for establishing these limits.

1.3 Definitions

1.3.1 Definition of tendon legs system is given in Sec 1, [2.2.3].

1.3.2 Tendon leg

A tendon leg is a collective group of tendons acting at the same corner or column of the TLP.

1.3.3 Tendon

Tendon is a system of components which form a link between the TLP and the subsea foundation. Tendons may be designed on various types, as stated in Sec 1, [2.2.3].

Usually, tendons present intermediate connections along the length such as mechanical coupling (bolted flanges, clamps, ...) or welded joints.

1.3.4 Top and bottom connectors

Top connectors are devices used to connect tendons to TLP hull. Bottom connectors are devices used to latch and unlatch tendons to the foundation system.

1.3.5 Flex element

Flex element is a device permitting relative angular movement of the tendon via deformation of an elastomeric/steel laminated element in order to reduce bending stresses due to TLP motion under environmental conditions. Flex element is provided at both top and bottom connectors.

1.3.6 Elastomer

Elastomer is a class of material including natural and synthetic rubbers, which return to their initial shape after large deformation.

2 TLS design principles

2.1 General

2.1.1 Parts of TLS which are essential for strength are to be designed, as far as practicable, to be capable of being inspected, maintained, replaced or repaired.

2.1.2 TLS or parts of TLS using novel or unproven technology are to be subject to a qualification process, before the design approval. The Society provides methodological guidelines for qualification in NI 525.

For mechanical parts of TLS, the qualification is to include at least the following testing on prototype:

- mechanical characteristics
- corrosion
- fatigue and fracture characteristics
- confirmation of design performance.

2.1.3 TLS mechanical components are to be designed, as far as practicable, such that their failure will not induce progressive failure of the TLS.

When components essential for strength cannot be designed following the above principle, special attention is to be given in the design to possible early detection of failure.

2.1.4 Adequate corrosion protection of TLS elements is to be provided in accordance with Sec 3, [6]. Satisfactory attention is to be given to the protection of sliding surfaces against wear.

2.2 Top connectors

2.2.1 Top connectors and elements ensuring the interface between the tendon and the TLP are to be designed to perform the following main functions:

- to apply a pre-defined level of tension to the tendon
- connect the tendon to the TLP
- to transfer side loads and absorb bending moments and relative rotations of tendons.

When dry top connector are used, the resistance to fire and explosion is to be evaluated and appropriate protection is to be provided.

2.3 Bottom connectors

2.3.1 Bottom connectors elements ensuring the interface between the tendon and the foundation are to be designed to perform the following main functions:

- to transfer side loads and absorb bending moments and relative rotations of tendons
- connect the tendon to the foundation
- to allow the disconnection of tendon for removal or replacing
- to allow a low level of tendon slacking without disengaging or buckling the tendon.

2.4 Materials

2.4.1 General

Metallic materials used for TLS construction are to comply with the requirements of Sec 3, [2].

In addition, the provisions of API RP 2T [9.3] are to be considered for classification purpose.

2.4.2 Elastomeric materials

For elastomeric materials, the provisions of API RP 2T [9.3.4] relating to selection and acceptance criteria are to be taken into account.

2.4.3 Other standards

The Society may accept materials for TLS construction on the basis of other recognized standards, on a case-by-case basis.

2.5 Design life

2.5.1 General

Design life of tendon legs system is to be specified by the party applying for classification. As a rule, TLS service life is to be at least equal to design life of the TLP.

2.6 General design procedure

2.6.1 In general, the design of TLS is carried out based on the following procedure:

- determination of overall TLP configuration
- preliminary tendon design and estimation of tendon pre-tension
- global behavior analysis and determination of minimum and maximum tendon loads
- tendon horizontal response and calculation of tendon bending loads and horizontal motions
- evaluation of minimum allowable tension
- preliminary stress analysis and check of maximum stress level, fatigue life and hydrostatic collapse
- check of operational limits acceptable for TLP (offset, tendon motions and displacements)
- check of fatigue life under combined axial and bending stresses
- final design check, including maximum stress, minimum tension, fatigue life, hydrostatic collapse, VIV
- optional model tests for validation of tendon motions and loads.

3 Loading conditions and load cases

3.1 Loading conditions

3.1.1 Tendon legs system is to be investigated under loading conditions as defined in Sec 4, [2], taking into account design loading conditions, accidental loading conditions and earthquake conditions.

Specific design loading conditions applicable within the scope of the additional feature **TLS PLUS** are defined in Sec 4, Tab 2.

3.2 Load cases

3.2.1 Load cases are to be defined based on the provisions of Sec 4, [4]. In addition, tendon legs systems are to be checked against fatigue and hydrostatic collapse.

3.3 Tendon analysis

3.3.1 Static loads

Tendon static loads are to be calculated from the equilibrium condition of the TLP. Static loads which are to be considered are due to the following effects:

- pre-tension of tendon
- tidal effects
- TLP offset due to wind and currents
- allowance of foundation mispositioning
- Tendon legs weight and buoyancy.

3.3.2 Dynamic loads

Dynamic tendon loads due to TLP motions and earthquake are to be calculated based on the provisions of Sec 4, depending on the type of loading condition which is investigated.

Dynamic loads due to TLP motions are to be calculated from the hydrodynamic global behavior analysis. When uncoupled analysis is used, modeling tendons with appropriate spring elements, a separate tendon analysis is to be performed in order to evaluate tendon responses along its length.

4 Minimum and maximum tendon tensions

4.1 General

4.1.1 Minimum and maximum tendon tensions are to be calculated over the tendon length for each loading condition, taking into account the relevant load cases.

4.1.2 Minimum and maximum tendon tensions are to be calculated taking into account relevant provisions of API RP 2T [7.8]. Guidelines and requirements of App 1 are also to be considered.

In general, the following items are to be considered:

- design pre-tension at mean water level
- tension variation due to tidal effects and storm surge (positive and negative values)
- tension variations due to operating loads
- tendon weight and buoyancy
- tension variations due to flooding of compartments and ballast, when relevant
- tension due to overturning moment from wind and current loads
- tension induced by TLP set-down, due to wind, current and wave drift
- tensions due to wave loads and wave induced motions about the mean offset (low frequency response)
- tension due to wave frequency response
- tension due to ringing and springing
- tension due to vortex induced vibration (VIV).

4.1.3 In addition to [4.1.2], the following are to be considered when relevant:

- thermal loads inducing stresses in tendons
- tolerances for fabrication and installation
- effects of spooling of flexible tendons
- eventual foundation uplift.

4.2 Minimum tension criteria

4.2.1 Minimum tension criteria stated in the present article is to be checked for the following design loading conditions, as defined in Sec 4:

- normal operating conditions
- extreme conditions
- survival conditions.

4.2.2 For normal operating conditions, minimum tension of all tendons is to be positive.

4.2.3 For loading conditions under extreme environment and reduced extreme environment (see Sec 4, [2.3]), temporary negative tension of tendon may be accepted provided that the minimum tension of at least one tendon per corner (leg) remains positive.

4.2.4 For loading conditions under survival environment (see Sec 4, [2.3]), the minimum tension of at least three corner groups of tendons (legs) is to be positive.

When the positive tension is not maintained in all legs, a comprehensive coupled analysis of tendon system performance demonstrating proper reengagement of the bottom connector is to be provided. As an alternative, relevant model tests may be accepted.

4.2.5 When temporary negative tension of tendon is accepted as stated above, an appropriate dynamic analysis demonstrating that the loss of tension has no unacceptable effect on tendon body, connectors or flex element is to be performed and submitted to the Society. Scenarios of tendon buckling and downstroke of bottom flex element are to be evaluated, at the satisfaction of the Society. Stresses induced by the reengagement of bottom connector are to be taken into account.

4.3 Maximum tension

4.3.1 Maximum tension of tendons is to be used for the evaluations of strength criteria for tendon pipe, connectors and components.

5 Tendon pipe

5.1 General

5.1.1 The design of tendon pipe is to comply with the requirements of API RP 2T [9.6], which are adopted as minimum requirements for classification purpose. Additional considerations of the present Section are to be taken into account.

5.2 Acting stresses

5.2.1 Tendon pipe acting stresses used for the check of strength criteria are to be obtained using appropriate finite element models, at the satisfaction of the Society, or conservative methods given in API RP 2T. All stresses are to be calculated on net scantlings, as defined in Sec 3.

5.2.2 In general, maximum stresses are to be obtained by superimposing the following stress components:

- axial tensile stress due to maximum tension
- bending stresses due to flex element rotational stiffness
- bending stress due to lateral motion and loads of tendon
- hoop stresses due to hydrostatic pressure
- thermal stresses, when relevant.

5.3 Strength criteria

5.3.1 Equivalent stress

The equivalent Von Mises stress is to comply with the criteria of Pt B, Ch 3, Sec 3, [5.4] of the Offshore Rules, taking into account the basic allowable stress factor as defined in Sec 4, Tab 2, for the relevant loading condition.

5.3.2 Global tension collapse strength criteria

Global tension collapse strength criteria with WSD safety factors given in API RP 2T [9.6.2.3] is to be complied with.

As an alternative, LRFD criteria given in API RP 2T may be used.

When applying these criteria, safety factors defined in API RP 2T are to be considered. Normal operating conditions, extreme conditions and survival conditions are to be taken into account as defined in Sec 4.

5.3.3 Local stresses

Local stresses criteria for diameter transition stresses and thickness transition stresses given in API RP 2T [9.6.2.3] are to be complied with.

When applying these criteria, safety factors defined in API RP 2T are to be considered. Normal operating conditions, extreme conditions and survival conditions are to be taken into account as defined in Sec 4.

5.4 Tendon pipe girth welds

5.4.1 Requirements given in API RP 2T [9.6.3] relating to girth welds design, including fatigue and fracture mechanics aspects, fabrication, inspection and testing are referenced for classification purpose.

6 TLS components

6.1 General

6.1.1 TLS components such as top and bottom connectors, joints and flex element are to be verified through appropriate finite element analysis, at the satisfaction of the Society. Testing may be required to complete or validate finite element analysis.

Generally, three dimensional models are to be used. Top-down models may be used when appropriate.

Testing may be required to complete or validate finite element analysis.

6.1.2 The loads for finite element models are to be obtained from tendon analysis, as stated in Sec 4 and App 1.

6.2 Connectors

6.2.1 Acting stresses

Connector acting stresses are generally to be obtained from the finite element analysis on local models, as stated in [6.1]methods given in API RP 2T for the calculation of acting stresses, including local and section stresses are also acceptable.

6.2.2 Strength criteria

Structural parts of connectors are to comply with the requirements of API RP 2T [9.6.4.3.1]. The following criteria are referenced:

- primary stress criteria
- primary and secondary stress criteria
- shear stress criteria
- bearing stress criteria.

When applying these criteria, safety factors defined in API RP 2T [9.6.4.3.1] are to be used.

6.3 Flex element

6.3.1 The analysis of flex element is to be performed on models taking into account specific properties of rubber material, with explicit modeling of the laminates. The model is to allow the application of axial forces with bending moment in one plane.

6.3.2 Flex element is to provide rotational stiffeness assumed in tendon response analysis. This stiffness is to be confirmed by full scale testing on prototype.

6.3.3 Strength criteria are to be applied for both rubber part and laminates.

Steel parts are to comply with criteria given in [6.2.2]. Rubber parts are to be checked against maximum allowable bulging under compression and maximum shear deformation under rotation. Acceptance criteria are to be specified and accepted by the Society.

6.3.4 Fatigue assessment of flex element is to be carried out based on the recommendations and requirements of API RP 2T [9.6.5.4].

7 Fatigue of TLS

7.1 General

7.1.1 All parts of tendon legs system are to be checked for fatigue.

7.1.2 Fatigue calculations are to consider all sea states expected over the lifetime of tendons and fatigue damage due to vortex induced vibrations (VIV) during in-place and installation conditions.

Recommendations of API RP 2T and App 1 are to be considered.

7.1.3 Tendon fatigue loading is to consider axial and bending stresses due to wave frequency, low frequency and high frequency loads.

7.1.4 Appropriate S-N curves are to be selected according to material, welding detail and workmanship, level of quality control and level of cathodic protection.

7.1.5 Appropriate stress concentration factors for tendon pipe and TLS components are to be determined based on parametric formulas or local finite element analyses, to the satisfaction of the Society.

7.1.6 Fatigue contributions due to wet transportation of tendons or other relevant pre-service conditions are to be taken into account.

7.1.7 For tendon receptacles and components attached to driven piles, fatigue damage due to driving is to be considered. Linear Palmgrem-Miner rule is generally to be applied for the accumulation of fatigue damage.

7.1.8 Fatigue assessment of tendon and TLS components is to consider a minimum safety factor on total fatigue damage equal to 10.

7.2 Fracture mechanics

7.2.1 Tendons are to have sufficient fracture toughness to prevent fracture unstable crack growth under extreme design loads within a period of 5 times the design life of tendon (see [2.5]) or tendon inspection period, whichever is less. The following types of flaws are to be considered:

- from tendon surface
- from tendon pipe subsurface
- through-wall flaws.

7.2.2 Fracture mechanics are to be carried out in accordance with BS 7910. Relevant recommendations of API RP 2T are also to be taken into account.

Other standards may be accepted by the Society on a case-by-case basis.

The target of fracture mechanics analysis is to:

- estimate crack growth rates
- define maximum allowable flaw size
- define inspection intervals and monitoring strategies.

Initial flaws of various aspect ratios and no threshold for fatigue crack growth are to be considered.

7.2.3 Maximum allowable flaw size is to be reliable detectable by NDT inspection system employed during tendon fabrication.

SECTION 7 FOUNDATIONS

1 General

1.1 Principle

1.1.1 Scope

The present section provides requirements for geotechnical site survey and the structural and geotechnical design of tendons leg system's foundations for TLPs. The requirements of the present section are given within the scope of additional features **TLS** and **TLS PLUS**.

Structural and geotechnical assessments is to be performed for the various design loading conditions required for tendon legs system defined in [3].

In addition, structural and geotechnical assessment of foundations is also to be performed for installation in order to insure achievement of geotechnical capacities of foundations and to account for consequences of installation phases on in-site structural strength.

1.1.2 References

The requirements of present section are consistent with the recommendations of API RP 2T, API 2A WSD and ISO 19901-4. The Society may refer to these standards when deemed necessary for classification purpose.

Minimum acceptance criteria on geotechnical ultimate holding capacity (UHC) and additional requirements are given in this section.

1.2 Geotechnical investigations and Soil data

1.2.1 General

In order to assess geotechnical capacity of TLPs foundations and feasibility of the retained solution, detailed soil data shall be provided by the designer. These design soil data shall be determined based on a site geotechnical survey, in accordance with API RP 2T recommendations.

A particular attention shall be drawn on the analyses of any possible geohazard such as bathymetry, earthquakes, pockmarks, dropped object that may influence foundation design.

1.2.2 Effects of cyclic loading and thixotropy on soil conditions shall be investigated or assessed by relevant mean.

For shallow foundations, understanding of present and past state of stress of the soil is also necessary.

1.2.3 Effect of scouring is to be considered. Scours – removal of seabed soils due to currents and waves – may induce an overstress of foundation elements due to the removal of vertical and lateral support. For sites where the scour is a concern, scouring effects are to be taken into account by the Designer and appropriate documentation is to be submitted to the Society.

1.3 Type of foundations

1.3.1 General

Different type of foundations may be provided for the anchoring of tendon system legs, such as:

- Long (soft) piles foundations
- Shallow foundations as gravity base and mudmats
- Suction piles and caissons.

Depending on the solution used for foundations, different types of calculations have to be performed with different design criteria, defined in [3] and [4]. Different constraints due to installation also have to be taken into account.

For other type of foundations that may be provided, approval will be performed on a case by case basis by the Society.

1.3.2 Pile foundations

Deep foundations may be provided for anchoring of TLPs in the seabed. Deep foundations consist generally in long unstiffened piles. Different type of pile foundation may be proposed such as:

- driven piles
- belled piles
- drilled and grouted piles.

Installation of deep piles in deepwater environments may require special considerations. Design and installation methods are to be in accordance with recommendations of API RP 2T [10.6.4].

In addition to long unstiffened piles, short piles systems – ratio length on diameter lower than 6 - may be provided, such as:

- suction piles
- driven short piles
- suction caissons.

These type of piles will not be addressed in the present Rules and are to be designed according to NR 493 Sec 4 [6] and NR 493 App 4. Requirement for short piles may be adapted to TLPs tendon legs loads on a case by case basis, approved by the Society.

1.3.3 Shallow foundations

Shallow foundations principally address:

- Gravity bases:

  massive shallow foundation withstanding the loads in tendons legs principally by gravity
- Mudmat:

  jacket-type shallow foundations.

For other type of shallow foundations that may be provided, approval will be performed on a case by case basis by the Society.

2 Loading conditions

2.1 General

2.1.1 As a general matter, all the Rules load cases defined for tendon legs system in Sec 4 and Sec 6 shall be investigated for foundation design.

Additional cases shall also be assessed for foundation design such as:

- Seismic loads
- Installation loads and conditions.

2.2 Additional Loadcases

2.2.1 Earthquakes

Earthquake loads are defined in terms of vertical and horizontal accelerations and ground motions. Seismic risk is to be assessed and seismic loads are to be estimated for TLP foundations. Both horizontal and vertical accelerations and motions are to be considered.

Foundations are to withstand 1000-year return period seismic loads and to be assessed in accordance to API RP 2T [10.3.3.7]. Ultimate strength seismic criterion is to be considered as a survival condition.

2.2.2 Installation

Installation loads and installation conditions are to be estimated by proper mean in order to assess the feasibility of the structure and pile structural resistance to installation loads and fatigue damage in the pile due to installation.

Installation are to be in accordance with API 2A-WSD [6].

For driven piles, pile self-penetration under self weight and hammer weight is to be assessed. Driving load and number of driving cycles are to be assessed with enough conservatism to assess yielding and buckling strength of the structure and to estimate fatigue damage due to installation to be added to in-place fatigue damage.

Driving loads and driving cycles limits are to be defined and criteria for refusal are to be specified. Procedures in case of refusal are to be submitted.

3 Geotechnical requirements

3.1 General

3.1.1 The geotechnical ultimate capacity of foundations are to be documented and established by analyses with due consideration of potential failure under combination of vertical load, horizontal load and overturning moment.

Effects of cyclic loading on the structure are to be taken into consideration by proper mean. Group effects on the foundation shall also to be considered in the estimation of foundation capacity. Scouring effects are to be considered.

Feasibility of installation, behavior during installation and related loads are also to be assessed and documented

For most of foundations, the full design geotechnical capacity may not be available immediately after installation, due to time required for set-up effects. These effects are to be assessed by proper means and considered in the overall scheduling of the project, taking into account the risk of occurrence of high loads during that period.

Foundations are to be designed in accordance with API RP 2T [10].

Foundation holding capacity is to be based on lower-bound soil values and installation is to be based on upper bound soil values.

3.2 Pile foundations

3.2.1 Geotechnical capacity

Pile foundations are to be designed in accordance with API RP 2T [10.6].

Axial pull-out loads, lateral loads and overturning moments are to be assessed separately. Axial Load and Lateral loads are to be assessed in accordance with API RP 2T [10.6].

Lateral loading and large lateral displacement are to be assessed, taking into account cyclic loading effects. Special consideration is to be taken into account when lateral displacement is higher than a quarter of pile diameter.

The pile foundations are to fulfil the following criteria on pile capacity:

$Q_a \geq SF_a\ L_a$ and $Q_l \geq SF_l\ L_l$

with:

Q_a, Q_l : Axial / Lateral holding capacity

SF_a, SF_l : Axial / Lateral Safety factor on load

L_a, L_l : Axial / Lateral Load estimated at foundation anchoring point.

Acceptance criteria for geotechnical capacity are defined in Tab 1 and depend on load classes.

Table 1 : Safety factors for pile foundations

	Normal operational conditions	Extreme conditions	Survival conditions
Axial Load	2 B	1,5 B	1,5 B
Lateral Load	1,6	1,2	1,2

Note 1: B-factor is a biased factor to be added to WSD methodologies taking into account soil and system uncertainties under tensile loading.

This factor is to be assessed based on Reserve Capacity Design methods (as defined for example in "Reserve Capacity Design of Piled Foundations for Deepwater Compliant Platforms", Audibert, Mueller, Bamford and Bogard, OTC 5761, 1998), taking into consideration:

- Uncertainties in soil-pile behavior under tensile loadings
- Lack of residual strength of soil-pile system
- Group effects and load redistribution capabilities of foundation systems
- Uncertainties of installation
- Cyclic load effects
- Long-term sustained loading effects.

The minimum value of B-factor for pile foundations is 1,5.

3.3 Shallow foundations

3.3.1

The ability of the soil to resist loads from shallow foundations is to be evaluated considering the stability against overturning, bearing, sliding, uplifting or a combination thereof.

3.3.2 Mudmat foundations

Mudmat foundations are to be designed in accordance with API RP 2T [10.7.2] and API 2A-WSD [6.12] to [6.16].

The pile foundations are to fulfil the following criteria on pile capacity:

$Q_a \geq SF_a\, L_a$ and $Q_l \geq SF_l\, L_l$

with:

Q_a, Q_l : Bearing and uplifting / sliding holding capacity

SF_a, SF_l : Bearing and uplifting / sliding Safety factor on load

L_a, L_l : Bearing and uplifting / sliding Load estimated at foundation anchoring point.

Safety factors on geotechnical capacity to be considered are defined in Tab 2.

Table 2 : Safety factor for shallow foundations

Failure mode	All Cases
Bearing and uplift failure	1,5
Sliding failure	1,2

3.3.3 Gravity base

Gravity bases foundations are to be designed in accordance with ISO19901-4, based on a Load and Resistance Partial Factor methodology.

Forces are to be divided into a static part Ts corresponding to mean tension under permanent metocean actions and a dynamic part Td, such as the design load is:

Td = Ts + Td

The pile foundations are to fulfil the following criteria on pile capacity:

$$Q(q/\gamma_m) \geq \gamma_s T_s + \gamma_d T_d$$

with:

$Q(q/\gamma_m)$: Total holding capacity considering degraded soil shear stresses (shear stress divided by material factor γ_m

γ_s, γ_d : Static and dynamic partial factor on load.

The partial factors in Tab 3 are to be considered. For Normal operational and Extreme conditions, two partial factor combinations on static load and dynamic load are to be considered.

Additionally, uplift resistance is to fulfil the following criterion:

$Q > 2T_a$ or $W > 1{,}25\ T_a$

with:

T_a : Uplift Load

W : Self weight of the gravity base

Q : Uplift capacity of the gravity base considering self weight, friction on embedded pile surface and soil suction due to pore pressure and adhesion.

Stability of gravity bases under its self-weight and during each installation step with corresponding loads and eccentricity are to be assessed by proper means as per ISO19901-4.

Table 3 : Partial factors on gravity bases holding capacity

Load Case	Extreme conditions		Survival conditions
	case a	case b	
Material factor	1,5	1,5	1,5
Static factor	1,3	1,0	1,0
Dynamic factor	1,0	1,3	1,0

4 Structural requirements

4.1 Materials

4.1.1 Materials are to conform to the relevant sections of the Offshore Rules and NR216 Materials and Welding.

4.2 Structural categories and design temperatures

4.2.1 For the selection of materials, and the definition of fabrication and NDT requirements, the following categories of construction (as defined in Part B, Ch 3, Sec 2 of the Offshore Rules) are to be considered:

- Connections with tendon legs and adjacent structure are to be considered as “Special Category elements”.
- The rest of foundation body is to be considered as “First Category” elements.
- A design temperature of 4°C is to be generally considered for anchoring devices in deep waters. In other cases, the design temperature is to be specified.

4.3 Strength

4.3.1 The strength and buckling is to be documented by appropriate calculations for all load cases defined in Sec 4, [4].

4.3.2 Connections with tendon legs system and adjacent structure are to be designed to withstand:

- the pile ultimate holding capacity of the foundation
- and tendon maximum tensions at bottom connector, as defined in Sec 6, [4.3].

The rest of foundation body is to be able to withstand the ultimate capacity of the foundation, with deformations within such limits as not to impair foundation geotechnical capacity. These loads are the reference load for each part of the foundation.

The angular variations resulting from tolerances in system geometry and installation and from TLP excursions are to be duly considered.

4.3.3 Structural elements of foundation are to comply with the criteria defined in Pt B, Ch 3, Sec 3, [5.4] of the Offshore Rules.

The stresses and basic allowable stress factors for the above criteria are to be taken as specified in Tab 4.

Table 4 : Loading conditions

Loading condition	Basic allowable stress factor
Normal operating conditions	0,6
Extreme conditions	0,8
Survival conditions	1,0
Earthquake	1,0
Accidental conditions	1,0
Installation conditions	0,6 **(1)**
(1) The basic allowable stress factor is to be taken 0,8 for driven piles	

4.4 Fatigue

4.4.1 The resistance to fatigue is to be documented by appropriate calculations. The achieved fatigue life is to be documented with a safety factor on total fatigue damage equal to 10.

For driven pile, fatigue damage due to installation is to be assessed and considered in calculation of the total fatigue damage.

4.5 Protection against corrosion

4.5.1 Protection against corrosion is to be provided by adequate means. When the geotechnical capacity of the foundation is relying on skin friction between soil and steel, the surface condition of steel is to be consistent with the assumptions made at time of design.

Where appropriate, protective coating is to be avoided in the relevant area of the foundation.

5 Installation

5.1

5.1.1 The installation at site of foundations is to be performed under Survey by the Society.

Installation procedures for foundations and connections with tendon legs are to be submitted in advance for review by the Society.

Installation records, with related analyses, as needed, are to provide evidence that target penetration and holding capacity of foundations have been achieved.

APPENDIX 1 GUIDELINES FOR HYDRODYNAMIC GLOBAL BEHAVIOUR ANALYSIS AND HYDRO-STRUCTURE INTERACTIONS FOR TENSION LEG PLATFORM

1 General

1.1 Introduction

1.1.1 The present Appendix discusses the issues related to the loading and the responses of the TLP platform under certain environmental conditions which are defined by the waves, wind and current. The main accent is put on hydrodynamic calculations which represent the basis for the assessment of the hydrodynamic, mooring and hydro-structure calculations. The necessary numerical methods are discussed and guidance is given for their use in the context of different TLP design issues.

1.2 Particularities of the TLP concept

1.2.1 When compared to other floating off-shore platforms, the TLP concept has the particularity that the buoyancy of the platform exceeds its weight and the vertical equilibrium is ensured by the taut moorings connecting the upper structure to the sea bed. The reason of doing this is to make sure that the vertical motion natural frequencies of the platform (heave, pitch and roll) fall out of the frequency range of the typical sea spectra. This leads to the vertical natural periods well below 5 seconds (usually in between 2 and 4 seconds). On the other hand the natural periods of the horizontal motions (surge and sway) are similar to those of the classical semi-submersible platforms and usually exceed 100 seconds.

These two facts make the analysis of the global TLP behavior more complex than those for classical off-shore platforms. Indeed, regardless of the exact value of the natural frequencies, the resonant platform response will always take place around the natural frequencies due to the nonlinearities of the hydrodynamic wave action. In the case of TLP two particular high frequency phenomena arise, namely springing and ringing. The main effect of springing is on the fatigue life of the tendons while the main effect of ringing is on extreme tendon response. In addition, due to the particular geometry of the TLP hull and the tendons, the resonant vibratory response of the structure might arise due to the vortex shedding around the structural members. The so called Vortex Induced Vibrations (VIV) of the tendons and even the Vortex Induced Motions (VIM) of the whole system might happen.

1.2.2 Springing

Springing is defined as a stationary high frequency response of TLP around its natural frequencies in the vertical plane (heave, pitch and roll). It is nowadays well accepted that the springing response can be evaluated using the second order sum frequency theory (see [2.3.5] for details). It is important to note that, in addition to the correct evaluation of the second order excitation forces, and due to the resonant character of springing, special attention should be given to the evaluation of different sources of damping (wave radiation, viscous effects, tendons structural damping …).

1.2.3 Ringing

Ringing is defined as the transient response due to non linear effects of large-amplitude waves that are moderately steep, steep or breaking. It is measured as sudden bursts of highly amplified resonant activity during storm events. The practical impact of ringing is on the extreme tension of tendons. Ringing is fundamentally different from springing as the ratios of the natural frequencies to the peak wave frequency are larger than 2, typically 3, 4 or more, so that highly non linear wave loading process must be involved. Slamming effects in steep or breaking waves may also contribute.

The simple models of Morison type have been developed with diverse corrections (to the classical Morison formulae) to account for non linear effects, see [1.2.3], Note 1). The higher order term in Morison type formulation, contributed by integration to instantaneous sea level, produces an impulsive type inertia force. Wave kinematics in the free surface zone can be extrapolated by stretching approximations. In general, the simple model of Morison type yields numerical results in reasonable agreement with experimental measurements.

The so called FNV method (see [1.2.3], Note 2) has also been developed based on the asymptotic expansion with respect to the small parameter defined as a product of the wavenumber and the column radius. It should be noted that this model is limited to very small values of this parameter.

Finally the 3rd order diffraction theory was used by Malenica and Molin (see [1.2.3], Note 3) in order to calculate the 3rd order forces in a fully consistent way. However, this model is limited to the triple frequency 3rd order forces in regular waves and can not be used for irregular sea states. It's main utility is to judge about the validity of the different approximate models.

However, in spite of all the above mentioned numerical models which have been proposed in the past the accurate numerical evaluation of ringing loads still seems to be a challenge so that model tests might be better alternative.

Note 1: Rainey R.C.T. "A new equation for calculating wave loads on offshore structures" in Journal of Fluid Mechanics, Vol. 204, pp 295-324 (1989).

Note 2: Faltinsen O.M.; Newman J.N. and Vinje T. "Nonlinear Wave Loads on a Slender Vertical Cylinder" in Journal of Fluid Mechanics, Vol. 298, pp 178-198 (1995).

Note 3: Malenica S. and Molin B. "Third-harmonic diffraction by a vertical cylinder" in Journal of Fluid Mechanics, Vol. 302. pp 203-229 (1995).

1.2.4 VIV and VIM

Vortex induced vibrations (VIV) and vortex induced motions (VIM) are defined as the resonant vibratory response of the structure induced by vortex shedding. The intensity of the vibrations/motions depends on the ratio in between the vortex shedding frequency and the natural frequency of the system. The vibration might be excited both in line and in transverse direction, the later one being usually more important. The vibrations are limited in the amplitude and hardly exceeding the characteristic length (diameter…) of the structure. This means that their effect will be more important to the fatigue life than to the extreme structural loading.

The VIM are usually of less importance in the TLP design even if their effect might have to be included in the evaluation of the maximum TLP offset. This depends however on the exact TLP design. In particular VIM is likely to be more important for mono-column type of TLP than for the 4 columns type.

On the other hand, the VIV of risers and tendons might be an important issue for their fatigue life. It is recommended to, at least, check the risk of VIV for the particular design (natural modes of the tubular elements) and operating conditions (current intensity). This means that we should check the eventual matching of the excitation frequencies (vortex shedding) and the risers/tendons natural frequencies. Due to the complexity of the problem, the overall accuracy of the existing VIV analysis tools and methods are rather limited and usually these methods are based on empirical load/response techniques. The model tests might be useful. They are however very difficult to design properly because of several number of similitudes which should be respected simultaneously (Froude, Reynolds, hydroelastic similitude…).

If proven that there is a serious risk for occurrence of the VIV type of responses some mitigation solutions should be proposed.

1.3 Basic design considerations

1.3.1 The design environmental conditions should be defined in such a way that they produce the extreme response that has very low probability to be exceeded in the TLP lifetime. The extreme conditions are representative of the maximum possible response for different failure modes of the TLP critical components (e.g. hull, tendons, foundations…). The extreme conditions should in addition cover the situations associated with the transportation and installations of TLP, if necessary. Normal operating conditions are those which occur frequently in the TLP lifetime. They are specific to the dedicated site where TLP is operating. These conditions are relevant for the evaluation of the fatigue life of the structural details (hull, tendons, tendon connections…).

The design conditions are usually described by the wave scatter diagram, wind spectrum and current intensity with the proper account for their combinations. The choice of the representative design combinations of wind, waves and current is far from trivial and should be done with care. The probability to encounter the extreme conditions for all the effects simultaneously is extremely low. The proper combination of the directions of the different effects is also an issue.

2 Hydrodynamic analysis

2.1 Introduction

2.1.1 It is important to note that nowadays the so called potential flow hydrodynamic approach based on wave diffraction radiation models are dominating the existing design methods. In some cases, these models are usually complemented by the simplified Morison method for slender parts of the structures. The pure CFD methods based on solving directly Navier Stokes or Euler equations are not used very often. The extreme CPU requirements and lack of the clear validation of the CFD methods, are probably the main reasons for this. However, the use of CFD can be helpful for some particular local applications such as: nonlinear wave run-up, wave overtopping, impact on deck…

2.1.2 The non exhaustive list of the main hydrodynamic issues is summarized below

- Offset and set-down
- Maximum yaw motion
- Tendons tensions
- Deck clearance & wave run-up
- Accelerations
- Internal loads in the hull structure
- Pressures.

Depending on the type of the TLP the above list can be extended (TLP with moon-pool, influence of sloshing motion in some tanks…).

2.1.3 Two types of approximation are usually employed in the hydrodynamic analysis of the floating platforms:

- Simplified Morison model
- Wave diffraction-radiation theory.

2.2 Morison method

2.2.1 The Morison method is the simplest one and its domain of validity is limited. It is based on the so called strip approach where the structure is cut into a certain number of regular sections on which the forces are calculated by relating the local geometry and the fluid kinematics (velocities and accelerations) through the Morison formula:

$$F_M = \frac{1}{2}\rho_w C_D D\left(v_F - \frac{d\xi_B}{dt}\right)\left|v_F - \frac{d\xi_B}{dt}\right|$$
$$+\frac{\rho_w \pi D^2}{4}\left[(1 + C_M)\gamma_F - C_M\frac{d^2\xi_B}{dt^2}\right]$$

where:

ρ_w : Water density

C_D : Drag coefficient

D : Characteristic sectional dimension (diameter)

v_F : Local fluid velocity

$d\xi_B / dt$: Local body velocity

C_M : Added mass coefficient

γ_F : Local fluid acceleration

$d^2\xi_B / dt^2$: Local body acceleration.

This method can be efficiently used for slender structures only. Indeed the main diffraction-radiation effects can not be taken into account since the implicit assumption is that the structural cross section is significantly smaller than the considered wave length. There is no possibility to include higher order diffraction effects. Good point is that the non-linear drag forces can be included.

The Morison forces include the added mass, damping and excitations effects.

It is important to mention that the Morison model can not be applied for the vertical forces on the columns.

2.3 Wave diffraction radiation theory

2.3.1 The assumptions of the potential flow are adopted. The usual methods are based on the Boundary Integral Equations Method (BIEM) in which the flow field is represented by the distribution of singularities (sources/sinks, dipoles…) over the wetted part of the body. Diffraction and radiation effects are taken into account consistently and the method can be used for linear (first order), weakly nonlinear (second order) and fully non linear calculations. Due to their complexity, the fully non linear calculations are usually employed only for very special purposes. Here below we discuss the first and second order methods only.

These methods should be applied for large bodies i.e. for the bodies which characteristic length is similar to the wave length where the diffraction radiation effects are important. For some applications the method can be combined with the Morison approach for slender members (bracings…) where the drag type forces might be important (see [2.2]).

The wave diffraction radiation theory can be applied in frequency or in time domain. Usual practice is to apply it in frequency domain and for some specific application use the hybrid frequency/time domain approach.

Usually we distinguish three independent types of models:

- Linear hydrodynamic model
- Low frequency second order hydrodynamic model (difference frequency)
- High frequency second order hydrodynamic model (sum frequency).

It is important to note that the linear calculations are prerequisite for the second order calculations and the second order calculations can not be performed if linear problem is not solved properly.

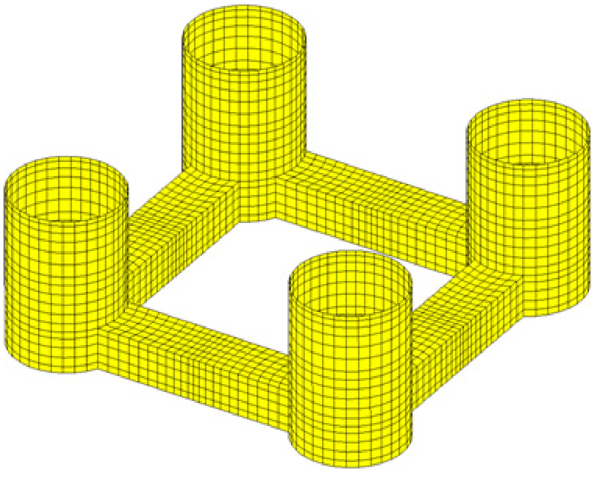
Linear wave forces are the governing loads for the structural design of the hull, low frequency wave forces are relevant for mooring analysis and the determination of the mean offset and set-down while the high frequency wave forces are relevant for determination of the tendons loading and for the evaluation of the non linear air-gap.

2.3.2 Linear diffraction-radiation numerical model in frequency domain

The main advantage of the frequency domain model is its relative simplicity and the low CPU time requirements. The linearization is made by assuming the small wave steepness which is reasonable assumption for most of the practical cases. Within the potential flow assumptions, and after performing the linearization, the total velocity potential is decomposed into seven components (incident, diffracted and 6 radiated components). For each of those components the dedicated Boundary Value Problem (BVP) is built. Each BVP is solved using the Boundary Integral Equation Method in which the fluid flow is represented by the distribution of singularities over the wetted part of the hull. In that respect this method requires the mesh of the underwater part of the body only, which represents great advantage when compared to other methods and in particular CFD type of methods where whole fluid domain need to be modelled. A typical hydrodynamic mesh for TLP is shown in Fig 1. Special care should be made as to the size of the mesh in order to ensure the proper convergence of the solution. The mesh size should be proportional to the shortest considered wave length, the usual practice being 6 elements per wave length and the mesh refinement might be necessary for some parts of the model (close to the free surface, around the sharp corners…).

Once the BVP solved, the hydrodynamic pressure is evaluated and the corresponding hydrodynamic coefficients (added mass, damping and excitation) are obtained after the integration of the pressure over the wetted part of the hull. At the same time the care should be taken when evaluating the body restoring matrix which should include both the classical hydrostatic restoring part and the part related to the action of tendons.

Figure 1 : Typical hydrodynamic mesh of 4 columns TLP



Once the dynamic coefficients evaluated, the motion equation is written:

$$\{-\omega^2([M]+[A])-i\omega[B]+[C]\}\{\xi\} = \{F\}$$

where:

ω : Wave frequency

[M] : Genuine mass matrix

[A] : Added mass matrix

[B] : Damping matrix (linearized)

[C] : Restoring matrix (from the change of hydrostatics and from the tendons)

$\{\xi\}$: Body motions

{F} : Excitation vector (diffracted + incident wave).

The solution of the motion equation gives the body motions (surge, sway, heave, roll, pitch and yaw) and the problem is formally solved. Access to any particular quantity in terms of RAO's (pressure, accelerations at particular points, internal bending moments, shear forces…) is straightforward.

Once the different RAO's are evaluated, spectral analysis for specific scatter diagram can be performed and the maximum probable design values can be evaluated.

2.3.3 Mixed diffraction - radiation - Morison model

In some cases, when slender elements are present, the combined diffraction-radiation-Morison model might be necessary. The idea is to use the Morison formula for slender elements by evaluating the fluid kinematics using the diffraction-radiation theory in order to account for important perturbation (diffraction-radiation) parts of the velocity potential. Due to the nonlinear character of the Morison formula (drag component) proper linearization should be performed before solving the motion equation.

2.3.4 Linear wave-current diffraction-radiation model in frequency domain

In the areas where strong current is present, the linear wave-diffraction model needs the improvements and the effects of current can become quite important. This importance is particularly visible on the results for the air gap which can be strongly influenced by the current. The numerical model, with current included, is much more complex than the one without current because of the change of the free surface condition which now includes several additional terms accounting for the current intensity and for the interaction of the steady and unsteady parts of the velocity potential.

Similar to the second order problem, the Boundary Integral Equation Method leads to the additional integral over the free surface. However, in this particular case this integral decays very rapidly so that efficient methods exist nowadays.

It is important to note that, in addition to the influence on the air gap, the solution of the wave-current interaction problem is also necessary for evaluation of the so called wave drift damping (WDD) which is important in the analysis of the low frequency simulations. Indeed the WDD is defined as the derivative of the steady drift forces with respect to the slow speed and only the above model allows for fully consistent determination of this coefficient.

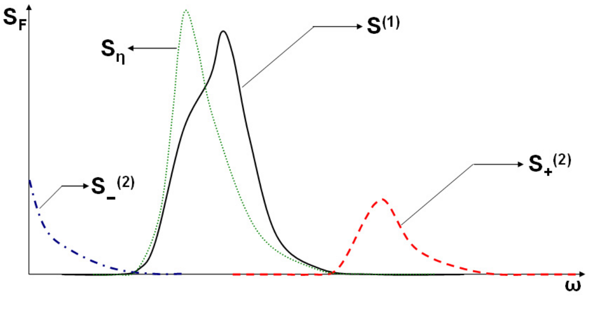
2.3.5 Second order diffraction-radiation numerical models in frequency domain

It is important to note that, in addition to the linear quantities, the so called second order mean drift forces can also be evaluated using the linear results only. These mean forces are very important for the evaluation of the mean TLP off-set and for mooring simulations in general. However these mean drift loads are not enough for complete low frequency simulations of the TLP horizontal motions and the slowly varying (second order difference frequency) loads should be evaluated using the weakly non-linear second order theory.

Unlike the linear first order model which gives rise to the quantities at particular wave frequency and the mean drift forces, the second order model produce the high frequency (super harmonic) and low frequency (sub harmonic) wave loads. In Fig 2, we qualitatively represent the effects of different orders in terms of the spectral responses

The theory behind the second order problem is nowadays well mastered even if only few numerical codes are able to perform these calculations in a fully consistent way. Contrary to the linear problem for which it is enough to perform the calculations for each frequency independently, the generic second order problem includes the bi-chromatic wave field i.e. the quadratic interaction of the two linear wave systems with two different frequencies coming from two different directions. This makes the overall procedure of the evaluation of the second order loads for a given wave spectra extremely complex.

Figure 2 : Excitation spectra S_F of the first ($S^{(1)}$) and second order difference ($S_-^{(2)}$) and sum ($S_+^{(2)}$) frequency loads together with the sea spectrum (S_η)



In the general case the second order interaction of two monochromatic waves of the frequencies (ω_i , ω_j) and amplitude (A_i , A_j), coming from the directions (β_i , β_j) will give rise to the second order loads (and any other second order quantities) which can be schematically written in the following form:

$F^{(2)}(t) = F_-^{(2)}(t) + F_+^{(2)}(t)$

where:

$F_-^{(2)}(t)$: Sub-harmonic (difference frequency) second order loads:

$F_-^{(2)}(t) = R\{A_iA_jf_-^{(2)}(\omega_i, \omega_j, \beta_i, \beta_j)e^{i[-(\omega i - \omega j) + \theta i - \theta j]}\}$

$F_+^{(2)}(t)$: Super harmonic (sum frequency) second order loads:

$F_+^{(2)}(t) = R\{A_iA_jf_+^{(2)}(\omega_i, \omega_j, \beta_i, \beta_j)e^{i[-(\omega i - \omega j) + \theta i + \theta j]}\}$

$f_-^{(2)}(t)$; $f_+^{(2)}(t)$:Qquadratic transfer functions

θ_i ; θ_j : Corresponding phases of two different incident wave systems

R{x} : Real component of the quantity x.

The complex quantities $f_-^{(2)}(t)$ and $f_+^{(2)}(t)$ are called quadratic transfer functions and represents the main difficulty for the numerical calculations. Indeed very complex second order boundary value problems need to be solved for all the combinations of the frequencies and the wave directions.

In the particular case of mono-directional ($\beta_i = \beta_j$) and monochromatic wave system ($\omega_i = \omega_j$), the above expressions reduce to the second order mean drift forces for $f_-^{(2)}(t)$ and to the double frequency second order forces for $f_+^{(2)}(t)$.

The numerical method which is usually employed for solving the second order boundary value problems is also based on the Boundary Integral Equations Technique and the same type of Green function is used. The main numerical difficulty comes from the fact that the associated second order free surface boundary condition becomes non-homogeneous and the Boundary Integral Equation must include the integration over the free surface which, strictly speaking, should extend to infinity. Due to highly oscillatory behavior of this integral several convergence problems appear and should be treated with care.

In addition, for the sum frequency problem, due to very short wave lengths which can appear, the mesh requirements might become prohibitive, and special numerical treatments are necessary.

As far as the low frequency second order problem is concerned, the situation is slightly simplified by the fact that the contribution of the free surface integral to the total loads is usualy not very important so that it can be neglected.

2.4 Time domain models

2.4.1 The most important advantage of the frequency domain approach is the computational efficiency and the most important limitations are the difficulties related to the linearization. Indeed the nonlinearities should be either ignored or replaced by the linear approximation. The exception are some special cases such as the second order frequency domain models in which the nonlinearities can be partially included (up to second order) but the price to pay are the complexities associated with the numerical solution of the corresponding boundary value problems.

The time domain analysis is based on the direct integration in time of the equations of motion which makes possible the inclusion of system nonlinearities at each time step. There are several types of nonlinearities which need to be included in the model and they can be of both mechanical and hydrodynamic character. The hydrodynamic nonlinearities include the higher order wave effects (second order diffraction, ringing…), nonlinear hydrostatics and different non potential effects (Morison loading, VIV, VIM…) while the nonlinear mechanical nonlinearities includes the nonlinear characteristics of the mooring system, large platform motions, dynamic effects of the risers and tendons.

The usual procedure for the time domain simulation models is to start with the linear frequency domain model and transfer it to the time domain using the inverse Fourier transform technique (see [2.4.1], Note 1) where any type of nonlinearities can be added at each time step. The idea behind is that we will include the most important linear part of the hydrodynamic loading using the results from the computationally efficient frequency domain analysis and the complex nonlinear terms will be added in time domain. Within this approach, the time domain motion equation equivalent to equation in [2.3.2] becomes:

$$([M] + [A^\infty])\left\{\frac{d^2\xi}{dt^2}\right\} + ([C])\{\xi(t)\} + \int_0^t [K(t-\tau)]\left\{\frac{d\xi}{dt}(\tau)\right\}d\tau$$

$$= \{F(t)\} + \{Q(t)\}$$

Where the different terms on the left hand side can be calculated from the frequency domain hydrodynamic database, F(t) represents the linear part of the wave excitation and Q(t) stands for the different non-linear effects.

We should be very careful when using the above equation in practice! Indeed, the difficulties is that the nonlinear terms represented by Q(t), depend directly on the solution of the motion equation (motion, velocities, acceleration) and unless some complex iteration process is involved the solution of the equation will remain inconsistent. In general it is very difficult to include consistently all the system nonlinearities, both mechanical and, especially, hydrodynamic nonlinearities. That is why, most often, the partial coupled models are used. It is important to realize that these models include only one part of the nonlinear effects i.e. the part which is believed to be the most important one for particular application.

Note 1: Cummings W.E. "The Impulse Response Function and Ship Motion" in David Taylor Model Bassin Report 1661; Washington DC (1962)

2.4.2 Uncoupled time domain model

The simplest time domain model is the uncoupled model which assumes no interaction between tendon/riser dynamic response and the platform dynamic response. Within this model the inertia effects of the tendons and risers on the platform motions is usually approximated by modification of the platform inertia while the restoring effects are modelled by simple springs.

In principle there is no need for the time domain model if only the linear terms has to be included, because the frequency domain model can do as well in a more efficient way. The advantage of the time domain model is that some non linear terms (damping, reasonably large motions…) can be included in simplified way.

2.4.3 Coupled time domain model

As already mentioned there are several types of nonlinearities which should be included in the coupled time domain model:

- Coupling of the tendons/risers dynamics and platform dynamics (influence increases with increased water depth)
- Large platform motions
- Drag forces on the hull and on the tendons/risers
- Large waves which introduce the important nonlinear hydrodynamic effects
- Nonlinear positioning
- Anchoring system.

Consistent inclusion of these nonlinear terms in the fully coupled motion equation (see [2.4.1]) is far from trivial and should be done with great care.

2.5 Hydrodynamic model tests

2.5.1 Hydrodynamic model tests in the wave basins might be an important part of the TLP design process. The numerical modelling and the model tests should be understood and used as complementary tools because both of them have important limitations. The limitations of the numerical models have been discussed in the previous sections and here below we mention few important limitations of the model tests:

- Scale effects:

  Usually the Froude scaling is used which means that the phenomena which are governed by Reynolds number will not be modelled correctly (drag, flow separation…).

  On the other hand the proper scaling of the tendons/risers dynamics is very difficult to achieve.
- Finite dimension of the existing model basins:

  This might lead to the important reflections from the tank walls, which in turn can significantly pollute the final results.
- Finite water depth:

  The water depth does not necessarily respect the scaling of the TLP dimensions.
- Accuracy of the measurements.
- Limited time records of the measurement data.
- High cost.

The responses which are usually assessed using the model tests include TLP motions, tendon/risers motions, internal loads in the TLP hull, air-gap and deck clearance, installation procedures, limited aspects of the VIV effects…

As already mentioned, the model tests and numerical simulations should be used in a complementary way. These complementarities include in particular the use of the model tests to provide the results for detailed validation of the numerical models, and the use of the numerical models in order to reduce the number of model tests.

The choice of the representative model tests heavily depend on the detailed TLP design.

3 Other environmental loads

3.1 Wind

3.1.1 Wind represents an important loading source in the design of TLP. The wind is represented by its mean and dynamic (gust) components. The dynamic component is usually described by the wind spectrum. The wind condition for design should be determined from the wind data collection on the site. The wind speed and direction usually vary in time which makes its characterization rather difficult.

The main influence of the wind is on the slow drift TLP horizontal motions (surge, sway and yaw) and the wind forces need to be included in the coupled time domain model for determination of the mean off-set and set down of the TLP as well as for the determination of the maximum platform excursions.

The wind forces are usually calculated using the simplified approach where the forcing is made proportional to the square of the relative velocity through the use of the so called shape coefficients.

$$F_w = \frac{1}{2}\rho_a C_s A\left|V + v' - \frac{dx}{dt}\right|\left(V + v' - \frac{dx}{dt}\right)$$

where:

ρ_a	:	Wind density
C_s	:	Shape coefficient
A	:	Characteristic area
V	:	Wind mean speed
v'	:	Wind fluctuating speed
dx / dt	:	Velocity of the structural member.

The shape coefficient can be related to particular structural elements but can also be used in a more global sense where it relates to the projected exposed area of the objects. Its determination is usually based on engineering experience otherwise the dedicated model tests might be performed.

3.2 Current

3.2.1 Depending on the site where TLP is operating the current forces might play an important role in the design of TLP. The site current data need to be collected and should include wind driven, tidal and background circulation components. Similar to the wind, the current data collection and current characterization is not an easy task because the current vary with the water depth both in terms of intensity and direction.

There are two main effects of current:

- Drag forces
- Vortex Induced Vibrations (Motions), VIV(M).

Through these effects current affects both the design of risers/tendons but also the overall TLP design. Similar to wind forces, the current induced drag forces are calculated using the simplified approach where the forces are related to the square of the relative velocity through the use of the drag coefficient:

$$F_c = \frac{1}{2}\rho_w \int_L C_D A_c \left|U - \frac{dx}{dt}\right|\left(U - \frac{dx}{dt}\right) dl$$

where:

ρ_w : Water density

L : Total length of the slender object (tendon/riser)

C_D : Drag coefficient

A_C : Characteristic sectional area

U : Current velocity

dx / dt : Velocity of the structural member.

The current effects do not produce the steady drag forces only, and can also produce the excitation and damping at low frequencies. The current damping effects are particularly important in the analysis of the slow drift TLP oscillations.

4 Hydro structure interactions

4.1 Introduction

4.1.1 In order to assess the structural design of the TLP dedicated direct hydro structure calculations needs to be performed. The calculations should be performed both for extreme structural responses (yielding and buckling) and for fatigue type of the responses in critical details. The issues and representative loading conditions are different for different parts of the TLP structure. In general the verification of the hull-structure and the tendons should be performed separately. The tendon connections and the area around them should be performed using the combined approach which mixes the procedure for hull and that for tendons.

The direct calculation procedure should be employed for verification of the hull structure in both extreme and fatigue conditions. In order to successfully perform the hydro-structure calculations within the reasonable time limits, the frequency and time domain approaches should be mixed.

4.2 Extreme structural response of TLP hull

4.2.1 For the verification of the structural response of the hull in extreme conditions, the concept of equivalent design wave is employed.

The procedure is performed in two main steps:

a) Determination of the long term value of the critical loading parameters (frequency domain)

b) Definition of the equivalent design wave

c) Nonlinear time domain hydro-structure simulations over the equivalent wave period

d) Yielding and buckling check for particular structural elements.

4.2.2 Determination of the long term value of the critical loading parameters (frequency domain)

Critical loading parameters are first identified. This is one of the most important steps because it should ensure that the most critical situations for all structural elements will be covered using only limited number of loading parameters. The exact list of the loading parameters will highly depend on the type of the TLP hull and on the engineering experience.

As an example, typical loading parameters for typical TLP concept are given below:

a) Squeeze-pry loads between columns

b) Torsion moment about the transverse horizontal axis

c) Longitudinal shear force between the pontoons

d) Longitudinal acceleration of deck mass

e) Transverse acceleration of the deck mass

f) Vertical acceleration of the deck mass

g) Vertical wave bending moment on the pontoons.

All these loads can be calculated using the hydrodynamic simulations only and there is no need for calculating the structural response. In principle the calculations needs to be performed at least for zero and maximum offset but some intermediate drafts might be necessary.

In order to calculate the long term value of each loading parameter, frequency domain calculations are performed using the linear wave diffraction-radiation theory. The range and number of wave frequencies and wave directions should be chosen in such a way that the design scatter diagram and other environmental conditions (wind, wave directions…) can be covered with sufficient accuracy. Usually this means at least 50 frequencies per wave direction. The outcomes of these calculations are the transfer functions (RAO's) of different loading parameters. Once the RAO's are evaluated, spectral analysis is performed for each sea state in the scatter diagram and long term values are obtained.

4.2.3 Definition of the equivalent design wave

The equivalent design wave is defined by dividing the long term value of the considered loading parameter by its maximum RAO value. For each loading parameter this gives the wave length, wave direction and wave amplitude of the design wave. In the cases where the peak wave length gives obviously unreasonable conservative results the wave length might need to be adjusted. This will depend on the engineering experience which might be supported by some dedicated calculations of the structural response.

4.2.4 Nonlinear time domain hydro-structure simulations over the equivalent wave period

Once the design wave characteristics are determined the hydrodynamic loading is transferred from the hydrodynamic model to the structural FE model. This includes the transfer of:

- hydrodynamic pressures
- inertia loads
- forces in tendons.

It is absolutely necessary to ensure the perfect equilibrium of these 3 different parts of the loading! This is the critical step in the overall procedure and requires very careful considerations.

It is important to note that, even if the long term analysis is based on the linear frequency domain approach, the application of the design wave should be done in a weakly nonlinear sense. This means that at least the non linear Froude Krylov pressures the non linear hydrostatics and the large body motions should be included.

In the cases where the Morison equation is used for some parts of the structure, these loading should also be transferred to the FE model in an efficient way and should not introduce any unbalance of the FE model.

4.3 Fatigue analysis of the hull structural details

4.3.1 The fatigue analysis of the hull structural details is performed using the spectral fatigue approach. The overall procedure can be subdivided into following steps:

a) Identification of the critical details
b) Identification of the representative loading conditions
c) Calculation of the linear global structural response in frequency domain
d) Top down analysis for evaluation of the concentrated stresses in the fine meshes of structural details
e) Spectral analysis
f) Calculation of the fatigue damage (SN approach or fracture mechanics approach).

Ultimately the calculation can be performed in time domain and the rainflow counting method can be applied. However due to much higher computational requirements this method appears to be of less practical interest.

The spectral fatigue analysis requires the calculation of relatively huge number of loading cases (large number of frequencies and headings, important number of loading conditions,…). Special care should be given to proper balancing (pressure, inertia and tendon forces) of the FE model. The top down analysis should also be performed with care and the local pressure loading (external and eventually internal) should be applied in addition to the imposed displacements of the fine mesh boundaries.

4.4 Structural analysis of the tendons

4.4.1 Similar to the structural analysis of the hull structure, the structural analysis of the tendons also includes the extreme and fatigue types of analyses.

Tendon loads consist of static and dynamic components.

Static loads arise from tendon pretension, platform offset due to steady wind, wave and current forces, and foundation installation position errors. The static loads can be determined from the equilibrium conditions of the platform, tendons (and risers).

Dynamic tendon loads arise from platform and seismic motions, wind gusts and direct hydrodynamic forces as wave forces and vortex-induced loads.

Dynamic axial and bending loads on tendons are primarily induced by platform motions. The platform motions as described above must include wave-frequency effects, low-frequency slow-drift and high-frequency springing and ringing effects.

In the general case the platform motions and dynamic behaviour of tendons are coupled and nonlinear so that fully coupled dynamic analysis of the tendons should be required.

However, for some types of TLP's at some steps of the design process the uncoupled analysis can be used. In the uncoupled analysis of platform motions, the tendons are considered as a spring and its stiffness is linearised and introduced in the motion equation of platform. An equivalent vertical mass of tendon can be applied to the platform/tendon attachment point to account for tendon inertial contribution. On the other hand, a forcing motion is applied at the platform/tendon attachment point in the dynamic analysis of tendons. The direct hydrodynamic forces as wave and current loads, and vortex-induced loads are applied along the tendon.

Special attention is to be given to tendons' axial vibrations and transversal vibrations of resonant type. They should be evaluated to determine the maximum/minimum tension and fatigue life of tendons.

Note 1: The extreme loading of the tendons should include the effects of ringing.

Note 2: Due to the particularities of the TLP design, the tendons are significantly excited by the second order high frequency type of loadings which means that the fatigue analysis of the tendons should include both linear and second order spectral analysis.

5 Overview of the hydrodynamic issues in TLP design and the associated methods of analysis

5.1

5.1.1 The non exhaustive list, of the important hydrodynamic issues in the TLP design, is given below.

Depending on the type of the TLP and the site conditions, this list should be extended (TLP with moon-pool, influence of sloshing motion in the tanks, strong current conditions…).

5.1.2 Offset and set-down

The maximum horizontal excursion is important for analysis of riser and tendon systems, and partially governs the deck height requirement because of platform set-down with offset.

The preliminary calculations include the evaluation of the mean offset by summing up the following effects:

- Tidal effects
- Mean wind forces on the superstructures
- Mean current forces on hull and tendons
- Mean second order drift forces
- Instantaneous mean forces in the tendons
- Instantaneous buoyancy.

More advanced calculations involve coupled slow drift time domain simulations which give the maximum off-sets and set down. The following effects should be included:

- Linear frequency domain effects
- Slowly varying second order wave forces
- Time dependent wind forces
- Time dependent current forces
- Nonlinear body motions
- Nonlinear hydrostatics
- Nonlinear forces in the tendons.

Special attention should be given to the evaluation of damping of slow drift motion (drag on tendons riser and hull, wave drift damping ...).

5.1.3 Yaw

The prediction of maximum yaw is important to determine the maximum rotation of riser and tendon top terminations and for the yaw contribution to horizontal excursions. The maximum yaw is obtained as the direct output of the coupled slow drift time domain simulations mentioned above.

5.1.4 Tendon tensions

The maximum and minimum tendon tensions are determined by considering the pretension and environmental effects. The nominal pretension is selected in order to limit maximum offset, and control minimum tensions. High-frequency oscillatory tensions determine the fatigue life of tendons. In addition, the maximum tendon angle at the upper and lower flex assemblies is an important factor of design.

The maximum and minimum tendon tensions are obtained from the coupled slow drift time domain simulations. If necessary, the maximum tendon tensions should be increased for ringing effects.

The fatigue related tendon response will be mainly governed by the linear frequency domain TLP response and by the high frequency springing response. The calculations can be performed in frequency domain from which the motions on top of the tendons is deduced and applied as the excitation on the tendons. Other forces which should be added on the structural model of the tendon are the current forces including drag and vortex shedding (VIV effects).

5.1.5 Deck clearance and run-up

A minimum clearance between the deck and a wave crest must be kept to avoid wave impact. Otherwise the deck structure should be reinforced in order to withstand the impact loading. The critical situation arises in the maximum offset and set-down conditions with the presence of the strong wave field. Due to the strong hydrodynamic interactions in between the columns, the maximum wave elevation in between the TLP columns is governed both by the first and higher order wave diffraction radiation effects. At least second order diffraction effects should be included. Model tests might be necessary.

5.1.6 Accelerations

The lateral accelerations of the platform are used in the design of the structure and equipment. The vertical accelerations may be assumed to be small due to taut stiffness of tendons. The maximum accelerations can be obtained either from the linear frequency domain simulations around the representative mean TLP positions, or from the coupled time domain simulations in which the wave frequency effects are included.

5.1.7 Internal loads in the hull structure

The different types of the internal loads (squeeze-pry loads between columns, torsion moment about a transverse horizontal axis, longitudinal shear force between the pontoons, vertical wave bending moment on the pontoons….) in the hull structure of the TLP, are important design parameters (see hydro-structure section). These loads are dominated by the linear wave diffraction radiation loads and can be calculated using the linear frequency domain method. However the resulting design cases for extremes should include the nonlinear corrections (Froude-Krylov, large motions, nonlinear hydrostatics, nonlinear tendon forces…). For fatigue issues the linear or linearized frequency domain simulations within the spectral approach are usually necessary except for some particular structural details (tendon attachements…).

5.1.8 Pressures

For both extreme responses and fatigue calculations the local hydrodynamic pressure loads should be consistently transferred to the FE structural model of the TLP and should be properly balanced by the respective inertia of the TLP structure and the restoring forces from hydrostatic pressure action and the tendon forces. In the case of the evaluation of the extreme structural responses the pressure distribution should be corrected by the nonlinear effects (Froude-Krylov, non linear hydrostatics, stretching of the dynamic pressure up to the real free surface) and the nonlinearities related to the large ship motions and nonlinear tendon forces should be included. In any case the final FE model should be perfectly balanced.