OFFSHORE STANDARD
DNV-OS-C105

STRUCTURAL DESIGN OF TLPS (LRFD METHOD)

JANUARY 2001

DET NORSKE VERITAS

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SECTION 1
INTRODUCTION

A. General

A 100 Introduction

101 This standard provides requirements and guidance to the structural design of TLPs, fabricated in steel, in accordance with the provisions of DNV-OS-C101. The requirements and guidance documented in this standard are generally applicable to all configurations of tension leg platforms.

102 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.

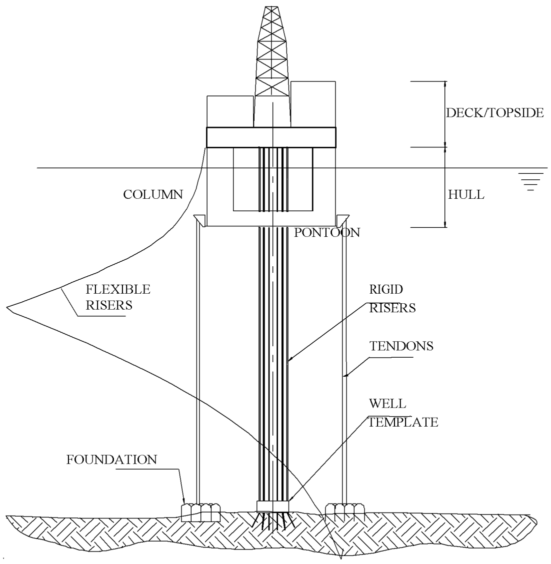


Figure 1
Example of a tension leg platform

103 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.

A 200 Objectives

201 The objectives of the standard are to:

- provide an internationally acceptable standard for structural design of TLPs
- serve as a conctractual reference document for suppliers, yards and owners
- serve as guidance for designers, suppliers, owners and regulators
- specify procedures and requirements for units and installations subject to DNV verification and classification services.

A 300 Scope and application

301 A TLP is usually applied for drilling, production and export of hydrocarbons. Storage may also be a TLP mission.

302 A TLP may be designed to function in different modes, typically operation and survival. Also horizontal movement (e.g. by use of catenary or taut mooring) of TLP above wells may be relevant. Limiting design criteria when going from one mode of operation to another shall be established.

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

304 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.

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

306 In case of application of a catenary or taut mooring system in combination with tendons, reference is made to DNV-OS-E301.

307 Requirements related to floating stability (intact and damaged) are given in DNV-OS-C301.

A 400 Classification

401 For use of this standard as technical basis for offshore classification as well as descriptions of principles, procedures and applicable class notations related to classification services see, DNV Offshore Service Specification given in Table B1.

402 Documentation requirements for classification are given in DNV-RP-A202.

B. Normative References

B 100 General

101 The standards given in Table B1 and Table B2 include provisions, which through reference in this text constitute provisions for this standard. Other recognised standards may be used provided it can be demonstrated that these meet or exceed the requirements of the standards referenced in 200 and 300.

B 200 Offshore service specifications and rules

201 The offshore service specifications and rules given in Table B1 are referred to in this standard.

Table B1 DNV Offshore Service Specifications and rules

Reference	*Title*
DNV-OSS-101	Rules for Classification of Offshore Drilling and Support Units
DNV-OSS-102	Rules for Classification of Floating Production and Storage Units
	Rules for Planning and Execution of Marine Operations

B 300 Offshore Standards

301 The offshore standards given in Table B2 are referred to in this standard.

Table B2 DNV Offshore Standards

Reference	*Title*
DNV-OS-A101	Safety Principles and Arrangement
DNV-OS-B101	Metallic Materials
DNV-OS-C101	Design of Offshore Steel Structures, General (LRFD method)
DNV-OS-C103	Structural Design of Column Stabilised Units (LRFD method)

DNV-OS-C106	Structural Design of Deep Draught Floating Units
DNV-OS-C301	Stability and Watertight Integrity
DNV-OS-C401	Fabrication and Testing of Offshore Structures
DNV-OS-E401	Helicopter Decks
DNV-OS-E301	Position Mooring
DNV-OS-F201	Dynamic Risers

C. Informative References

C 100 General

101 The documents listed in Table C1 include acceptable methods for fulfilling the requirements in the standard and may be used as a source of supplementary information.

Table C1 DNV Recommended Practices, Classification Notes and other references

Reference	*Title*
DNV-RP-C202	Buckling Strength of Shells
DNV-RP-C203	Fatigue Strength Analysis of Offshore Steel Structures
DNV Classification Note 30.1	Buckling Strength Analysis
DNV Classification Note 30.5	Environmental Conditions and Environmental Loads
DNV Classification Note 30.6	Structural Reliability Analysis of Marine Structures
SNAME 5-5A	Site Specific Assessment of Mobile Jack-Up Units
API RP 2T	Planning, Designing and Constructing Tension Leg Platforms
N-004	NORSOK - Design of Steel Structures

D. Definitions, Abbreviations and Symbols

D 100 Verbal forms

101 *Shall:* Indicates a mandatory requirement to be followed for fulfilment or compliance with the present standard. Deviations are not permitted unless formally and rigorously justified, and accepted by all relevant contracting parties.

102 *Should:* Indicates a recommendation that a certain course of action is preferred or particularly suitable. Alternative courses of action are allowable under the standard where agreed between contracting parties but shall be justified and documented.

103 *May:* Indicates a permission, or an option, which is permitted as part of conformance with the standard.

104 *Can:* Can-requirements are conditional and indicate a possibility to the user of the standard.

D 200 Terms

201 *Heave resisted TLP (HRTLP):* A tension leg platform which is free to roll and pitch, but restrained in the heave eigenmode.

202 *High frequency (HF) responses:* Defined as TLP rigid body motions at, or near heave, roll and pitch eigenperiods due to non-linear wave effects.

203 *Low frequency (LF) responses:* Defined as TLP rigid body non-linear motions at, or near surge, sway and yaw eigenperiods.

204 *Mini TLP:* Small tension leg platform with one, or multiple columns.

205 *Ringing:* Defined as the non-linear high frequency resonant response induced by transient loads from high, steep waves.

206 *Roll, pitch, and yaw:* Rotational modes around surge, sway and heave axis, respectively.

207 *Springing:* Defined as the high frequency non-linear resonant response induced by cyclic (steady state) loads in low to moderate seastates.

208 *Surge, sway, heave:* Translatory displacements of TLP in horizontal planes (surge, sway) and vertical plane (heave).

209 *TLP deck structure:* The structural arrangement provided for supporting the topside equipment or modules. 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.

210 *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.

211 TLP hull: Consists of buoyant columns, pontoons and intermediate structural bracings, as applicable.

212 *TLP tendon system:* Comprises all components associated with the mooring system between, and including the top connection(s) to the hull and the bottom connection(s) to the foundation(s). Guidelines, control lines, umbilicals etc. for tendon service and/or installation are considered to be included as part of the tendon system.

213 *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.

214 *Wave frequency (WF) responses:* TLP linear rigid body motions at the dominating wave periods.

D 300 Abbreviations

301 The abbreviations given in Table D1 are used in this standard.

Table D1 Abbreviations

Abbreviation	*In full*
ALS	Accident limit states
DFF	Design fatigue factors
DNV	Det Norske Veritas
FLS	Fatigue limit states
HF	High frequency
HRTLP	Heave resisted TLP
IC	Inspection category
LAT	Lowest astronomical tide
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
TLP	Tension leg platform
TLWP	Tension leg wellhead platform
ULS	Ultimate limit states
VIV	Vortex induced vibrations
WF	Wave frequency

D 400 Symbols

401 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.

402 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
γ_m material factor.

E. Description of the Tendon System

E 100 General

101 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.

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

— apply, monitor and adjust 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.

103 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.

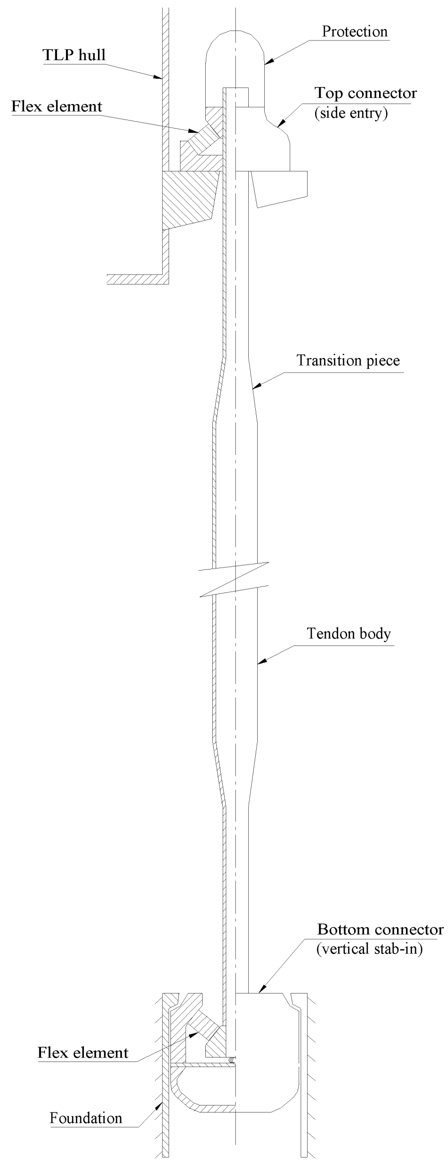


Figure 2
Typical TLP tendon system

104 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.

105 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.

SECTION 2
SELECTION OF MATERIAL AND INSPECTION CATEGORIES

A. Introduction

A 100 General

101 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 DNV-OS-C101 Sec.4.

102 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.

103 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 DNV-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 DNV-OS-106.

B. Structural Categorisation

B 100 General

101 Application categories for structural components are defined in DNV-OS-C101 Sec.4. Structural members of foundations, tendons and their connections are normally found in the following groups:

Special category

a) tendon interfaces with the foundation and the TLP hull
b) complex tendon or tendon connections.

Primary category

a) simple tendon or tendon connections
b) interface arrangements outside locations of complex connections including general stiffened plate fields (e.g. at hull interface).

Secondary category

a) normally no locations are relevant for tendons or tendon interfaces.

C. Material Selection

C 100 General

101 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 DNV-OS-C101.

102 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.

103 The structural categorisation assumes that the tendon system is demonstrated to have residual strength, and that the TLP structural system satisfies the requirements of the accidental damaged condition with failure of the tendon (or a connection in the tendon) as the defined damage. If this is not the case, then structural category special shall be used for the tendon system and its connections.

104 Material designations are defined in DNV-OS-C101.

C 200 Design temperatures

201 For TLPs, materials in structures above the lowest astronomical tide (LAT) shall be designed for service temperatures down to the lowest, average, daily, atmospheric temperature for the area(s) where the unit is to operate.

202 Materials in structures below the LAT are normally to be designed for service temperatures of 0°C. A higher service temperature may be used if adequate supporting data shows relative to the lowest average temperature applicable to the relevant actual water depths.

D. Inspection Categories

D 100 General

101 Welding and the extent of non-destructive testing (NDT) during fabrication, shall be in accordance with the requirements stipulated for the appropriate inspection category as defined in DNV-OS-C101 Sec.4.

102 Inspection categories determined in accordance with DNV-OS-C101 provide requirements for the minimum extent of required inspection. When considering the economic consequence that repair during in-service operation may entail, for example, in way of complex connections with limited or difficult access, it may be considered prudent engineering practice to require more demanding requirements for inspection than the required minimum.

103 When determining the extent of inspection and the locations of required NDT, in additional 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.

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

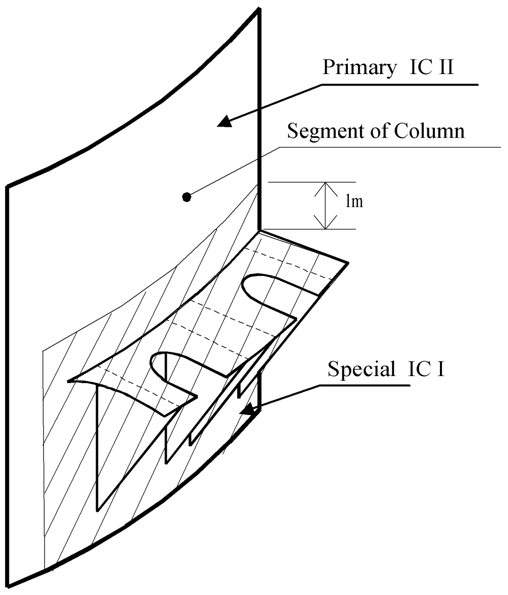
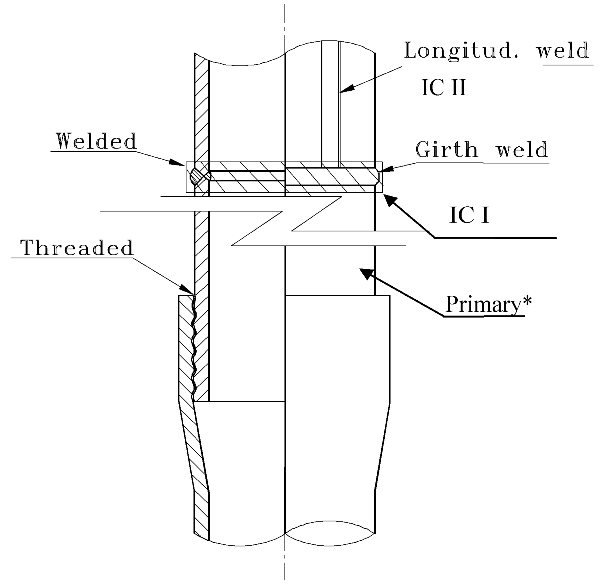


Figure 1
Principles of the extent of structural categorisation special and inspection categories at tendon foundation



* Special if damaged condition is not fulfilled, see C103.

Figure 2
Example of tendon connections

SECTION 3
DESIGN CRITERIA

A. Introduction

A 100 General

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

a) The TLP is to be able to sustain all loads liable to occur during all relevant temporary and operating design conditions for all applicable limit states.
b) Direct wave loads on the deck structure should not occur in the ultimate limit states (ULS). Direct wave loads 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.

102 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 reliability 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.

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B. Design Conditions

B 100 General

101 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
— sea transportation
— installation
— operation
— decommissioning.

102 Structural design covering marine operation and construction sequences shall be undertaken in accordance with DNV-OS-C101.

103 Marine operations may be undertaken in accordance with the requirements stated in Rules for Planning and Execution of Marine Operations. 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.

104 Structural responses resulting from one temporary phase condition (e.g. a fabrication or transportation operation) that may effect design criteria in another phase shall be clearly documented and considered in all relevant design workings.

B 200 Fabrication

201 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.

202 Major lifting operations shall be evaluated to ensure that deformations are within acceptable levels, and that relevant strength criteria are satisfied.

B 300 Mating

301 All relevant load effects incurred during mating operations shall be considered in the design process. Particular attention should be given to hydrostatic loads imposed during mating sequences.

B 400 Sea transportation

401 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.

402 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.

403 Satisfactory compartmentation and stability during all floating operations shall be ensured.

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

B 500 Installation

501 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.

502 For novel installation activities (foundations and tendons), relevant model testing should be considered.

503 Tendon stand-off (pending TLP installation) phases shall be considered with respect to loads and responses.

504 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.

B 600 Decommissioning

601 Abandonment of the unit shall be planned for in the design stage.

C. Design Principles, Tendons

C 100 General

101 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.

102 Tendon mechanical components shall, as far as practicable, be designed “fail to safe”. Consideration is to be given in the design to possible early detection of failure for essential components, which cannot be designed according to this principle.

103 Certain vital tendon components may, due to their specialised and unproven function, require extensive engineering and prototype testing to determine:

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

104 The tendon system and the securing or supporting arrangements shall be designed in such a manner that a possible failure 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.

105 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 a reasonable level of reliability. Elements of this strategy include:

— design fatigue life
— fracture toughness
— reliability of inspection during fabrication
— in-service inspection intervals and methods.

106 Fracture mechanics should be used to define allowable flaw sizes, estimate crack growth rates and thus help define inspection intervals and monitoring strategies.

107 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.

108 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.

109 Satisfactory considerations shall be given to settlement or subsidence, which may be a significant factor in determining tendon-tension adjustment requirements.

SECTION 4 DESIGN LOADS

A. General

A 100 General

101 Characteristic loads are to be used as reference loads. Design loads are, in general, defined in DNV-OS-C101. Guidance concerning load categories relevant for TLP designs are given in B.

B. Load Categories

B 100 General

101 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 DNV-OS-C101.

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

103 In relation to determination of environmental conditions and loads, see Classification Note 30.5.

104 The wave loads on the tendons can be described as recommended in DNV-OS-C101 and Classification Note 30.5 for slender structures with significant motions.

105 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.

106 The earthquake loads at the foundation of the tendons are described in DNV-OS-C101.

107 The following loads should be considered:

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

108 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.

109 "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).

110 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 or storm surge effects.

SECTION 5 GLOBAL PERFORMANCE

A. Introduction

A 100 General

101 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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102 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.

103 During the design process, the methods for analytical or numerical prediction of important system responses shall be verified (calibrated) by appropriate model tests.

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

105 Motion components shall be determined, by relevant analysis techniques, for those applicable design conditions specified in DNV-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.

106 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 DNV-OS-C103 or DNV-OS-C106.

107 The method of platform-motion 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.

B. Frequency Domain Analysis

B 100 General

101 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 DNV-OS-C101.

102 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.

103 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.

104 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:

— changes in topside weights (e.g. future modules)
— tendon system changes (altered utilisation)
— changes in ballast weights or distributions.

B 200 High frequency analyses

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

202 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.

203 Damping level applied in the springing response analyses shall be duly considered and documented.

B 300 Wave frequency analyses

301 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.

302 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.

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

304 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.

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

306 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.).

307 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.

B 400 Low frequency analyses

401 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.

402 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.

C. Time Domain Analyses

C 100 General

101 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).

102 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 can 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.

103 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.

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

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

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

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

108 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 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.

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

D. Model Testing

D 100 General

101 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.

102 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.

103 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.

104 Wave headings and other variable parameters (water levels, vertical centre of gravity, etc.) need to be varied and tested as required.

105 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.

E. Load Effects in the Tendons

E 100 General

101 Load effects in the tendons comprise mean and dynamic components.

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

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

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

105 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.

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

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

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

SECTION 6
ULTIMATE LIMIT STATES (ULS)

A. Introduction

A 100 General

101 General considerations in respect to methods of analysis and capacity checks of structural elements are given in DNV-OS-C101.

102 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.

103 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.

104 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 DNV-OS-C101 Sec.2 D400 and values are given in Table A1.

Table A1 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.

105 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 DNV-OS-C101.

106 The material factor γ_m for ULS yield check should be 1.15 for steel. The material factor γ_m for ULS buckling check is given in DNV-OS-C101 Sec.5.

B. Hull

B 100 General

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

1) *Analysis of the initial mean position*

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 offset*

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) *Design wave analysis*

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 and are applied to the platform in its offset position. The results are superimposed on the steady-state solution to obtain maximum stresses.

4) *Spectral analysis*

Assuming the same offset position as described in 2. and with a relevant storm spectrum, an analysis is carried out using ‘n’ wave frequencies from ‘m’ directions. Traditional spectral analysis methods should be used to compute the relevant response spectra and their statistics.

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

— split forces (transverse, longitudinal or oblique sea for odd columned TLPs)
— 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.

103 It is recommended that a full stochastic wave load analysis is used as basis for the final design.

104 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.

B 200 Structural analysis

201 For global structural analysis, a complete three-dimensional structural model of the TLP is required. See DNV-OS-C101 Sec.5 and DNV-OS-C103 Sec.4 and App.B.

202 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 DNV-OS-C103.

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

B 300 Structural design

301 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.

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

303 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.

C. Deck

C 100 General

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

C 200 Air gap

201 In the ULS condition, positive air gap should be ensured, see DNV-OS-C103 Sec.4 D. 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.

202 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).

203 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.

204 Evaluation of air gap adequacy shall include consideration of all influenced structural items including lifeboat platforms, riser balconies, overhanging deck modules etc.

D. Tendons

D 100 Extreme tendon tensions

101 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).

102 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.

103 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.

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

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

106 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.

107 If temporary (part of a high frequency cycle) tendon tension loss is permitted, 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 flex elements.

D 200 Structural design of tendons

201 The structural design of tendons shall be carried out according to DNV-OS-C101 with the additional considerations given in this subsection.

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

203 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.

204 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.

E. Foundations

E 100 General

101 Foundations may be designed according to the requirements in DNV-OS-C101 Sec.11.

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

103 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 and friction.

F. Scantlings and Weld Connections

F 100 General

101 Minimum scantlings for plate, stiffeners and girders are given in DNV-OS-C101 Sec.5.

102 The requirements for weld connections are given in DNV-OS-C101 Sec.9.

SECTION 7
FATIGUE LIMIT STATES (FLS)

A. Introduction

A 100 General

101 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.

102 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.

103 General requirements for fatigue design are given in DNV-OS-C101, DNV-OS-C103 and DNV-RP-C203.

104 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.

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

B. Hull

B 100 General

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

C. Deck

C 100 General

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

D. Tendons

D 100 General

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

102 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. HF and WF tendon responses shall be combined realistically.

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

104 Vortex induced vibrations (VIV) shall be considered and taken into account. This applies to operation and non-operational (e.g. tendon stand-off) phases.

105 Series effects (welds, couplings) shall be evaluated.

106 When fracture-mechanics methods are employed, realistic estimates of strains combined with maximum defect sizes likely to be missed with the applicable NDT methods shall be used.

E. Foundation

E 100 General

101 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.

SECTION 8
ACCIDENTAL LIMIT STATES (ALS)

A. General

A 100 General

101 Requirements concerning accidental events are given in DNV-OS-C101.

102 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.

103 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.

104 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.

105 Structural design in 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.

106 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.

107 Requirements for compartmentation and stability in the damage condition are given in DNV-OS-C301. When the deck structure becomes buoyant in satisfying requirements for damage stability, consideration shall be given to the structural response resulting from such loads.

B. Hull and Deck

B 100 General

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

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

102 Compartmentation is a key issue for TLPs due to the fine balance between weight, buoyancy and pretensions. See DNV-OS-C301.

C. Tendons

C 100 General

101 The most relevant accidental events for the tendons are:

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

102 Missing (e.g. due to change-out, or inspection) tendon requires analysis with environmental loads with 10^{-2} annual probability of exceedance to satisfy the ALS. The same applies to tendon flooding, if relevant.

103 For accidental events leading to tendon failure, the possible detrimental effect of the release of the elastic energy stored in the tendon may have on the surrounding structure shall be considered.

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

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

D. Foundations

D 100 General

101 Accidental events to be considered for the foundations shall as a minimum be those listed for tendons.