DNV·GL

OFFSHORE STANDARD

DNVGL-OS-C105 Edition July 2015

# Structural design of TLPs - LRFD method



DNV GL AS

# FOREWORD

DNV GL offshore standards contain technical requirements, principles and acceptance criteria related to classification of offshore units.



Any comments may be sent by e-mail to *rules@dnvgl.com*

# CHANGES – CURRENT

## General

This document supersedes DNV-OS-C105, July 2014.

Text affected by the main changes in this edition is highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

On 12 September 2013, DNV and GL merged to form DNV GL Group. On 25 November 2013 Det Norske Veritas AS became the 100% shareholder of Germanischer Lloyd SE, the parent company of the GL Group, and on 27 November 2013 Det Norske Veritas AS, company registration number 945 748 931, changed its name to DNV GL AS. For further information, see www.dnvgl.com. Any reference in this document to "Det Norske Veritas AS", "Det Norske Veritas", "DNV", "GL", "Germanischer Lloyd SE", "GL Group" or any other legal entity name or trading name presently owned by the DNV GL Group shall therefore also be considered a reference to "DNV GL AS".

## Main changes

### • General

The revision of this document is part of the DNV GL merger, updating the previous DNV standard into a DNV GL format including updated nomenclature and document reference numbering, e.g.:

— Main class identification **1A1** becomes **1A**.
— DNV replaced by DNV GL.
— DNV-RP-A201 to DNVGL-CG-0168. A complete listing with updated reference numbers can be found on DNV GL's homepage on internet.

To complete your understanding, observe that the entire DNV GL update process will be implemented sequentially. Hence, for some of the references, still the legacy DNV documents apply and are explicitly indicated as such, e.g.: Rules for Ships has become DNV Rules for Ships.

### • Ch.2 Sec.1 Structural categorisation, material selection and inspection principles

— [2] More clear definition of structural categories have been provided.
— [3.1] Special considerations have been added for casting material.
— [3.2] Design temperature definition to be aligned with other OS has been updated.

### • Ch.2 Sec.2 Design principles

— [2.1] Better definition of class scope with respect to temporary phases has been provided.
— [2.3] Considerations/guidance notes for tendon fabrication have been added.
— [2.6] Considerations have been added for VIV/VIM during tendon free standing phase.
— [3] Better definition of tendon design principal, guidance note have been added to explain 'fail proof' philosophy.
— [4] Design principles for foundation have been added.
— [5] Design principles for systems have been added - special consideration for TLP application.
— [6] Design principles for simultaneous operations have been added.

### • Ch.2 Sec.3 Design loads

— [2] Guidance note has been added with regards to minimum sea pressure.

### • Ch.2 Sec.4 Global performance

— [1] More clear definition of design conditions to be considered.

### • Ch.2 Sec.5 Ultimate limit states (ULS)

— [1.1.8] Reference has been added for material factors for foundation under ULS condition.
— [1.2.6] Guidance note has been added with regards to inclining test requirement for TLP.

— [6] Foundation design section has been updated with more detailed requirements.

- Ch.2 Sec.7 Accidental limit states (ALS)

— [1.2] Guidance note has been added with regards to ballast system capacity.

— [2] More clear definition has been provided with respect to accidental loads required in the design.

— [3] Requirement of analysis to evaluate consequence of tendon failure has been deleted.

— [4] Reference has been added for material factors for foundation under ALS condition.

- Ch.3 Sec.2 Certification of tendon system

— [1] List of acceptable standards have been deleted and reference is made to Table 1-1 and 1-2.

— [4] Definition of IRN has been deleted because this is no longer issued; certification for sub-components is clarified.

— [5.2] Guidance note has been updated to clarify requirements for line pipes.

— [5.5] Previous sub-section about Foundation has been deleted; relevant requirements are moved to relevant sections in Chapter 2. Because all the requirements are related to main class design approval rather than certification or fabrication.

— [5.7] Some requirements for tendon tension monitoring system (TTMS) that were accidentally deleted have been reinstated.

— [5.8] Acceptance criteria for tendon porch has been added.

— [5.10] Requirements for load management program (LMP) has been further clarified.

— [6] Categorization of tendon components, sub-components and their certificate requirements have been clarified.

— [7] Guidance note has been added with regards to level of NDT for tendon pipes.

## Editorial corrections

In addition to the above stated main changes, editorial corrections may have been made.

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# CHAPTER 1 INTRODUCTION

## SECTION 1 INTRODUCTION

### 1 General

#### 1.1 Introduction

**1.1.1** This standard provides requirements and guidance to the structural design of TLPs. The requirements and guidance documented in this standard are generally applicable to all configurations of tension leg platforms.

**1.1.2** This standard is based on the load and resistance factor design method (LRFD). LRFD is defined in DNVGL-OS-C101.

**1.1.3** A TLP can alternatively be designed according to working stress design principles, which is defined in DNVGL-OS-C201.

**1.1.4** A TLP can also alternatively be designed to API RP 2T as it has been accepted that it meets the safety levels required by this Standard. For requirements that are not specifically defined in API RP 2T, applicable requirements stated in this offshore standard shall be followed.

**1.1.5** A *Tension Leg Platform (TLP)* is defined as a buoyant unit connected to a fixed foundation (or piles) by pre-tensioned tendons. The tendons are normally parallel, near vertical elements, acting in tension, which usually restrain the motions of the TLP in heave, roll and pitch. The platform is usually compliant in surge, sway and yaw. Figure 1 shows an example of a tension leg platform.

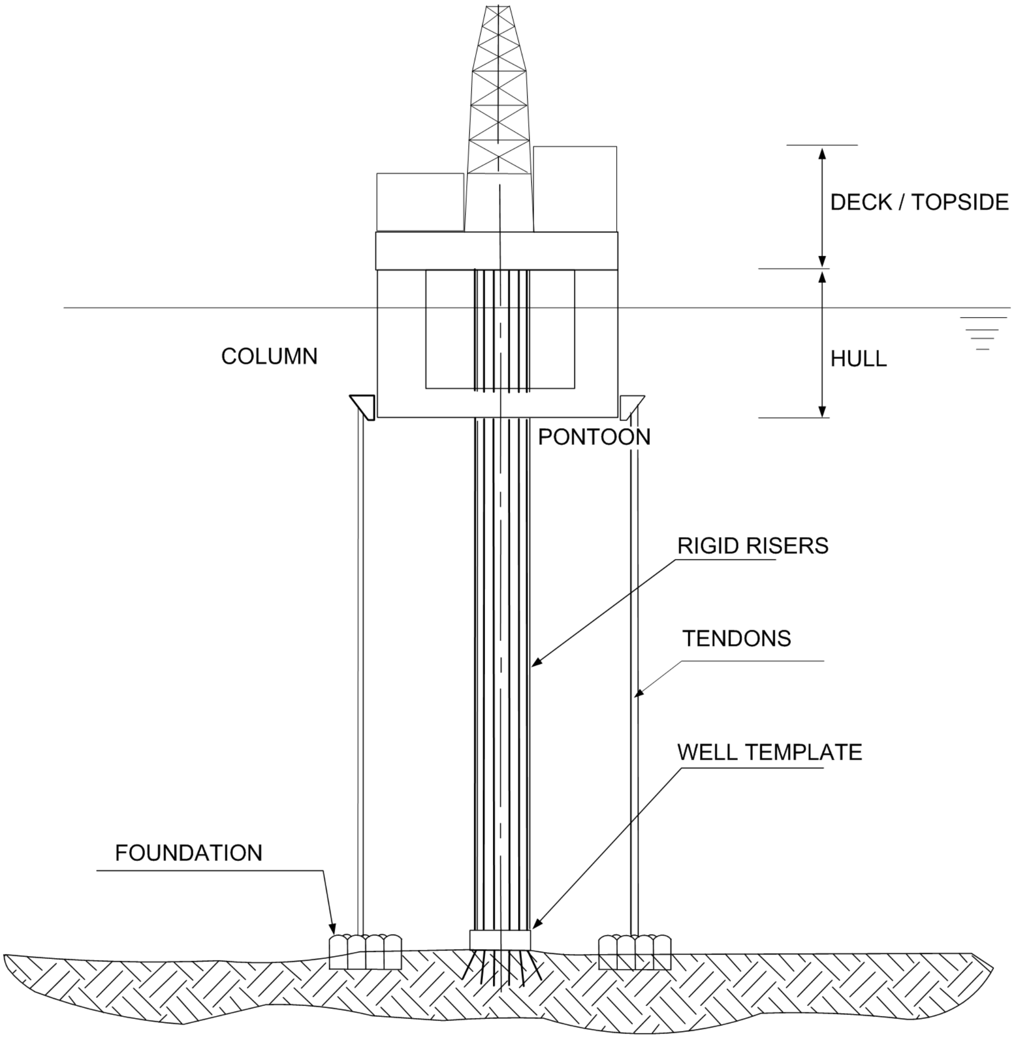



**Figure 1 Example of a tension leg platform**

**1.1.6** The standard has been written for general world-wide application. Governmental regulations may include requirements in excess of the provisions of this standard depending on size, type, location and intended service of the offshore unit/installation.

## 1.2 Objectives

The objectives of the standard are to:

- provide an internationally acceptable standard of safety by defining minimum requirements for structural design of TLPs
- serve as a contractual reference document for suppliers and purchasers
- serve as guidance for designers, suppliers, purchasers and regulators
- specify procedures and requirements for TLP units subject to DNV GL verification classification and certification services.

## 1.3 Scope and application

**1.3.1** A TLP is usually applied for drilling, production and export of hydrocarbons. Storage may also be a TLP function.

**1.3.2** The TLP unit should also be designed for transit relocation, if relevant.

**1.3.3** For novel designs, or unproved applications of designs where limited, or no direct experience exists, relevant analyses and model testing shall be performed which clearly demonstrate that an acceptable level of safety can be obtained, i.e. safety level is not inferior to that obtained when applying this standard to traditional designs.

**1.3.4** Requirements concerning riser systems are given in DNV-OS-F201.

**1.3.5** In case of application of a catenary or taut mooring system in combination with tendons, reference is made to DNVGL-OS-E301. Combined effects of mooring system (e.g. backline moorings) and tendon systems should be properly accounted for in the design.

**1.3.6** Requirements related to stability (intact and damaged) are given in Ch.2 Sec.5 for ULS condition and Ch.2 Sec.7 for ALS condition.

## 2 References

DNVGL/DNV Offshore Standards and DNVGL/DNV recommended practices in Table 1 and other recognized codes and standards in Table 2 are referred to in this standard.

Other recognised standards may be applied provided it can be demonstrated that they meet or exceed the level of safety of actual DNVGL Offshore Standards.

**Table 1 DNVGL and DNV reference documents**

| *Reference* | *Title* |
|---|---|
| DNVGL-OS-A101 | Safety principles and arrangement |
| DNVGL-OS-B101 | Metallic materials |
| DNVGL-OS-C101 | Design of offshore steel structures, general (LRFD method) |
| DNVGL-OS-C103 | Structural design of column stabilised units (LRFD method) |
| DNVGL-OS-C106 | Structural design of deep draught floating Units |
| DNVGL-OS-C201 | Structural design of offshore units (WSD method) |
| DNVGL-OS-C301 | Stability and watertight integrity |
| DNVGL-OS-C401 | Fabrication and Testing of offshore structures |
| DNV-OS-C501 | Composite Components |
| DNV-OS-C502 | Offshore Concrete Structures |
| DNVGL-OS-D202 | Instrumentation and telecommunication systems |
| DNVGL-OS-E401 | Helicopter decks |
| DNVGL-OS-E301 | Position mooring |
| DNV-OS-F101 | Submarine Pipeline System |
| DNV-OS-F201 | Dynamic Risers |
| DNV-RP-B401 | Cathodic Protection Design |
| DNVGL-RP-C103 | Column-stabilised units |
| DNVGL-RP-C201 | Buckling of plated structures |
| DNV-RP-C202 | Buckling Strength of Shells |
| DNVGL-RP-C203 | Fatigue strength analysis |
| DNV-RP-C204 | Design against Accidental Loads |
| DNV-RP-F201 | Composite Risers |
| DNV-RP-F203 | Riser Interference |
| DNV-RP-F204 | Riser Fatigue |
| DNVGL-RP-0001 | Probabilistic methods for planning of inspection for fatigue cracks in offshore structures |
| DNV Classification Notes 30.1 Sec. 2 | Buckling Strength Analysis (Bars and Frames) |
| DNV Classification Notes 30.6 | Structural Reliability Analysis of Marine Structures |
| DNV-OS-H101 | Marine Operations, General |

**Table 1 DNVGL and DNV reference documents (Continued)**

| *Reference* | *Title* |
|---|---|
| DNV-OS-H102 | Marine Operations, Design and Fabrication |
| DNV-OS-H201 | Load Transfer Operations |
| DNV-OS-H202 | Sea transport operations (VMO Standard – Part 2-2) |
| DNV-OS-H203 | Transit and Positioning of Offshore Units |
| DNV-OS-H204 | Offshore Installation Operations (VMO Standard Part 2-4) |
| DNV-OS-H205 | Lifting Operations (VMO Standard - Part 2-5) |
| DNV-OS-H206 | Loadout, transport and installation of subsea objects (VMO Standard - Part 2-6) |

**Table 2 Other references**

| *Reference* | *Title* |
|---|---|
| API RP 2A | Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design |
| API RP 2T | Planning, Designing and Constructing Tension Leg Platforms |
| API RP 2R | Recommended Practice for Design, Rating and Testing of Marine Drilling Riser Couplings |
| API RP 2RD | Design of Marine Risers for Floating Production System and TLPs |
| N-004 | NORSOK - Design of Steel Structures |
| API SPEC 2H | Specification for Carbon Manganese Steel Plate for Offshore Platform Tubular Joints |
| API RP 2L | Recommended Practice for Planning, Designing and Constructing Heliports for Fixed Offshore Platforms |
| BS 7910 | Guide on Methods for Assessing the Acceptability of Flaws in Fusion Welded Structures |
| BS 7448 | Fracture Mechanics Toughness Tests |
| ISO 19902 | Petroleum and natural gas industries - fixed steel offshore structures |
| Eurocode 3 | Design of steel structures |

# 3 Definitions

## 3.1 Verbal forms

**Table 3 Verbal forms**

| *Term* | *Definition* |
|---|---|
| shall | verbal form used to indicate requirements strictly to be followed in order to conform to the document |
| should | verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required |
| may | verbal form used to indicate a course of action permissible within the limits of the document |

## 3.2 Terms

**Table 4 Terms**

| *Term* | *Definition* |
|---|---|
| heave restrained platform (HRP) | a platform which is free to roll and pitch, but restrained in the heave eigenmode |
| high frequency (HF) responses | defined as TLP rigid body motions at, or near heave, roll and pitch eigenperiods due to non-linear wave effects |
| low frequency (LF) responses | defined as TLP rigid body non-linear motions at, or near surge, sway and yaw eigenperiods |
| mini TLP | small tension leg platform with one, or multiple columns |
| ringing | defined as the non-linear high frequency resonant response induced by transient loads from high, steep waves |
| roll, pitch, and yaw | rotational modes around surge, sway and heave axis, respectively |

**Table 4 Terms (Continued)**

| *Term* | *Definition* |
|---|---|
| springing | defined as the high frequency non-linear resonant response induced by cyclic (steady state) loads in low to moderate seastates |
| surge, sway, heave | translatory displacements of TLP in horizontal planes (surge, sway) and vertical plane (heave) |
| TLP deck structure | the structural arrangement provided for supporting the topside equipment or modules<br>Normally, the deck serves the purpose of being the major structural component to ensure that the pontoons, columns and deck act as one structural unit to resist environmental and gravity loads. |
| TLP foundation | defined as those installations at, or in, the seafloor which serve as anchoring of the tendons and provides transfer of tendon loads to the foundation soil |
| TLP hull | consists of buoyant columns, pontoons and intermediate structural bracings, as applicable |
| TLP tendon system | comprises all components between, and including the top connection(s) to the hull and the bottom connection(s) to the foundation(s)<br>Guidelines, control lines, umbilicals etc. for tendon service and or other permanent installation aids are considered to be included as part of the tendon system |
| vortex induced motions (VIM) | vortex induced motion (VIM): Transverse (cross) and in-line, current induced floater motions |
| vortex induced vibrations (VIV) | the in-line and transverse oscillation of a tendon, riser, or floater in a current induced by the periodic shedding of vortices |
| wave frequency (WF) responses | TLP linear rigid body motions at the dominating wave periods |

# 4 Abbreviations and symbols

## 4.1 Abbreviations

**Table 5 Abbreviations**

| *Abbreviation* | *In full* |
|---|---|
| ALS | accident limit states |
| AUT | automatic ultrasonic testing |
| BTI | bottom tendon interface |
| BTC | bottom tendon connector |
| DFF | design fatigue factors |
| FLS | fatigue limit states |
| FPSO | floating production storage and offloading unit |
| HF | high frequency |
| HRP | heave restrained platform |
| IC | inspection category |
| LAJ | length adjustment joint |
| LAT | lowest astronomical tide |
| LMP | load management program |
| OS | offshore standard |
| OSS | offshore service specification |
| LF | low frequency |
| LRFD | load and resistance factor design |
| NDT | non-destructive testing |
| QTF | quadratic transfer function |
| RAO | response amplitude operator |

**Table 5 Abbreviations (Continued)**

| *Abbreviation* | *In full* |
|---|---|
| SIMOP | simultaneous operation |
| TAD | tender assisted drilling |
| TLP | tension leg platform |
| TLWP | tension leg wellhead platform |
| TTI | top tendon interface |
| TTMS | tendon tension monitoring system |
| ULS | ultimate limit states |
| VIM | vortex induced motion |
| VIV | vortex induced vibrations |
| WF | wave frequency |

## 4.2 Symbols

**4.2.1** The following Latin symbols are used:

$x_D$ load effect
D number of years
$F_X(\chi)$ long-term peak distribution
$H_s$ significant wave height
$N_D$ total number of load effect maxima during D years
$T_p$ wave period.

**4.2.2** The following Greek symbols are used:

$\gamma_{f,D}$ load factor for deformation loads
$\gamma_{f,E}$ load factor for environmental loads
$\gamma_{f,G,Q}$ load factor for permanent and functional loads
$\gamma_m$ material factor.

# 5 Description of the tendon system

## 5.1 General

**5.1.1** Individual tendons are considered within this standard as being composed of three major parts:

— interface at the platform
— interface at the foundation (seafloor)
— link between platform and foundation.

In most cases, tendons will also have intermediate connections or couplings along their length, see Figure 2.

**5.1.2** Tendon components at the platform interface shall adequately perform the following main functions:

— apply, monitor and adjust (if possible) a prescribed level of tension to the tendon
— connect the tensioned tendon to the platform
— transfer side loads and absorb bending moments or rotations of the tendon relative to TLP.

**5.1.3** Tendon components providing the link between the platform and the foundation consist of tendon elements (tubulars, solid rods etc.), termination at the platform interface and at the foundation interface, and intermediate connections of couplings along the length as required. The intermediate connections may take the form of mechanical couplings (threads, clamps, bolted flanges etc.), welded joints or other types of connections. Figure 2 shows a typical TLP tendon system.

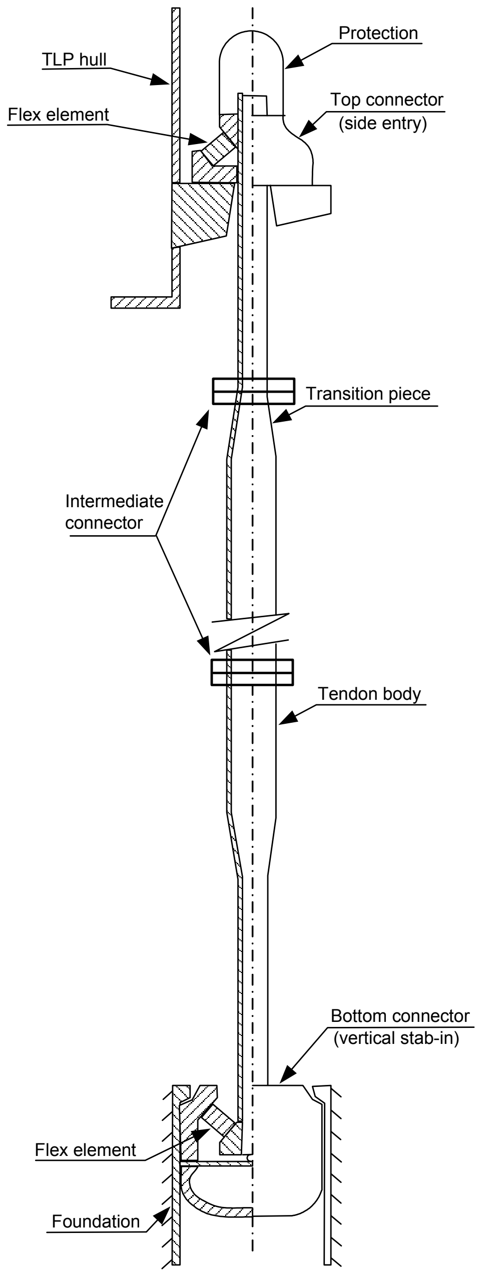



**Figure 2 Typical TLP tendon system**

**5.1.4** Tendon components at the foundation interface shall adequately perform the following main functions:

— provide the structural connection between the tendon and the foundation
— transfer side loads and absorb bending moments, or rotations of the tendon
— tolerate certain level of tendon slacking without disengaging or buckling the tendon
— allow for future change-out of tendons (if required).

**5.1.5** The tendon design may incorporate specialised components, such as:

— corrosion-protection system components
— buoyancy devices
— sensors and other types of instrumentation for monitoring the performance and condition of the tendons

- auxiliary lines, umbilicals etc. for tendon service requirements and/or for functions not related to the tendons
- provisions for tendons to be used as guidance structure for running other tendons or various types of equipment
- elastomeric elements
- intermediate connectors with watertight bulkheads for tendon compartmentation (if needed).

**5.1.6** Certification requirements for tendon system are specified in Ch.3 Sec.2.

# CHAPTER 2 TECHNICAL CONTENT

## SECTION 1 STRUCTURAL CATEGORISATION, MATERIAL SELECTION AND INSPECTION PRINCIPLES

## 1 Introduction

### 1.1 General

**1.1.1** Selection of materials and inspection principles shall be based on a systematic categorisation of the structure according to the structural significance and the complexity of the joints or connections as given in DNVGL-OS-C101 Ch.2 Sec.3.

**1.1.2** In addition to in-service operational phases, consideration shall be given to structural members and details utilised for temporary conditions, e.g. fabrication, lifting arrangements, towing and installation arrangements, etc.

**1.1.3** For TLP structures that are similar to column stabilised units, the structural categorisation and extent of inspection for the structural components should follow the requirements as given in DNVGL-OS-C103. For TLPs that are similar to deep draught floaters, the structural categorisation and extent of inspection for the structural components should follow the requirements as given in DNVGL-OS-C106.

## 2 Structural categorisation

### 2.1 General

**2.1.1** Application categories for structural components are defined in DNVGL-OS-C101 Ch.2 Sec.3. Structural members of TLPs are grouped as follows, see Figure 1 and Figure 2.

*Special category*

a) External shell structure in way of intersections of columns, topside deck, lower hull and tendon porch etc.
b) "Through" material used at connections of columns, topside decks and lower hull which are designed to provide proper alignment and adequate load transfer.
c) External brackets, portions of bulkheads, and frames which are designed to receive concentrated loads at intersections of major structural members.
d) Tendon interfaces with the foundation and the TLP hull (e.g. piles, tendon porch etc).
e) Tendon and tendon connectors.
f) Highly utilized areas supporting crane pedestals, flare booms etc.

**Guidance note:**
Highly utilized areas are normally considered to be areas utilized more than 85% of the allowable capacity.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

*Primary category*

a) External shell structure of columns, lower and upper hulls.
b) Bulkheads, decks, stiffeners and girders which provide local reinforcement or continuity of structure in way of intersections, except areas where the structure is considered for special application.
c) Truss rows and horizontal diagonal bracings on the deck.
d) Main support structure of heavy substructures and equipment, e.g. cranes, life boat platform and helicopter deck.

*Secondary category*

a) Bulkheads, stiffeners, flats or decks and girders in columns, decks and lower hulls, which are not considered as primary or special application.

b) Horizontal braces and members on the decks.
c) Well-bay trusses and reaming members.
d) Other structures not categorised as special or primary.

**2.1.2** When using composite materials the structural categories (special, primary and secondary) as defined in [2.1.1] are equivalent to safety class high, normal and low as defined in DNV-OS-C501 Sec.2 [3.3].

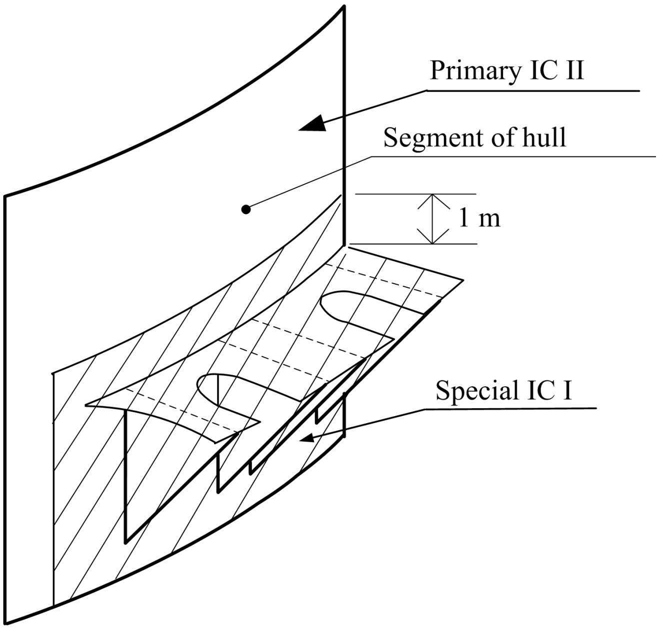
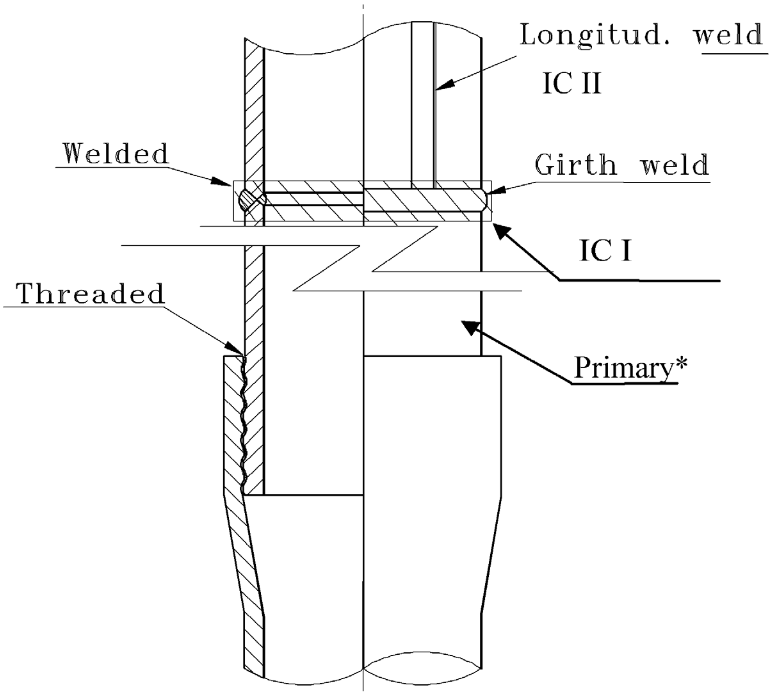



**Figure 1 Principles of the extent of structural categorisation special and inspection categories at tendon foundation**




* Special if damaged condition is not fulfilled.

**Figure 2 Example of tendon connections**

# 3 Material selection

## 3.1 General

**3.1.1** Material specifications shall be established for all structural materials. Such materials shall be suitable for their intended purpose and have adequate properties in all relevant design conditions. Material selection shall be undertaken in accordance with the principles given in DNVGL-OS-C101.

**3.1.2** Examples of considerations with respect to structural categorisation of tendons and tendon interfaces are given in the Figure 1 and Figure 2. These examples provide minimum requirements.

**3.1.3** Material selection is defined in DNVGL-OS-C101.

Further detailed information about material designation is defined in DNVGL-OS-B101.

**3.1.4** Composite materials shall be designed in accordance with DNV-OS-C501.

**3.1.5** When casting material is used for critical structural components, special attention shall be paid to the variation of material properties across the thickness. Such material property variation should be correctly reflected in the design evaluation.

## 3.2 Design temperatures

**3.2.1** The design temperature for a unit is the reference temperature for assessing areas where the unit can be transported, installed and operated. The design temperature for a TLP shall be lower or equal to the lowest mean daily temperature in air for the area(s) where the unit is to operate.

**3.2.2** The service temperatures for different parts of a unit apply for selection of structural steel. The service temperatures are defined as presented in [3.2.3] to [3.2.6]. In case different service temperatures are defined in [3.2.3] to [3.2.6] for a structural part the lower specified value shall be applied.

**3.2.3** External structures above the LAT shall not be designed for a service temperature higher than the design temperature for the unit.

**3.2.4** External structures below the LAT need not be designed for service temperatures lower than 0ºC.

**3.2.5** Internal structures of columns, pontoons and decks shall have the same service temperature as the adjacent external structure, if not otherwise documented.

**3.2.6** Internal structures in way of permanently heated rooms need not to be designed for service temperatures lower than 0ºC.

# 4 Fabrication inspection categories

## 4.1 General

**4.1.1** Welding and the extent of non-destructive testing (NDT) during fabrication, shall in general be in accordance with the requirements stipulated for the appropriate inspection category as defined in DNVGL-OS-C101 Ch.2 Sec.3.

**4.1.2** Inspection categories determined in accordance with DNVGL-OS-C101 provide requirements for the minimum extent of required inspection. When considering the consequences during in-service operation, it may be necessary to specify more demanding inspection requirements than the required minimum. Examples are in way of complex connections with limited or difficult access, or special material/process without proven characteristics.

**4.1.3** When determining the extent of inspection and the locations of required NDT, in addition to evaluating design parameters (for example fatigue utilisation), consideration should be given to relevant fabrication parameters including:

— location of block (section) joints
— manual versus automatic welding

- start and stop of weld etc.
- materials and criticality of location
- types of NDT used
- first time welds or repair welds.

**4.1.4** The Figure 1 and Figure 2 shows examples of structural categorisation and inspection category (IC).

**4.1.5** Inspection of composite components is described in DNV-OS-C501 Sec.12 [2]. Quality aspects regarding fabrication are described in DNV-OS-C501 Sec.11.

# SECTION 2 DESIGN PRINCIPLES

## 1 Introduction

### 1.1 General

**1.1.1** The following basic design criteria shall be complied with for the TLP design:

a) The TLP shall be able to sustain all loads liable to occur during all relevant temporary and operating design conditions for all applicable limit states.
b) Wave loading on the deck structure should not occur in the ultimate limit states (ULS). Wave loading on the deck structure may be accepted in the accidental limit states (ALS) condition provided that such loads are adequately included in the design.
c) Momentary (part of a high frequency cycle) loss of tendon tension may be accepted provided it can be documented that there will be no detrimental effects on tendon system and supporting (foundation and hull) structures, and it would not cause the tendon to become disengaged.

**1.1.2** Operating tolerances shall be specified and shall be achievable in practice. Normally, the most unfavourable operating tolerances shall be included in the design. Active operation shall not be dependent on high accountability of operating personnel in an emergency situation.

**Guidance note:**
Active operation of the following may be considered in an emergency situation, as applicable:

- ballast distribution
- weight distribution
- tendon tension
- riser tension.

A clearly defined and well calibrated Load Management Program or equivalent should be available onboard to facilitate safe management of these parameters in normal operation and emergency situation. Details of Load Management Program is given in Ch.3 Sec.2 [5.10].

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## 2 Design conditions

### 2.1 General

**2.1.1** The structure shall be designed to resist relevant loads associated with conditions that may occur during all stages of the life cycle of the unit. Such stages may include:

— fabrication
— site moves
— mating/assembly
— sea transportation
— installation
— operation
— decommissioning.

**2.1.2** Although classification scope is limited to in-place condition, any detrimental effects from other phases shall be accounted for. Such documentation shall be provided for class records.

Structural design covering marine operation and fabrication sequences shall be undertaken in accordance with DNVGL-OS-C101.

**2.1.3** Marine operations may be undertaken in accordance with the requirements stated in Rules for Planning and Execution of Marine Operations as described in DNV-OS-H101 to H206. All marine operations shall, as far as practicable, be based upon well proven principles, techniques, systems and equipment and shall be undertaken by qualified, competent personnel possessing relevant experience.

## 2.2 General fabrication

**2.2.1** The planning of fabrication sequences and the methods of fabrication shall be performed. Loads occurring in fabrication phases shall be assessed and, when necessary, the structure and the structural support arrangement shall be evaluated for structural adequacy.

**2.2.2** Major lifting operations shall be evaluated by the project to ensure that deformations are within acceptable levels, and that relevant strength criteria are satisfied.

## 2.3 Tendon fabrication

As tendon integrity is most critical to a TLP, it is important that a holistic approach throughout the tendon design and fabrication phases is maintained. The approach shall consider all variables to obtain the required confidence and reliability in the tendon system for the entire lifecycle.

Considerations shall be given to all stake holders involved in the tendon system build-up and how the quality is managed across all stakeholders and their interdependencies to ensure a robust tendon system. Number of subcontractors for fabrication of various tendon components /sub-components shall be carefully considered to ensure appropriate level of quality control and interface management.

**Guidance note:**
The holistic approach to a reliable fully assembled tendon system should include as a minimum the following parameters and understanding of the interdependencies between these parameters and how they affect the integrity of the final installed tendon assembly.

— material selection
— welding design and methods
— NDT methods and NDT operators' qualification
— achieved fabrication tolerances within the tendon pipe and between the tendon and tendon components
— fracture mechanics properties.

Design iterations may be needed if above parameters deviate from the original assumptions to ensure that the tendon system will achieve the originally designed target safety.

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## 2.4 Hull and deck mating

All relevant load effects incurred during mating operations shall be considered in the design process, e.g. hydrostatic load, lock-in stresses, tolerances, deflections, snatch/shock loads (if applicable) etc.

## 2.5 Sea transportation

**2.5.1** A detailed transportation assessment shall be undertaken which includes determination of the limiting environmental criteria, evaluation of intact and damage stability characteristics, motion response of the global system and the resulting, induced load effects. The occurrence of slamming loads on the structure and the effects of fatigue during transport phases shall be evaluated when relevant.

The accumulated fatigue damage during transportation phases shall be included in the fatigue assessment of in-place condition.

**2.5.2** In case of transportation (surface or sub surface) of tendons; this operation shall be carefully planned and analysed. Special attention shall be given to attachment or securing of buoyancy modules. Model testing shall be considered.

**2.5.3** Satisfactory compartmentation and stability during all floating operations shall be ensured. See details in Sec.5 for ULS condition and Sec.7 for ALS condition.

**2.5.4** All aspects of the transportation, including planning and procedures, preparations, seafastenings and marine operations should comply with the requirements of the warranty authority.

## 2.6 Installation

**2.6.1** Installation procedures of foundations (e.g. piles, suction anchor or gravity based structures) shall consider relevant static and dynamic loads, including consideration of the maximum environmental conditions expected for the operations.

**2.6.2** For novel installation activities (e.g. foundations and tendons), relevant model testing should be considered.

**2.6.3** Free standing tendon (pending TLP installation) phases shall be considered with respect to loads and responses.

Depending on site conditions and duration of free standing tendon phase the following loads shall be considered,

— current induced vibrations due to vortex shedding (VIV)
— vortex induced motion (VIM) of buoyancy cans.

The possibility of experiencing large angles at the bottom connector during free standing tendon phase shall be considered.

**2.6.4** The loads induced by the marine spread mooring involved in the operations, and the forces exerted on the structures utilised in positioning the unit, such as fairleads and pad eyes, shall be considered for local strength checks.

**2.6.5** For segmented tendons, tendon buckling should also be checked for the lifting of the segment during installation.

### 2.7 Decommissioning

Decommissioning and removal of the unit shall be planned for in the design stage.

## 3 Design principles, tendons

### 3.1 General

**3.1.1** Essential components of the tendon system shall be designed by the principle that, as far as practicable, they are to be capable of being inspected, maintained, repaired and/or replaced.

**3.1.2** Tendon mechanical components shall, as far as practicable, be designed to be “fail proof”. Consideration shall be given in the design to possible early detection of failure for essential components.

**Guidance note:**
Due to criticality and uncertainty in tendon component designs, usually high safety factors are used for tendon components (e.g. DFF in a range of 10-40). As any failure in the tendon system has a severe consequence, the design philosophy should include monitoring and early detection of any failure, e.g. leak-before-break.

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**3.1.3** Certain vital tendon components may, due to their specialized functions, and if unproven, require engineering and prototype qualification testing to determine:

— confirmation of anticipated design performance
— fatigue characteristics
— fracture characteristics
— corrosion characteristics
— mechanical characteristics.

**3.1.4** A TLP shall be designed with sufficient safety margin to prevent the potential of tendon rupture. The tendon system and the securing or supporting arrangements shall be designed in such a manner that a possible failure or removal of one tendon is not to cause progressive tendon failure or excessive damage to the securing or supporting arrangement at the platform or at the foundation.

**3.1.5** A fracture control strategy should be adopted to ensure consistency of design, fabrication and in service monitoring assumptions. The objective of such a strategy is to ensure that the largest undetected flaw from fabrication of the tendons will not grow to a size that could induce failure within the design life of the tendon, or within the planned in-service inspection interval, within an adequate level of reliability. Elements of this strategy include:

— adequate design fatigue life



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— adequate fracture toughness
— reliability of inspection during fabrication
— in-service inspection intervals and methods.

See Sec.6 for guidance on fracture control and required fatigue life for tendons.

**3.1.6** Inspection to detect damage due to accidental loads or overloads may be replaced by monitoring the loads and comparing them to the design loads, provided that the events can be measured by the monitoring system. If this method is used the component must be replaced after any overload occurrence or other events exceeding the design scenario.

**3.1.7** All materials liable to corrode shall be protected against corrosion. Special attention should be given to:

— local complex geometries
— areas that are difficult to inspect or repair
— consequences of corrosion damage
— possibilities for electrolytic corrosion
— dissimilar metal.

**3.1.8** All sliding surfaces shall be designed with sufficient additional thickness against wear. Special attention should be given to the following:

— cross-load bearings
— seals
— ball joints.

# 4 Design principles, foundations

The foundation system must provide a secure connection to the ground throughout the life of the TLP.

The foundation system shall be designed for the same in-place loading conditions as the tendon system it supports, including tendon damage and removal cases. The analysis shall reflect positioning tolerances for installation and installation loads such as pile driving.

The foundation system shall be designed adequately against yielding, fatigue and corrosion, and fabrication shall be carried out in accordance with recognized standards. Permanent long term or dynamic deflections needs to be taken into account.

Tendon foundation receptacle and pile above the mudline need to be protected from external corrosion by a combination of coatings and passive cathodic protection systems.

Satisfactory considerations shall be given to settlement or subsidence, which may be a significant factor in determining tendon-tension adjustment requirements. Subsidence assumed in the design shall be justified in conjunction with safety margin in design, e.g. airgap.

# 5 Design principles, systems

System design standards are defined in DNVGL-OS-A101, DNVGL-OS-D101, DNVGL-OS-D301, DNVGL-OS-D201 and DNVGL-OS-D202.

TLP may have different design and operational considerations for certain marine systems, e.g. ballast system with different functional design requirements than conventional ballast designs for ships and MODUs. Accordingly special considerations can be given when applying the rules to such “passive systems” based on the criticality of the system. In all cases, proposed deviations from the classification rules or international codes shall be discussed and properly documented early in the approval process, if applicable.

Units intended for both drilling and production service shall comply with the technical requirements for production units and for drilling units as referred to in DNVGL-RU-OU-0101 and DNVGL-RU-OU-0102 respectively. In case of conflicting requirements, the most stringent requirement governs.

**Guidance note:**
Water treatment may be necessary to prevent corrosion and marine growth from impairing ballast water performance. Special considerations should be given to stagnant ballast water.

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# 6 Design principles, simultaneous operation

If a TLP is working with a tender assisted drilling unit (TAD) or FPSO, considerations related to simultaneous operation (SIMOP) from all aspects of the combined use of the facility shall be considered, including but not limited to the following:

— effect of global performance due to coupled hydrodynamic effects
— mooring and structural design implications
— safety systems (e.g. firefighting, power system, accommodation and safe evacuation etc.).

# SECTION 3 DESIGN LOADS

## 1 General

Characteristic loads are to be used as reference loads. Design loads are, in general, defined in DNVGL-OS-C101. Guidance concerning load categories relevant for TLP designs are given in [2].

## 2 Load categories

### 2.1 General

**2.1.1** All relevant loads that may influence the safety of the structure or its parts from commencement of fabrication to permanent decommissioning should be considered in design. The different loads are defined in DNVGL-OS-C101.

**2.1.2** For the deck and hull of the TLP, the loads are similar to those described in DNVGL-OS-C103 for TLPs similar to column stabilised units. TLPs similar to deep draught floaters are to be designed with loads as given in DNVGL-OS-C106. Loads are described in the above with exception of the tendon loads (inclusive potential ringing and springing effects).

**Guidance note:**
Reference is made to DNVGL-RP-C103 [3.8.4]. In combination with the maximum tank pressures, the external sea pressure up to the lowest waterline at wave trough may be considered in the design of external plate field boundaries.

For a TLP, the static component of such external sea pressure should be the minimum draught account for lowest surge/tide etc; the dynamic component shall account for the maximum wave trough.

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**2.1.3** In relation to determination of environmental conditions and loads, see DNV-RP-C205 and DNV-OS-C501 for composites.

**2.1.4** The wave loads on the tendons may be described as recommended in DNV-RP-C205 for slender structures with significant motions.

**2.1.5** The disturbance of wave kinematics from hull (columns and pontoons) in relation to the riser system and tendons shall be accounted for if it is of importance.

**2.1.6** The earthquake loads at the foundation of the tendons are described in DNVGL-OS-C101.

**2.1.7** The following loads should be considered:

- permanent loads
- variable functional loads
- environmental loads
- deformation loads
- accidental loads.

**2.1.8** For preliminary design stages it is recommended that "contingency factors" are applied in relation to permanent loads to reflect uncertainties in load estimates and centres of gravity.

**2.1.9** "Contingency factors" should also be considered for early design stages in relation to variable functional loads, especially for minimum facilities TLPs (e.g. TLWP and Mini TLP).

**2.1.10** The environmental loads are summarised as:

- wind loads:
  - mean (sustained) wind
  - dynamic (gust) wind.
- wave and current loads:
  - loads on slender members

  - loads induced by TLP motions
  - slamming and shock pressure
  - wave diffraction and radiation
  - mean drift forces
  - higher order non-linear wave loads (slowly varying, ringing and springing)
  - wave enhancement
  - vortex shedding effects.

- marine growth
- snow and ice accumulation
- direct ice loads (icebergs and ice flows)
- earthquake
- tidal and storm surge effects
- effects from sand/marine growth getting into the connectors or the tendon body.

# SECTION 4 GLOBAL PERFORMANCE

## 1 Introduction

### 1.1 General

**1.1.1** The selected methods of response analysis are dependent on the design conditions, dynamic characteristics, non-linearities in loads and response and the required accuracy in the actual design phase.

**Guidance note:**
For a detailed discussion of the different applicable methods for global analysis of tension leg platforms, see API RP 2T.

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**1.1.2** The selected methods of analysis and models employed in the analysis shall include relevant non-linearities and motion-coupling effects. The approximations, simplifications and/or assumptions made in the analysis shall be justified, and their possible effects shall be quantified e.g. by means of simplified parametric studies. Various design conditions shall be evaluated, e.g. various mass conditions and mass distributions, multi-body interactions etc throughout all operating phases of the platform. Most severe conditions shall be documented.

**1.1.3** During the design process, the methodology and software used for analytical or numerical prediction of important system responses shall be verified (calibrated) by appropriate model tests.

**1.1.4** Model tests may also be used to determine specific responses for which numerical or analytical procedures are not yet fully developed and recognised.

**1.1.5** Motion components shall be determined, by relevant analysis techniques, for those applicable design conditions (design analyses matrix) specified in DNVGL-OS-C101. The basic assumptions and limitations associated with the different methods of analysis of global performance shall be duly considered prior to the selection of the methods.
Typically a combination of frequency domain and time domain analyses will be applied by the designers.

**1.1.6** The TLP should be analysed by methods as applicable to column-stabilised units or deep draught floaters when the unit is free floating, respectively see DNVGL-OS-C103 or DNVGL-OS-C106.

**1.1.7** The method of global performance analysis as outlined in this standard is one approximate method that may be applied. The designer is encouraged also to consider and apply other methods in order to discover the effects of possible inaccuracies etc. in the different methods.

## 2 Frequency domain analysis

### 2.1 General

**2.1.1** Frequency domain high frequency (HF), wave frequency (WF) and low frequency (LF) analyses techniques may be applied for a TLP. Regarding load effects due to mean wind, current and mean wave drift, see DNVGL-OS-C101.

**2.1.2** For typical TLP geometries and tendon arrangements, the analysis of the total dynamic load effects may be carried out as:

— a HF analysis of springing
— a WF analysis in all six degrees of freedom
— a LF analysis in surge, sway and yaw.

**2.1.3** The following assumptions are inherent in adopting such an independent analysis approach:

— the natural frequencies in heave, roll and pitch are included in the wave frequency analysis
— the natural frequencies in surge, sway and yaw are included in the low frequency analysis
— the high and low natural frequencies are sufficient separate to allow independent dynamic analysis to be carried out

— the low frequency excitation forces have negligible effect on the wave frequency motions
— the low frequency excitation forces have a negligible dynamic effect in heave, roll and pitch
— tendon lateral dynamics are unimportant for platform surge or sway motions.

**2.1.4** Typical parameters to be considered for global performance analyses are different TLP draughts, wave conditions and headings, tidal effects, storm surges, set down, foundation settlement(s), subsidence, mispositioning, tolerances, tendon flooding, tendon removal and hull compartment(s) flooding. Possible variations in vertical centre of gravity shall also be analysed (especially if ringing responses are important).

This may be relevant in case of:

— change in operation mode (e.g. drilling/production)
— changes in topside weights (e.g. future modules)
— tendon system changes (altered utilisation)
— changes in ballast weights or distributions
— deviations from weight estimate
— riser phasing scenarios
— lateral positioning.

## 2.2 High frequency analyses

**2.2.1** Frequency domain springing analyses shall be performed to evaluate tendon and TLP susceptibility to springing responses.

**2.2.2** Recognised analytical methods exist for determination of springing responses in tendons. These methods include calculation of quadratic transfer functions (QTF's) for axial tendon (due to sum frequency loads on the hull) stresses which is the basis for determination of tendon fatigue due to springing.

**2.2.3** Total damping level applied in the springing response analyses shall be duly considered and documented.

## 2.3 Wave frequency analyses

**2.3.1** A wave frequency dynamic analysis may normally be carried out by using linear wave theory in order to determine first-order platform motions and tendon response.

**2.3.2** First order wave load analyses shall also serve as basis for structural response analyses. Finite wave load effects shall be evaluated and taken into account. This may e.g. be performed by use of beam models and application of Morison load formulation and finite amplitude waves.

**2.3.3** In linear theory, the response in regular waves (transfer functions) is combined with a wave spectrum to predict the response in irregular seas.

**2.3.4** The effect of low-frequency set-down variations on the WF analysis is to be investigated by analysing at least two representative mean offset positions determined from the low-frequency analysis.

**2.3.5** Set-down or offset induced heave motion may be included in the wave frequency response amplitude operators (RAOs).

**2.3.6** A sufficient number of wave approach headings shall be selected for analyses (e.g. with basis in global configuration, number of columns, riser configuration etc.).

**2.3.7** In determination of yaw induced fatigue responses (e.g. tendon and flex element design) due account must be given to wave spreading when calculating the long term responses.

## 2.4 Low frequency analyses

**2.4.1** A low frequency dynamic analysis could be performed to determine the slow drift effects at early design stages due to fluctuating wind and second order wave loads.

**2.4.2** Appropriate methods of analysis shall be used with selection of realistic damping levels. Damping coefficients for low frequency motion analyses are important as the low frequency motion may be dominated by resonant responses.

# 3 Time domain analyses

## 3.1 General

**3.1.1** For global motion response analyses, a time domain approach will be beneficial. In this type of analyses it is possible to include all environmental load effects and typical non-linear effects such as:

- hull drag forces (including relative velocities)
- finite wave amplitude effects
- non-linear restoring (tendons, risers).

**3.1.2** Highly non-linear effects such as ringing may also require a time domain analysis approach. Analytical methods exist for estimation of ringing responses. These methods may be used for the early design stage, but shall be correlated against model tests for the final design. Ringing and springing responses of hull and deck may however be analysed within the frequency domain with basis in model test results, or equivalent analytical results.

**3.1.3** For deep waters, a fully coupled time domain analysis of tendons, risers and platform may be required. This may e.g. be relevant if:

- model basin scale will not be suitable to produce reliable design results or information
- consistent global damping levels (e.g. in surge, sway and yaw) due to the presence of slender structures (risers, tendons) are needed
- it is desirable to perform the slender structure response analyses with basis in coupled motion analyses.

**3.1.4** A relevant wave spectrum shall be used to generate random time series when simulating irregular wave elevations and kinematics.

**3.1.5** The simulation length shall be long enough to obtain sufficient number of LF maxima (surge, sway and yaw).

**3.1.6** Statistical convergence shall be checked by performing sensitivity analyses where parameters as input seed, simulation length, time step, solution technique etc. are varied.

**3.1.7** Determination of extreme responses from time domain analyses shall be performed according to recognised principles.

**3.1.8** Depending on selected TLP installation method, time domain analyses will probably be required to simulate the situation when the TLP is transferred from a free floating mode to the vertical restrained mode. Model testing shall also be considered in this context.

**Guidance note:**
*Combined loading*

Common practice to determine extreme responses has been to expose the dynamic system to multiple stationary design environmental conditions. Each design condition is then described in terms of a limited number of environmental parameters (e.g. Hs, Tp) and a given seastate duration (3 to 6 hours). Different combinations of wind, wave and current with nearly the same return period for the combined environmental condition are typically applied.

The main problem related to design criteria based on environmental statistics is that the return period for the characteristic load effect is unknown for non-linear dynamic systems. This will in general lead to an inconsistent safety level for different design concepts and failure modes.

A more consistent approach (as required in API RP 2T March, 2010 edition) is to apply design based on response statistics. Consistent assessment of the *D*-year load effect will require a probabilistic response description due to the long-term environmental loads on the system. The load effect with a return period of *D*-year, denoted $x_D$, can formally be found from the long-term load effect distribution as:

$$F_X(\chi_D) = 1 - 1/N_D$$

$N_D$ = total number of load effect maxima during *D* years
$F_X(\chi)$ = long-term peak distribution of the (generalised) load effect

The main challenge related to this approach is to establish the long-term load effect distribution due to the non-linear behaviour. Design based on response statistics is in general the recommended procedure and should be considered whenever practicable for consistent assessment of characteristic load effects.

Further details may be found in Appendices to DNV-OS-F201.

For guidance on coupled analysis, see DNV-RP-F205.

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# 4 Model testing

## 4.1 General

**4.1.1** Model testing will usually be required for final check of TLP designs. The main reason for model testing is to check that analytical results correlate with model tests.

**4.1.2** The most important parameters to evaluate are:

— air-gap
— first order motions
— total offset
— set-down
— WF motions versus LF motions
— tendon responses (maximum and minimum)
— accelerations
— ringing
— springing
— susceptibility to hull VIM.

**4.1.3** The model scale applied in testing shall be appropriate such that reliable results can be expected. A sufficient number of seastates need to be calibrated covering the relevant limit states.

**4.1.4** Wave headings, multidirectional sea, tests with wind, wave and current, wave steepness and other variable parameters (water levels, vertical centre of gravity, etc.) need to be varied and tested as required.

**4.1.5** If HF responses (ringing and springing) shows to be governing for tendon extreme and fatigue design respectively, the amount of testing may have to be increased to obtain confidence in results.

# 5 Load effects in the tendons

## 5.1 General

**5.1.1** Load effects in the tendons comprise mean and dynamic components.

**5.1.2** The steady state loads may be determined from the equilibrium condition of the platform, tendon and risers.

**5.1.3** Tendon dynamic load effects arise from platform motions, any ground motions and direct hydrodynamic loads on the tendon.

**5.1.4** Dynamic analysis of tendon responses shall take into account the possibility of platform heave, roll and pitch excitation (springing and ringing effects).

**5.1.5** Linearised dynamic analysis does not include some of the secondary wave effects, and may not model accurately extreme wave responses. A check of linear analysis results using non-linear methods may be necessary. Model testing may also be used to confirm analytical results. Care shall be exercised in interpreting model-test results for resonant responses, particularly for loads due to platform heave, roll and pitch, since damping may not be accurately modelled.

**5.1.6** Lift and overturning moment generated on the TLP by wind loads shall be included in the tendon response calculations.

**5.1.7** Susceptibility to vortex induced vibrations shall be evaluated in operational and non-operational phases.

**5.1.8** Interference (tendon/riser, tendon/tendon, tendon/hull, and tendon/foundation) shall be evaluated for non-operational as well as the operational phase.

# SECTION 5 ULTIMATE LIMIT STATES (ULS)

## 1 Introduction

### 1.1 General

**1.1.1** General considerations in respect to methods of analysis and capacity checks of structural elements are given in DNVGL-OS-C101.

**1.1.2** The TLP hull shall be designed for the loading conditions that will produce the most severe load effects on the structure. A dynamic analysis shall be performed to derive the characteristic largest stresses in the structure.

**1.1.3** Analytical models shall adequately describe the relevant properties of loads, stiffness and displacement, and shall account for the local and system effects of, time dependency, damping and inertia.

**1.1.4** The LRFD format shall be used when the ULS capacity of the structure is checked. Two combinations shall be checked, a) and b). The load factors are defined in DNVGL-OS-C101 Ch.2 Sec.1 [4.4] and values are given in Table 1.

**Table 1 Load factors – Ultimate limit states**

| *Combination of design loads* | *Load categories* | | |
|---|---|---|---|
| | Permanent and variable functional loads, $\gamma_{f,G,Q}$ | Environmental loads, $\gamma_{f,E}$ | Deformation loads, $\gamma_{f,D}$ |
| a) | 1.2 [1)] | 0.7 | 1.0 |
| b) | 1.0 | 1.3 | 1.0 |
| 1) If the load is not well defined e.g. masses or functional loads with great uncertainty, possible overfilling of tanks etc. the coefficient should be increased to 1.3. | | | |

**1.1.5** The loads shall be combined in the most unfavourable way, provided that the combination is physically feasible and permitted according to the load specifications. For permanent loads, a load factor of 1.0 in load combination a) shall be used where this gives the most unfavourable response. Other considerations for the partial coefficients are given in DNVGL-OS-C101.

**1.1.6** The material factor $\gamma_m$ for ULS yield check should be 1.15 for steel. The material factor $\gamma_m$ for ULS buckling check is given in DNVGL-OS-C101 Ch.2 Sec.4.

**1.1.7** The material factors for composites are given in DNV-OS-C501 Sec.8 [2.7] for use with this standard.

**1.1.8** The material factors for foundation are given in DNVGL-OS-C101 Sec.10 for use with this standard. For foundations where there are no or small possibilities for load redistribution from one foundation to another, higher material factors shall be used. This may for example apply to pile foundations for TLPs. In such cases the material factor shall not be taken less than $\gamma_m$ = 1.7 for ULS design.

### 1.2 Stability

**1.2.1** The intact and damaged stability of a TLP in free-floating condition during construction, tow out and installation stages shall, in general, satisfy requirements applicable to column- stabilized units as defined in DNVGL-OS-C301.

**1.2.2** Stability of a TLP in the in-place condition is typically provided by the pretension and stiffness of the tendon system, rather than by the waterplane area. The stability analysis is to demonstrate that the system is sufficiently constrained by the tendon system, and is safe from overturning in all environmental conditions. It is therefore important to monitor the weight change and COG (Center of Gravity) shift in various operational modes and environmental conditions.

**1.2.3** The allowable horizontal shift of the COG shall be calculated for at least the following three load conditions or operational modes:

— still water

— operating environment
— survival environment.

**1.2.4** The allowable shift of COG may be presented as an envelope relative to the originally calculated COG.

**1.2.5** The allowable weight and horizontal COG shift shall be calculated based on maximum and minimum allowable tendon tension. Variation of the vertical COG, which results in changes in motion response and dynamic loads, shall be taken into account in the calculation.

**1.2.6** An inclining test or equivalent procedure shall be conducted to accurately determine the weight and COG of the TLP. Proper load management tools shall be installed onboard and appropriate procedures shall be defined in the operations manual to control weight, COG and tendon tensions during service.

**Guidance note:**
A TLP is weight sensitive in general and the inclining test calibrates the baseline for weight and COG, which are important for transit condition as well as ballast management and tendon tension control in in-place condition. Consideration for waiving such requirement may be considered on case-by-case basis, for example, for TLP configurations that are not stable in the free floating condition as a fully assembled platform. In such cases, alternative means of determining the weight and COG may be utilized. Such alternative methods include accurate weighing of TLP or components using certified load cells, and careful weight control methods and procedures to assemble the final weight and COG of the completed system. Some additional requirements to the details of weight reports and additional margin on VCG and TCG (for sensitivity check) may be required in such case due to the increased uncertainties. If there is a difference between estimated weight of the TLP and the results of the lightweight survey (allowable depending on the size of TLP and the resulted impact on tendon tensions) while float out, further evaluation may be required to confirm the accuracy of weight and COG.

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# 2 Hull

## 2.1 General

**2.1.1** The following analysis procedure to obtain characteristic platform-hull response shall be applied:

1) *Analysis of the initial mean position in still water condition*
In this analysis, all vertical loads are applied (weights, live loads, buoyancy etc.) and equilibrium is achieved taking into account pretension in tendons and risers.
2) *Mean response analysis*
In this analysis the lateral mean wind, mean wave-drift and current loads are applied to the TLP resulting in a static offset position with a given set-down.
3) *Wave response analysis*

   — *Design wave approach*
   To satisfy the need for simultaneity of the responses, a design wave approach may be used for maximum stress analysis.
   The merits of the stochastic approach are retained by using the extreme stochastic values of some characteristic parameters in the selection of the design wave. Effects due to offset as described in 2) shall be taken into account in the analysis.
   or
   — *Spectral approach*
   An analysis is carried out using ‘n’ wave frequencies from ‘m’ directions. Effects due to offset as described in 2) shall be taken into account in the analysis. Traditional spectral analysis methods should be used to compute the relevant response spectra and their statistics.

**Guidance note:**
When using Design wave approach, it is important to capture all the waves that induce most critical characteristic responses, e.g. max squeeze/pry loads, max accelerations, max tendon tensions etc. The most important design wave for a conventional four-column TLP design is the wave that maximizes squeeze and pry loads. The critical value for this response generally occurs with the waves approaching along the platform diagonal axis, with a wavelength being slightly more than twice the diagonal column centreline spacing. This response will normally give the maximum moment at the connection between the pontoons (or braces) and columns, and/or connection between the deck and columns. A second important squeeze/pry load case is with beam seas and a wavelength slightly more than twice the column centreline spacing in that direction. This response will normally give the maximum axial force in the transverse horizontal bracing or pontoon members.

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**2.1.2** For a TLP hull, the following characteristic global sectional loads due to wave forces shall be considered as a minimum:

— split forces or squeeze/pry (transverse, longitudinal or oblique sea)
— torsional moment about a transverse and longitudinal, horizontal axis (in diagonal or near-diagonal)
— longitudinal opposed forces between parallel pontoons (in diagonal or near-diagonal seas)
— longitudinal, transverse and vertical accelerations of deck masses.

**2.1.3** It is recommended that a full stochastic wave load analysis taking into account relevant non-linear effects is used as basis for the final design.

**2.1.4** Local load effects (e.g. maximum direct environmental load on an individual member, wave slamming loads, external hydrostatic pressure, ballast distribution, internal tank pressures etc.) shall be considered. Additional loads from e.g. high-frequency ringing accelerations shall be taken into account.

**2.1.5** For earthquake analyses, the Strength Level event (SLE) and the Ductility Level event (DLE) criteria should be used as applied to fixed Offshore platforms. A Probabilistic seismic hazard assessment (PSHA) should be developed, which is consistent with the seismic risk at the particular site.

**2.1.6** Hull vibration due to current induced vibration of tendons or risers shall be evaluated.

## 2.2 Structural analysis

**2.2.1** For global structural analysis, a complete three-dimensional structural model of the TLP is required. See DNVGL-OS-C101 Ch.2 Sec.4 and DNVGL-OS-C103 Ch.2 Sec.3 and App.B.

**2.2.2** Additional detailed finite-element analyses may be required for complex joints and other complicated structural parts to determine the local stress distribution more accurately and/or to verify the results of a space-frame analysis. See also DNVGL-OS-C103.

**2.2.3** Local environmental load effects, such as wave slamming and possible wave- or wind-induced vortex shedding, are to be considered as appropriate.

## 2.3 Structural design

**2.3.1** Special attention shall be given to the structural design of the tendon supporting structures to ensure a smooth transfer and redistribution of the tendon concentrated loads through the hull structure without causing undue stress concentrations.

**2.3.2** The internal structure in columns in way of bracings should to be designed stronger than the axial strength of the bracing itself.

**2.3.3** Special consideration shall be given to the pontoon strength in way of intersections with columns, accounting for possible reduction in strength due to cut-outs and stress concentrations.

**2.3.4** Special attention shall be given to the structural design of the columns in way of intersection with deck structure to ensure smooth load transfer.

# 3 Deck

## 3.1 General

**3.1.1** Structural analysis and design of deck structure shall follow the principles as outlined in DNVGL-OS-C103, additional load effects (e.g. global accelerations) from high-frequency ringing and springing shall be taken into account when relevant.

**3.1.2** Deck vibration due to current induced vibration of tendons or risers shall be evaluated

## 3.2 Air gap

**3.2.1** In the ULS condition, an air gap of 1.5m (5ft) should be ensured under wave with $10^{-2}$ annual probability of exceedance. Positive air gap should be ensured under wave with $10^{-3}$ annual probability of exceedance. However, wave impact may be permitted to occur on any part of the structure provided that it can be demonstrated that such loads are adequately accounted for in the design and that safety to personnel is not significantly impaired.

**3.2.2** Analysis undertaken to document air gap should be calibrated against relevant model test results. Such analysis shall include relevant account of:

- wave and structure interaction effects
- wave asymmetry effects
- global rigid body motions (including dynamic effects)
- effects of interacting systems (e.g. riser systems)
- maximum or minimum draughts (set down, tidal surge, subsidence, and settlement effects).

**3.2.3** Column ‘run-up’ load effects shall be accounted for in the design of the structural arrangement in way of the column or deck box connection. These 'run-up' loads shall be treated as an environmental load component, however, they need not to be considered as occurring simultaneously with other environmental responses.

**3.2.4** Evaluation of air gap adequacy shall include consideration of all influenced structural items including lifeboat platforms, riser balconies, overhanging deck modules and module support beams.

# 4 Scantlings and weld connections

## 4.1 Scantlings

Minimum scantlings for plate, stiffeners and girders are given in DNVGL-OS-C101 Ch.2 Sec.4.

**Guidance note:**
The extreme draft $T_E$ used in calculation of external pressure for minimum scantlings should include maximum storm and tide surge, horizontal offset, set down, and subsidence.

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## 4.2 Weld connections

The requirements for weld connections are given in DNVGL-OS-C101 Ch.2 Sec.8.

# 5 Tendons

## 5.1 Extreme tendon tensions

**5.1.1** As a minimum the following tension components shall be taken into account:

- pretension (static tension)
- tide (tidal effects)
- storm surge (positive and negative values)
- tendon weight (submerged weight)
- overturning (due to current, mean wind or drift load)
- set down (due to current, mean wind or drift load)
- WF tension (wave frequency component)
- LF tension (wind gust and slowly varying drift)
- ringing (HF response)
- hull VIM influence on tendon responses
- tendon VIV induced loads.

**5.1.2** Additional components to be considered are:

- margins for fabrication, installation and tension reading tolerances
- operational requirements (e.g. operational flexibility of ballasting operations)

— allowance for foundation mispositioning
— field subsidence
— foundation settlement and uplift
— loads due to spooling during transportation and storage of flexible tendons.

**5.1.3** Bending stresses along the tendon shall be analysed and taken into account in the design. For the constraint mode the bending stresses in the tendon will usually be low. In case of surface, or subsurface tow (non-operational phase) the bending stresses shall be carefully analysed and taken into account in the design.

**5.1.4** For nearly buoyant tendons the combination of environmental loads (axial and bending) and high hydrostatic water pressure may be a governing combination (buckling).

**5.1.5** Limiting combinations (envelopes) of tendon tension and rotations (flex elements) need to be established.

**5.1.6** For specific tendon components such as couplings, flex elements, top and bottom connections etc. the stress distribution shall be determined by appropriate finite element analysis.

**5.1.7** For ULS conditions (A and B), temporary loss in tendon tension is acceptable provided that minimum tendon tension in at least one tendon per corner remains non-negative.

**5.1.8** If temporary (part of a high frequency cycle) tendon tension loss is permitted, a comprehensive tendon dynamic analyses shall be conducted to evaluate its effect on the complete tendon system and supporting structures. Alternatively, model tests may be performed. The reasoning behind this is that loss of tension could result in detrimental effects to e.g. tendon body, connectors, or/and supporting structures.

## 5.2 Structural design of tendons

**5.2.1** The structural design of tendons shall be carried out according to DNVGL-OS-C101 or API RP 2T with the additional considerations given in this subsection.

**5.2.2** Buckling checks of tendon body/pipes may be performed according to API RP 2T or NORSOK, N-004.

**5.2.3** When deriving maximum stresses in the tendons relevant stress components shall be superimposed on the stresses due to maximum tendon tension, minimum tendon tension or maximum tendon angle, as relevant.

**5.2.4** Such additional stress components may be:

— tendon-bending stresses due to lateral loads and motions of the tendon
— tendon-bending stresses due to flex-element rotational stiffness
— thermal stresses in the tendon due to temperature differences over the cross sections
— hoop stresses due to hydrostatic pressure.

**5.2.5** Composite tendons shall be designed in accordance with DNV-OS-C501 with additional considerations given in this section.

# 6 Foundations

## 6.1 General

The geotechnical design of foundations shall be carried out in accordance with the requirements in DNVGL-OS-C101 Ch.2 Sec.10 and guidelines in DNV Classification Notes 30.4. The foundation shall be designed to withstand static and cyclic inclined loading. Effects of cyclic loading on the soil strength shall be accounted for.

Relevant combinations of tendon tensions and angles of load components shall be analysed for the foundation design.

## 6.2 Piled foundations

The steel pile foundation design shall be in accordance with DNVGL-OS-C101 and guidelines in DNV Classification Notes 30.4.

The characteristic pile/soil resistance may be estimated based on empirical relationships and relevant test data. Due consideration shall be given to the conditions under which these relationships and data are established and the relevance of these conditions with respect to the actual soil conditions, shape and size of piles and loading conditions.

For piles subjected to permanent tension, the combined effect of creep and cyclic loading shall be considered when estimating the characteristic pile/soil resistance.

The pile/soil resistance will change with time, from a fully remoulded resistance immediately after installation towards a higher long-term resistance. In the phase immediately after hook-up, the potentially reduced resistance should be evaluated. As this is a temporary condition, lower environmental load exposure may be considered. See DNVGL-OS-C101.

The effect of installation, such as pile driving damage shall be accounted for.

## 6.3 Gravity based foundations

For gravity foundations the pretension shall be compensated by submerged weight of the foundation, whereas the varying loads may be resisted by for example suction. Interface with tendon bottom connector and receptacle is given in DNV-OS-C502.

Concrete Gravity Based Foundations shall be designed in accordance with DNV-OS-C502.

The effect of installation, such as buckling of skirts due to applied under base suction must be accounted for.

# SECTION 6 FATIGUE LIMIT STATES (FLS)

## 1 Introduction

### 1.1 General

**1.1.1** Structural parts where fatigue may be a critical mode of failure shall be investigated with respect to fatigue. All significant loads contributing to fatigue damage (non-operational and operational) shall be taken into account. For a TLP, the effects of springing and ringing resonant responses shall be considered for the fatigue limit state.

**1.1.2** Fatigue design may be carried out by methods based on fatigue tests and cumulative damage analysis, methods based on fracture mechanics, or a combination of these.

**1.1.3** General requirements for fatigue design are given in DNVGL-OS-C101, DNVGL-OS-C103, DNVGL-RP-C203.

Industry accepted fatigue S-N curves different from the DNVGL standards may be considered for acceptance. Fatigue design for composite tendon is given in DNV-OS-C501.
Improved fatigue performance (comparing to what is defined in DNVGL-RP-C203) of base material may be accounted for in the design, provided that the fatigue performance and fracture mechanic properties of the same, are documented through testing.

**1.1.4** Careful design of details as well as stringent quality requirements for fabrication are essential in achieving acceptable fatigue strength. It is to be ensured that the design assumptions made concerning these parameters are achievable in practice.

**1.1.5** The results of fatigue analyses shall be fully considered when the in-service inspection plans are developed for the platform.

**1.1.6** Structures that are susceptible to low cycle/ high stress fatigue should be analysed to assess damage accumulation during rare events that may be of extended duration. Therefore single event fatigue damage for the hull structure and tendons to be considered for units that are to operate in tropical regions where hurricanes, cyclones etc. can be present. The API RP 2T can be used for further guidance.

## 2 Hull

Fatigue design of hull structure shall be performed in accordance with principles given in DNVGL-OS-C103.

## 3 Deck

Fatigue design of deck structure shall be performed in accordance with principles given in DNVGL-OS-C103.

## 4 Tendons

### 4.1 General

**4.1.1** All parts of the tendon system shall be evaluated for fatigue.

**Guidance note:**
Free-standing phase can have significant contribution to tendon fatigue damage. Assumption of installation duration (tendon free-standing duration) should be carefully considered with sufficient design margin to account for the predictability of weather window and reliability of metocean data.

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**4.1.2** First order wave loads (direct or indirect) will usually be governing, however also fatigue due to springing shall be carefully considered and taken into account. Combined load effect due to wave frequency, high frequency and low frequency loads shall be considered in fatigue analysis.

**4.1.3** In case of wet transportation (surface or subsurface) to field, these fatigue contributions shall be accounted for in design.

**4.1.4** Vortex induced vibrations (VIV) shall be considered and taken into account. This applies to operation and non-operational (e.g. tendon free standing) phases.

**4.1.5** Size effects (e.g. length of weld, number of connections) of welds and couplings etc. shall be evaluated.

For guidance see Sec.2.3 in DNVGL-RP-C203.

**4.1.6** Tendon and tendon components shall have a minimum design fatigue factor (DFF) of 10.

**4.1.7** Fracture toughness of tendon components and welds shall be sufficient to meet design fatigue life and fracture criteria.

**Guidance note:**
Fracture toughness testing is performed to establish material properties that in turn can be used to calculate critical flaw sizes. The most common testing is CTOD (Crack Tip Opening Displacement) testing which in most cases are done using 3-point bend specimens. Testing should be performed for both base material and fusion line locations. As a minimum 3 tests should be performed per location and the lowest value of the 3 test results should be used in fracture toughness assessments. Further guidance on fracture toughness testing and assessments can be found in DNV-OS-F101.

CTOD tests performed in bending may give very conservative results. One way to reduce the conservatism is to perform the testing in tension (SENT specimens). Test performed like this will give a testing condition (constraint) close to that associated with a defect in a girth welded pipe loaded in tension. For SENT testing a minimum of 6 specimens per location will be required.

In case of materials with good fracture toughness properties (typically CTOD values above 0.25 mm), CTOD – Resistance or J – Resistance testing should be performed to establish the tearing resistance of the material.

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**4.1.8** Fracture mechanics assessment shall be performed in accordance with BS7910 or equivalent standard to estimate crack growth rates, define maximum allowable flaw sizes and thus help define inspection intervals and monitoring strategies.

**4.1.9** The maximum allowable flaws under extreme design loads shall not grow to a critical size causing unstable crack growth in 5 times the tendon design life or tendon inspection period, whichever is less. The preferred critical flaw is a through-thickness fatigue crack. All possible initial flaws including surface flaws, embedded flaws and through thickness flaws shall be considered. Various aspect ratio and initial location shall be evaluated. Stress concentration factors (SCFs) shall be included when assessing the maximum allowable flaw size.

**4.1.10** The maximum allowable flaw size shall be reliably detectable by the NDT inspection system employed in fabrication of the tendons.

To be able to size flaw heights, an ultrasonically based NDT system (UT) must be utilised. The detection ability of an ultrasonically based NDT system shall be deemed sufficient if the probability of detecting a flaw of the smallest allowable height determined during an Engineering Critical Assessment (ECA) is 90% at a 95% confidence level and the probability of under-sizing a defect is less than 5%.

**Guidance note:**
In general, ultrasonic systems should be qualified and the performance of the system should be documented. If such documentation does not exist, fracture mechanics assessments are recommended to be carried out assuming an initial flaw size of 3 × 25 mm (height × length) for Automated Ultrasonic Testing (AUT) or 9 × 50 mm for Manual Ultrasonic Testing.

With the AUT sensitivity level set at 50% of the echo from a 3 mm flat bottom hole, a flaw satisfying the Probability Of Detection (POD) of 90% at 95% confidence level has in most cases been found to be approx. 3 mm in height. This is the basis for suggesting an initial flaw size of 3 × 25 mm for the ECA, provided no other data are available. Refer also DNV-OS-F101, Appendix E, Section H related to AUT system qualification.

For manual UT, typical POD curves has been established in the Nordtest NDE Programme. With an echo of 20% of the echo from a 3 mm side drilled hole, flaw size corresponding to POD of 90% at 95% confidence level has been found to be approx. 9 mm in height. This is the basis for suggesting an initial flaw size of 9 × 50 mm to be used for the ECA, provided no other data are available.

If UT is based on smaller reference reflectors and/or better sensitivities than those stated above, a reduction of the assumed initial flaw sizes may be made, if properly justified Unless the system can be qualified with the criteria as follows, an initial flaw size of 3 × 25 mm (height × length) should be assumed for Automatic Ultrasonic Testing (AUT) or 9 × 50 mm (height x length) should be assumed for Manual Ultrasonic Testing.

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**4.1.11** When tendons are fixed to the seabed using piles, it is also important to perform a fatigue and fracture evaluation of the welded joints in the piles. The welds next to the tendon connection point will be the most critical as these will be exposed to the same loads as the tendons. The load due to pile driving shall be included in addition.

**4.1.12** For tendon receptacles and other components connected to the pile while it is driving, fatigue damage due to pile driving shall also be taken into account.

**4.1.13** Composite materials and their interfaces may also be treated with a fracture mechanics approach if a defect size can be defined and the propagation can be described. Otherwise fatigue analysis of composite materials should be described by SN curves and Miner sum calculations as given in DNV-OS-C501 Sec.6 [11].

# 5 Foundation

Tendon responses (tension and angle) will be the main contributors for fatigue design of foundations. Local stresses shall be determined by use of finite element analyses and due attention to geotechnical properties and reaction loads.

For piled foundation, fatigue damage due to pile driving shall also be taken into account.

# SECTION 7 ACCIDENTAL LIMIT STATES (ALS)

## 1 General

### 1.1 General

**1.1.1** Requirements concerning accidental events are given in DNVGL-OS-C101.

**1.1.2** Units shall be designed to be damage tolerant, i.e. credible accidental damages, or events, should not cause loss of global structural integrity. The capability of the structure to redistribute loads should be considered when designing the structure.

**1.1.3** In the design phase, attention shall be given to layout and arrangements of facilities and equipment in order to minimise the adverse effects of accidental events.

**1.1.4** Satisfactory protection against accidental damage may be obtained by a combination of the following principles:

— reduction of the probability of damage to an acceptable level
— reduction of the consequences of damage to an acceptable level.

**1.1.5** Structural design with respect to the ALS shall involve a two-stage procedure considering:

— resistance of the structure to a relevant accidental event
— capacity of the structure after an accidental event.

**1.1.6** Global structural integrity shall be maintained both during and after an accidental event. Loads occurring at the time of a design accidental event and thereafter shall not cause complete structural collapse.

The TLP structure shall be designed to sustain one hull compartment flooding, one tendon flooding or removal of one tendon.

### 1.2 Stability

**1.2.1** In-place stability of a TLP under accidental event shall be measured and controlled by minimum and maximum tension criteria using same principle as defined in Sec.5 [1.2]. Allowable weight and COG shift envelope shall be established for the damaged condition using same procedure as defined in Sec.5 [1.2]. The annual probability level of design loads, load and resistance factors are defined in DNVGL-OS-C101. Time lapse between the occurrence of the damage and the restoring of stability should be considered in the design to assure the safety of the TLP unit during this period. In assessing the structural strength and adequacy of the tendon tension, the following flooding scenario shall be assumed:

1) Any one tendon compartment.
2) All compartments that could be flooded as a result of damages that are as minimum 1.5 m deep and 3.0 m high occurring at any level between 5.0 m above and 3.0 m below the still waterline.

   **Guidance note:**
   Due consideration should be given for the size of the supply boats and other collision scenario before deciding the extent of the damage.

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3) No vertical bulkhead shall be assumed damaged, except where bulkheads are spaced closer than a distance of one eighth of the column perimeter at the still waterline, measured at the periphery, in which case one or more of the bulkheads shall be disregarded.

   **Guidance note:**
   The above accidental scenario should typically be assessed with 1-year return environmental loads and no ballast compensation (re-adjustment) against the ALS design criteria. It is recommended that the unit should have ballast system capacity and availability (incl. power supply) to restore tendon tensions within 8 hours. Increased environmental load level may have to be considered in case of insufficient ballast system capacity to restore tendon tensions within 8 hours. Alternate duration can be considered provided that safe operation can be satisfactorily documented.

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All piping, ventilation systems, trunks, etc., within the extent of damage shall be assumed damaged. Positive means of closure shall be provided at watertight boundaries to preclude the progressive flooding of other spaces that are intended to be intact.

# 2 Hull and deck

The most relevant accidental events for hull and deck designs are:

— dropped objects
— fire
— explosion
— collision
— unintended flooding
— abnormal wave events.

Credible accidental loads to be considered in design shall be based on risk assessment and safety philosophy adopted. See detailed guidance in DNVGL-OS-A101.

# 3 Tendons

## 3.1 General

**3.1.1** The most relevant accidental events for the tendons are:

— missing tendon
— tendon flooding
— dropped objects
— flooding of hull compartment(s).

**3.1.2** Tendon removal condition (e.g. for maintenance and/or inspection) requires analysis of the TLP structure with environmental loads with $10^{-2}$ annual probability of exceedance to satisfy the ALS. The same applies to tendon flooding, if relevant. Consideration should be given to the expected frequency of tendon removal and the length of period for which one tendon is likely to be out of service.

**3.1.3** Tendon failure may have substantial consequences and therefore the tendons shall be designed with sufficient safety margin.

**3.1.4** For ALS condition, minimum tension in at least three corner groups of tendons shall remain non-negative in the required accidental environment as defined by DNVGL Offshore Standards. If non-negative tension is not maintained in all corner groups in the required accidental environment, then a comprehensive coupled analysis of the tendon system performance under loss of tension shall be performed to demonstrate proper reengagement of the bottom connector with the foundation receptacle and adequate robustness against subsequent snatch loading. The analysis shall examine detailed load sequences induced in all components (top and bottom) on all tendons to ensure load capacities are not exceeded and components function as intended in order to prevent tendon disconnect.

**3.1.5** Dropped objects may cause damage to the tendons and in particular the top and bottom connectors may be exposed. Shielding may be required installed.

**3.1.6** Flooding of hull compartments and the effects on design shall be analysed thoroughly.

# 4 Foundations

The design load cases for accidental events to be considered for the foundations shall as a minimum, include those corresponding cases considered for the tendons.

Material factors and resistance factors for soil are given in DNVGL-OS-C101 Ch.2 Sec.10 Foundation design.

For foundations where there are no or small possibilities for redistribution of loads from one foundation to another, larger material factors shall be used. This may for example apply to pile foundations for TLPs. In such cases it should be considered if there is a need to use a material factor greater than $\gamma_m$ = 1.0 for ALS design.

# CHAPTER 3 CLASSIFICATION AND CERTIFICATION

## SECTION 1 CLASSIFICATION

### 1 General

#### 1.1 Classification

#### 1.2 Introduction

**1.2.1** As well as representing DNV GL's recommendations on safe engineering practice for general use by the offshore industry, the offshore standards also provide the technical basis for DNV GL classification, certification and verification services.

**1.2.2** This chapter identifies the specific documentation, certification and surveying requirements to be applied when using this standard for certification and classification purposes.

**1.2.3** A complete description of principles, procedures, applicable class notations and technical basis for offshore classification is given by the applicable DNV GL rules for classification of offshore units as listed in Table 1.

**Table 1 DNV GL Rules for classification - Offshore units**

| *Reference* | *Title* |
|---|---|
| DNVGL-RU-OU-0101 | Offshore drilling and support units |
| DNVGL-RU-OU-0102 | Floating production, storage and loading units |
| DNVGL-RU-OU-0103 | Floating LNG/LPG production, storage and loading units |
| DNVGL-RU-OU-0104 | Self-elevating units |

#### 1.3 Application

**1.3.1** It shall be agreed with DNV GL, at the start of the project, what documents from the project Master Document Register (MDR) shall be the subject to approval.

**1.3.2** It is possible to limit the classification to a selected scope (e.g. hull, topside, drilling module, accommodation etc,). Details of the scope for classification shall be discussed and agreed with DNV GL at the start of the project.

**1.3.3** Some of the design phases (e.g. hull and deck mating, transportation, installation and decommissioning) presented in the standard are not covered by normal classification scope, Technical requirements given in DNVGL-OS-C101 Ch.2 Sec.7, related to Serviceability Limit States, are not mandatory as part of classification.

**1.3.4** Where codes and standards call for the extent of critical inspections and tests to be agreed between contractor or manufacturer and client, the resulting extent is to be agreed with DNV GL.

**1.3.5** DNV GLmay accept alternative solutions found to represent an overall safety level equivalent to that stated in the requirements of this standard.

**1.3.6** Any deviations, exceptions and modifications to the design codes and standards given as recognised reference codes shall be approved by DNV GL.

#### 1.4 Documentation

Documentation for classification shall be in accordance with the NPS DocReq (DNV GL Nauticus Production System for documentation requirements) and DNVGL-CG-0168.

# SECTION 2 CERTIFICATION OF TENDON SYSTEM

## 1 Introduction

Certification of the tendon system is accomplished through the Certification of Material and Components (CMC) from various manufacturers. Since the Tendon system itself is a main load-bearing element of the TLP, a CMC coordinator role shall be established with close interaction with the Responsible Approval Center. Design approval of these various components need to be aligned with the global performance of the TLP and applicable load cases. Approval of all the components of the Tendon system and its interfaces shall be handled by the same DNV GL office whose is responsible for the approval of the TLP main structure. Survey may however be carried out by the local DNV GL stations in accordance with the requirements of this Section.

Tendon system generally consists of the following main elements:

— tendon pipe
— bottom tendon interface (BTI)
— flex bearings
— foundation
— top tendon interface (TTI)
— tendon intermediate connectors
— tendon tension monitoring system (TTMS)
— tendon porch
— tendon cathodic protection system
— load management program (LMP).

DNV GL standards and international standards that are considered acceptable standards for design and fabrication of various components are presented in Chapter 1, Table 1 and Table 2.

## 2 Equipment categorization

DNV GL uses categorization in order to clearly identify the certification and approval requirements for different equipment and components.

Categorization of equipment depends on importance for safety and takes operating and environmental conditions into account. Once assigned, the category of equipment refers to the scope of activities required for DNV GL certification and approval, as consistent with the importance of the equipment.

If there are any other equipment which is not defined in the following tables, categorization of the same shall be decided on a case by case basis with prior discussion with DNV GL.

Regardless of the equipment categorization, project specifications for tendon components shall be submitted for review prior to start of fabrication. Equipment categorization for offshore installations or units is as follows:

I = Equipment/component important for safety and integrity of the TLP and for which a DNV GL certificate is required.
II = Equipment/component of less importance for safety and integrity of the TLP and for which a works certificate prepared by the manufacturer is accepted.

*Equipment category I*

For equipment category I, the following approval procedure shall be followed:

— design approval, documented by a design verification report (DVR) or type approval certificate
— fabrication survey, documented by issue of a product certificate.

Specific requirements:

— pre-production meeting prior to the start of fabrication

— survey during fabrication, as applicable
— witness final functional, pressure and load tests, as applicable
— review of fabrication records.

These requirements are typical and the final extent of DNV GL survey required will be decided based on:

— complexity, size and previous experience of equipment type
— manufacturer's QA/QC system
— manufacturing survey arrangement (MSA) with DNV GL
— type of fabrication methods.

*Equipment category II*

Equipment of category II is normally acceptable on the basis of a works certificate prepared by the manufacturer. As a minimum, the certificate shall contain the following data:

— equipment specification or data sheet
— operating limitation(s) of the equipment
— statement from the manufacturer to confirm that the equipment has been constructed and manufactured according to recognised methods, codes, and standards
— test records as applicable.

# 3 Fabrication record

Fabrication record shall be maintained by the manufacturer in a traceable manner, so that relevant information regarding design specifications, materials, fabrication processes, inspection, heat treatment, testing, etc. can be checked.

Fabrication record for Category I equipment shall be available for review. The following particulars shall be included, as applicable:

— manufacturer's statement of compliance
— reference to design specifications and drawings
— location of materials and indication of respective material certificates
— welding procedure specifications and qualification test records
— location of welding indicating where the particular welding procedures have been used
— heat treatment records
— location of non-destructive testing (NDT) indicating where the particular NDT method has been used and its record
— load, pressure and functional test reports
— as-built part numbers and revisions.

# 4 Documentation deliverables for certification of equipment

The following documentation will normally be issued by DNV GL for equipment and systems covered by certification activities (CMC):

a) *Design Verification Report, (DVR)*

   — DVR will be issued by the design approval responsible for all equipment of category I, unless covered by a valid type approval certificate.
   — in addition to each individual equipment, DVRs shall be issued for each system not covered by plan approval.

   The DVR shall contain all information needed to be followed up by the surveyor attending fabrication survey and installation of the equipment, and as a minimum include:

   — design codes and standards used for design verification

- design specification (e.g. temperature, pressure, SWL, etc.)
- follow-up comments related to e.g. testing, fabrication and installation of the equipment or system.

An approval letter may be issued instead of a DVR, however such a letter shall as a minimum contain the same information as listed above.

b) *Product Certificate, (PC)*

- PC should be issued for all category I equipment or systems.
- PC will be issued upon successful completion of design verification, fabrication survey and review of final documentation. As stated above, PC can not be issued if design verification or non-conformances are outstanding.
- Sub-components of a product will not receive a Product Certificate. DNV GL will issue either a Material Certificate for the base material or a Survey Report(s) detailing surveillance during fabrication follow up.

c) *Survey Report*

- Survey report shall be issued for all category I equipment or systems upon satisfactory installation, survey and testing onboard. A survey report may cover several systems or equipment installed. The survey report shall contain clear references to all DVRs and PCs on which the survey report is based, and shall state testing and survey carried out.

# 5 Tendon systems and components

## 5.1 General

The loads for the tendon component analysis are to be obtained from the tendon global analysis. All relevant requirements as mentioned in Ch.1 Sec.1 to Ch.2 Sec.7 as applicable for the component shall be followed. The requirements specified below are some additional requirements that are specific to some of the components.

As most of these connectors are complex in design and fabrication, detailed linear elastic Finite Element Analysis (FEA) shall be carried out using industry recognized FE programs. In general, a 3D finite element analysis using solid/brick elements will be required unless a 2D analysis can realistically represent and simulate the connectors, applicable loads and interfaces. Testing will be required where necessary to justify and document the FEA.

The design and construction shall cover all applicable load conditions transportation, lifting, installation and operation etc. The effects of fabrication tolerances, fit-up misalignment etc. shall be included. All connectors must be designed and fabricated with due consideration for installation and removal of damaged tendons.

If the transportation and installation phase of the tendons are not certified by DNV GL, information shall be submitted to DNV GL to document the fatigue damage, locked-in stresses etc. resulting from the lifting, transportation, free-standing tendon etc.

A protection shield/hat above the bottom connector may be considered in order to prevent debris entering the bottom connector housing.

A higher safety margin shall be considered for the tendon components than for the tendon pipes due to the complexity of the components and uncertainties in the response calculation.

**Guidance note:**
In general a Design Fatigue Factor of minimum 10 shall be used for fatigue design of tendon and tendon components provided that the analyses are based on a reliable basis as described above. However, if the fatigue life assessment is associated with a larger uncertainty, a higher Design Fatigue Factor for complex tendon components may be recommended. In such cases, a higher Design Fatigue Factor should be determined based on an assessment of all uncertainties in the fatigue analysis with due consideration to the consequence of a fatigue failure. Before increasing the Design Fatigue Factor one should aim to reduce the uncertainties in the design basis as much as possible.

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## 5.2 Tendon pipe

Pipe manufacturer shall be an approved manufacturer by DNV. The pipes must be adequately specified for the service conditions. The following as a minimum shall be specified as applicable:

- the pipe shall be formed from Thermo-Mechanically Controlled Process (TMCP) plates
- Submerged Arc Welding (SAW) process shall be used for the pipe manufacturing of the pipes
- the steel shall be fully killed and melted to fine grain practice
- tensile and compression testing shall be performed also in the longitudinal direction
- the variation in yield stress should be limited
- material fracture resistance properties shall be specified
- the impact toughness of base material, weld and Heat-Affected Zone (HAZ) must be acceptable considering the service temperature
- the hardness of welds must not exceed 330 Brinell's Hardness Number (BHN) and tendons and weld areas must have a high grade coating to prevent hydrogen embrittlement (especially important for high tensile steels)
- NDT should be performed to ensure freedom of imperfections especially transverse to the direction of stress in the weld and
- base material as little variation as possible in wall thickness, diameter and out of roundness to reduce stress concentrations around welds.

Welding shall be performed with low hydrogen welding consumables/processes that give a diffusible hydrogen content of maximum 5 ml/100 g weld metal. Welding procedure qualification for girth welds shall be performed on the actual tendon pipe material and shall include:

- transverse weld tensile testing
- all weld tensile testing
- bend testing
- impact testing of base material, weld, fusion line and fusion line +2 mm
- macro examination and hardness testing
- fracture toughness testing of weld metal and at fusion line.

Adequate acceptance criteria for the service condition and minimum design temperature shall be specified in line with the requirements for tendon pipe.

Repair welding procedures shall be separately qualified on an existing weld and shall include:

- full and half thickness repair
- shallow multipass repairs
- single pass repairs.

Full and half thickness repair welding procedures shall be tested and meet the same acceptance criteria as the tendon pipe girth welds. Shallow multipass repairs welding procedures shall be tested and meet the same acceptance criteria as the tendon pipe girth welds except that fracture toughness testing may not be required. Single pass repairs shall be root, face and side bend tested, macro examined and hardness tested and meet the same acceptance criteria as the tendon pipe girth welds.

**Guidance note:**
Line pipe according to DNV-OS-F101 will normally meet the required service requirements, e.g. pipe designated DNVGL SAWL 415 SD. Suffix U may be added to enhance uniform tensile properties. Line pipe according to API 5L shall be specified with additional requirements for tendon pipes as given above.

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## 5.3 Bottom tendon interface (BTI)

The bottom tendon interface assembly must provide a secure connection throughout the design life of the TLP. The connector shall be designed adequately against yielding, fatigue and corrosion. BTI normally consist of the following main elements:

- a receptacle which will be welded to the pile

— a bottom tendon connector (BTC) which locks in to the receptacle
— a flex bearing element
— a tendon extension piece that is welded to the tendon pipe.

The maximum angular stiffness of the connection shall be specified consistent with the tendon design. There shall be no disengagement of the load bearing surfaces assuming a minimum tendon tension of "zero" or during temporary phases of negative tension in ULS or ALS conditions at the bottom tendon interface. A mechanical latch may be provided on the BTC to prevent stroke-out and the risk of disengagement.

The tendon receptacle and other interfaces attached to the pile shall be subjected to all applicable loads related to pile design and installation.

BTI and flex bearing design shall allow for rotation between the tendon and pile considering all applicable operation and installation conditions. Maximum installation angle shall be specified for the BTC to enter and lock in to the receptacle. Protection shielding shall be considered to prevent debris from entering between tendon and bottom receptacle.

Pile installation loads and applicable impact loads for all components that are relevant during the installation and transportation phase shall be considered in the design

Guidance on fatigue methodology is defined in DNVGL-RP-C203. If no documented S-N curve exists for the material selected, S-N curves shall be selected from DNVGL-RP-C203.

Fracture Mechanics tests shall be carried out in accordance with Ch.2 Sec.6.

## 5.4 Flex bearings

The selected material and manufacturer should have adequate prior experience with successful in-service history to demonstrate adequacy for its intended purpose. If a new material or manufacturer without sufficient prior experience for similar application is selected, the material and manufacturing process shall go through an adequate level of qualification.

**Guidance note:**
DNV-RP-A203 gives an outline for the qualification procedures.

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Manufacturer shall demonstrate by in-depth analysis and testing that the product meets the specified properties for the flex element including but not limited to:

— specified tendon loads
— maximum rotational stiffness
— minimum axial stiffness
— design life
— internal pressure (if applicable)
— other properties as specified.

Flex bearings shall be tested to adequately characterize rotational stiffness, axial capacity and angular capacity.

Acceptance criteria for the all elements of the finished product shall be clearly specified and agreed before fabrication.

## 5.5 Top tendon interface (TTI)

The top tendon interface assembly must provide a secure connection throughout the life of the TLP. The connector shall be designed adequately against yielding, fatigue and corrosion. TTI normally consist of the following main elements:

— tendon porch that is attached to the HULL
— the Length Adjustment Joint (LAJ) that will be welded to the top tendon piece
— tendon connector with the flex bearing
— TTMS interface.

TTI and flex bearing design shall allow for rotation between the tendon and hull connection considering all applicable operation and installation conditions. Maximum installation angle shall be specified for the Tendon to enter and lock in to the TTI.

Adequate protection (including corrosion) mechanism shall be provided for the TTI to protect the LAJ.

Connector in way of the LAJ shall be checked for strength and fatigue with the reduced cross section.

## 5.6 Intermediate tendon connectors (ITC)

The intermediate tendon connectors (ITC) must provide a secure connection throughout the life of the TLP. The connector shall be designed adequately against yielding, fatigue and corrosion, ratcheting and fretting as applicable.

The connectors must be sealed and form a watertight connection. The design shall ensure that all potential damage during handling and installation for the sealing mechanism is identified and designed against.

## 5.7 Tendon tension monitoring system (TTMS)

Suitable and reliable tendon tension monitoring devices shall be installed to obtain the actual tension during operation.

**Guidance note:**
Generally, one TTMS unit per corner (a group of tendons) is sufficient.

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This system generally consists of load cells, data acquisition system and alarm system. Load cells shall be calibrated to the required accuracy for the range of tension anticipated accounting for all possible system errors.

Alarm shall be pre-set for the values that exceed the design conditions so that adequate load balancing and operational measures can be taken to ensure that the tendon tension remains within the maximum allowable values. The alarms shall be audible and visually represented in the room where the LMP is monitored.

The load cells and all critical elements of the data acquisition system shall be redundant. There shall be more than one load cell per tendon. It shall monitor both tendon tension and bending moments (requires 3 load cells).

Marine quality cables shall be used and a watertight sealing shall be arranged for the top and bottom load ring interface.

## 5.8 Tendon porch

Hull interfaces with the tendons including the backup structure are to be designed for the breaking load of the tendons with acceptance criteria equal to yield strength of the material.

Cast steel shall be a weldable low carbon and fine grained steel. Test coupons representing the greatest end thickness of welding to the hull shall be developed from each casting to facilitate actual production weld testing qualifications. NDT for the special areas (welding attachment to the hull) or wherever the stress level (under ULS condition) exceeds 67% of yield shall be subjected to more rigorous NDT than other areas.

Acceptance criteria for weld repairs and acceptability shall be clearly defined in the specifications and agreed upon. Casting shall in general be in accordance with DNV GL offshore standard DNVGL-OS-B101 Ch.2 Sec.4.

## 5.9 Tendon corrosion protection system

Tendon assembly shall in general be protected using a combination of coating systems, sacrificial-anodes, material selection, and corrosion allowance considered for the life time of the platform and the inspection philosophy during operation. Special areas like the TTI may need corrosion inhibitors, corrosion cap etc for protecting the moving parts. An affective corrosion protection system shall be in place from the time the structure is initially installed.

Cathodic protection shall be carried out in accordance with DNV Recommended Practice DNV-RP-B401.

Site specific data shall be used for the corrosion protection design. Special considerations shall be given for the higher ambient temperature effect for areas like West Africa.

Anode and other attachment details and welding to the tendon system shall be specifically approved by DNV GL.

**Guidance note:**
Design of the corrosion protection system, shall consider the electric continuity between tendon, hull and pile.

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## 5.10 Load management program

Load management program (LMP) shall facilitate the safe operation of the TLP and the tendon systems under the defined load conditions by monitoring the weight changes and centre of gravity (CG) shifts compared with the pre-defined envelope. It shall be possible to automatically calculate weight redistribution of live loads and ballast water. Other relevant variable data such as draft, wave, wind etc. shall be used by the program as appropriate.

The output from the LMP program shall be validated to demonstrate "same CG predictions" as obtained from a calibrated analysis and model test results to gain confidence. This shall be documented for approval and accepting the LMP Program onboard.

The system shall operate from a UPS power supply and shall have a redundant fail safe system. Data shall be backed-up continuously and all important data saved on a regular basis.

The load management system shall meet the continuous availability requirement as defined in DNVGL-OS-D202 Ch.2 Sec.1 [2.2].

# 6 Categorization of tendon components

**Table 1 Categories for tendon systems, equipment and components**

| *Relevant text* | *Material or equipment* | *DNV GL approval categories* | | *Certificate*[1] |
|---|---|---|---|---|
| | | *I* | *II* | |
| TENDON PIPE | Pipe | X | | Material Certificate |
| TOP TENDON INTERFACE | LAJ, Top Flex Bearing, TTI Connector, TTMS interface etc | X | | Product Certificate |
| BOTTOM TENDON INTERFACE | BTI Connector, BTI receptacle, BTI Flex Bearing etc | X | | Product Certificate |
| INTERMEDIATE CONNECTORS | Connectors | X | | Product Certificate |
| FOUNDATION | Piles, Gravity based foundations | X | | Product Certificate |
| TENDON TENSION MONITORING SYSTEM | Load Cell and associated interface | X | | Product Certificate |
| LOAD MANAGEMENT PROGRAM (LMP) | Hardware and Software | X | | Product Certificate |
| TENDON CATHODIC PROTECTION SYSTEM | Anodes | | X | Survey report |
| | Attachments | | X | Survey Report[2] |
| TENDON PORCH | Casting | X | | Product Certificate |

*Notes:*
[1] Depending on the extent of integrated delivery from a particular vendor, the level of certification can be varied and discussed for a particular component or assembly in the beginning of the project.
[2] Attachment should not adversely affect the integrity of tendon pipes.

# 7 Tendon fabrication

Tendon systems are critical load carrying elements and are essential for the integrity of the TLP. Fabrication of the tendon system in general shall meet the requirements as applicable for "special areas". NDT requirement on all welding shall, as a minimum, be in accordance with the butt weld requirement for inspection category 1 as defined in DNV GL Offshore standard DNVGL-OS-C401. In all cases, where the global design requires more stringent standards than what is outlined in the DNV GL standard, fabrication requirements shall be adjusted such that the tendon joints meet those higher requirements.

The extent and the methods of NDT chosen for the tendon fabrication shall meet the requirements of DNVGL-OS-C401 Ch.2 Sec.2 [3.1.5].

**Guidance note:**
Although class requires minimum 100% NDT, typical industry practice considers minimum 200% and up to 400% NDT for tendon circumferential welds.

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Casting, forging techniques used for the tendon fabrication shall, as a minimum, meet the good practices as outlined in DNVGL-OS-B101 Ch.2 Sec.4 and Ch.2 Sec.3.

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