

Planning, Designing, and Constructing Tension Leg Platforms

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This recommended practice for planning, designing, and constructing tension leg platforms incorporates the many engineering disciplines that are involved with offshore installations, either floating or fixed. Defined herein are guidelines developed from the latest practices in tension leg platforms, and adapted from successful practices employed for related structural systems in the offshore and marine industries.

A tension leg platform (TLP) is a vertically moored, buoyant, compliant structural system wherein excess buoyancy of the platform (in excess of weight and riser loads) maintains tension in the mooring system. A TLP may be designed to serve a number of functional roles associated with offshore oil and gas exploitation. It is considered particularly suitable for deepwater applications. A TLP system consists of many components, each of which has a precedent in the offshore or marine industry. The uniqueness of a TLP is in the systematic influence of one component on another. Consequently, the design is a highly interactive process which should account for functional requirements, component size and proportion, equipment layout and space allocation, hydrodynamic reaction, structural detail, weight and centers of gravity, etc. All disciplines involved in the design process should anticipate several iterations to achieve proper balance of the design factors. This publication summarizes available information and guidance for the design, fabrication, and installation of a TLP system.

These recommendations are based on published literature and the work of many companies who are actively engaged in TLP design. As with earlier editions of this publication, it represents a snapshot of the state of the art and practice of TLP design. As new technology develops, this publication will be updated to reflect the latest accepted design and analysis methods.

Each section of this publication covers a specific aspect of tension leg platforms. The main text contains basic engineering design principles which are applicable to the design, construction, and operation. Equations for analyses are included where appropriate. In many cases these equations represent condensations of more complete analysis procedures, but they can be used for making reasonable and conservative predictions of motions, forces, or component strength. More detailed discussions of these engineering principles, describing the logic basis and advanced analytical concepts from which they were developed, are given in the commentary. The designer and operator are encouraged to use the most current analysis and testing methods available, and bring forth to the Institute any newfound principles or procedures for review and consideration.

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Planning, Designing, and Constructing Tension Leg Platforms

1 Scope

This recommended practice is a guide to the designer in organizing an efficient approach to the design of a tension leg platform (TLP). Emphasis is placed on participation of all engineering disciplines during each stage of planning, development, design, construction, installation, and inspection.

2 Normative References

The following referenced documents are indispensable in the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification 5L, *Specification for Line Pipe*

DNV-RP-B401 ¹, *Cathodic Protection Design*

NACE SP0176 ², *Corrosion Control of Submerged Areas of Permanently Installed Steel Offshore Structures Associated With Petroleum Production*

3 Terms, Definitions, Acronyms, Abbreviations and Symbols

3.1 Terms and Definitions

For purposes of this document, the following terms and definitions apply.

3.1.1

added mass

Effective addition to the system mass, which is proportional to the displaced mass of water.

3.1.2

bluff body

An opaque object located in a fluid flow stream and developing a high drag force because it lacks streamlining.

3.1.3

braces

Structural members that serve to stiffen the hull structure and provide deck support.

3.1.4

bulkhead

Stiffened vertical or horizontal load bearing diaphragm.

3.1.5

connector

A riser device used to latch and unlatch risers and lower marine riser packages to subsea equipment, or a tendon device used to latch and unlatch tendons to the foundation system and to connect the tendon to the platform.

¹ Det Norske Veritas, Distribution Department, NO-1322 Høvik, Norway, e-mail: distribution@dnv.com.

² NACE International, 1440 South Creek Drive, Houston, Texas, 77084-4906, www.nace.org.

3.1.6**deck beam**

Secondary structural element spanning between intermediate girders and/or main girders.

3.1.7**deck plate**

Flat plate or grating spanning between deck beams.

3.1.8**deck structure**

A multilevel facility consisting of trusses, deep girders, and deck beams for supporting operational loads.

NOTE See Figure 1.

3.1.9**design life**

Maximum anticipated operational years of service for the platform.

EXAMPLE The period of time from installation until completion of functional use of the structure.

3.1.10**elastomer**

Any of the class of materials, including natural and synthetic rubbers, which return to their original shape after being subjected to large deformations.

3.1.11**extreme offset**

An estimated maximum offset of the platform corresponding to given environmental conditions.

3.1.12**flat**

Horizontal bulkhead in column structure.

3.1.13**flex element**

Any of a variety of devices that permit relative angular movement of the riser or tendon via deformation of an elastomeric/steel laminated element in order to reduce bending stresses caused by vessel motions and environmental forces.

3.1.14**foundation**

Templates and piles, or a gravity system.

NOTE See Figure 1.

3.1.15**heave**

Platform motion in the vertical direction.

3.1.16**hull**

Buoyant columns, pontoons, and intermediate structure bracing.

NOTE See Figure 1.

3.1.17**intermediate girder**

Primary deck element spanning between main girders.

3.1.18**load**

Any action causing stress or strain in the structure.

3.1.19**lock-in**

Synchronization of vortex-shedding frequency and structural vibration frequency producing resonant flow induced vibration.

3.1.20**low-frequency motion**

Motion response at frequencies below wave frequencies typically with periods ranging from 30 to 300 seconds.

3.1.21**lower deck**

Lowest primary deck level consisting of girders, beams and plate elements.

3.1.22**main girder**

Deck elements spanning between the primary load carrying subsystem.

3.1.23**mean offset**

The average offset, corresponding to the average horizontal forces on the TLP in the given environmental conditions.

EXAMPLE Ball joints or elastomeric joints.

NOTE When curvature control is necessary, tapered joints may also be used.

3.1.24**mooring system**

Tendons and foundation.

NOTE See Figure 1.

3.1.25**offset**

Horizontal distance of the platform at any instant from its static, stillwater, still air, equilibrium position.

3.1.26**pitch/roll**

Platform rotations about orthogonal horizontal axes.

3.1.27**platform**

Hull and deck structure.

NOTE See Figure 1.

3.1.28**pontoon**

Horizontal, cylindrical, or rectangular buoyancy members of the hull structure which interconnect with columns to form a frame below the waterline.

3.1.29**preload**

A load purposely induced in a component to improve its in-service strength, fatigue life, or sealing capabilities.

3.1.30**pretension**

Tension applied to a tendon in its static, zero offset equilibrium position.

3.1.31**primary load carrying subsystem**

Structure tying column tops together and supporting deck levels.

NOTE This structure may consist of trusses, box girders, plate girders or a combination thereof.

3.1.32**ringing**

High-frequency vertical vibration of the TLP spring-mass system excited by impulsive loading.

3.1.33**riser joint**

A section of pipe, with couplings on each end.

NOTE A riser joint may have provision for supporting integral and non-integral auxiliary lines (flowlines, choke and kill lines, control bundles, etc.) and buoyancy devices.

3.1.34**risers**

Vertical pipes connecting the TLP with the seabed for purposes of drilling, production, or connecting to pipelines.

NOTE See Figure 1.

3.1.35**setdown**

The increase in TLP platform draft with offset due to tendon system restraint.

3.1.36**springing**

The high-frequency vertical vibration of the TLP spring-mass system excited by cyclic loading at or near the TLP pitch or heave resonant periods.

3.1.37**subsea well template**

A structural frame, which provides location and anchor, points for the subsea wellheads, riser systems, and guidance systems.

3.1.38**surge**

Horizontal motion of the platform in the plant north-south direction.

3.1.39**sway**

Horizontal motion of the platform in the plant east-west direction.

3.1.40**tendon**

A system of components, which form a link between the TLP platform and the subsea foundation for the purpose of mooring the TLP.

3.1.41**tendon access tube**

A conduit within a platform column between the bottom of the column and the tendon top connector through which a tendon passes.

3.1.42**tendon connector**

A device used to connect a tendon to the platform hull (top connector) or to the foundation template (bottom connector).

3.1.43**tendon element**

Each of the similar or identical but discrete structural components which, when assembled with the flex elements, top and bottom connectors, and any other special components, comprise a complete tendon.

3.1.44**tension leg**

The collective group of tendons associated with one column of the platform.

3.1.45**tension leg platform****TLP**

Includes the entire above plus all deck equipment and hull marine systems.

NOTE See Figure 1.

3.1.46**tensioner**

A device, usually pneumatically or hydraulically powered, used to apply tension to tendons or risers.

3.1.47**tensioner systems**

Units used to maintain risers in tension as the platform moves in response to wind, waves, and current.

NOTE Horizontal motions, heave, and setdown of the platform necessitate changes in length of the risers. Tensioners accommodate these movements, as well as relative angular motion between the platform and riser, while maintaining a nearly constant tension on the risers.

3.1.48**upper deck**

Upper or roof deck level consisting of girder, beam, and plate elements.

3.1.49**well system**

Risers, riser tensioners, wellhead, and subsea well templates.

NOTE See Figure 1.

3.1.50

yaw

Platform rotation about the vertical axis.

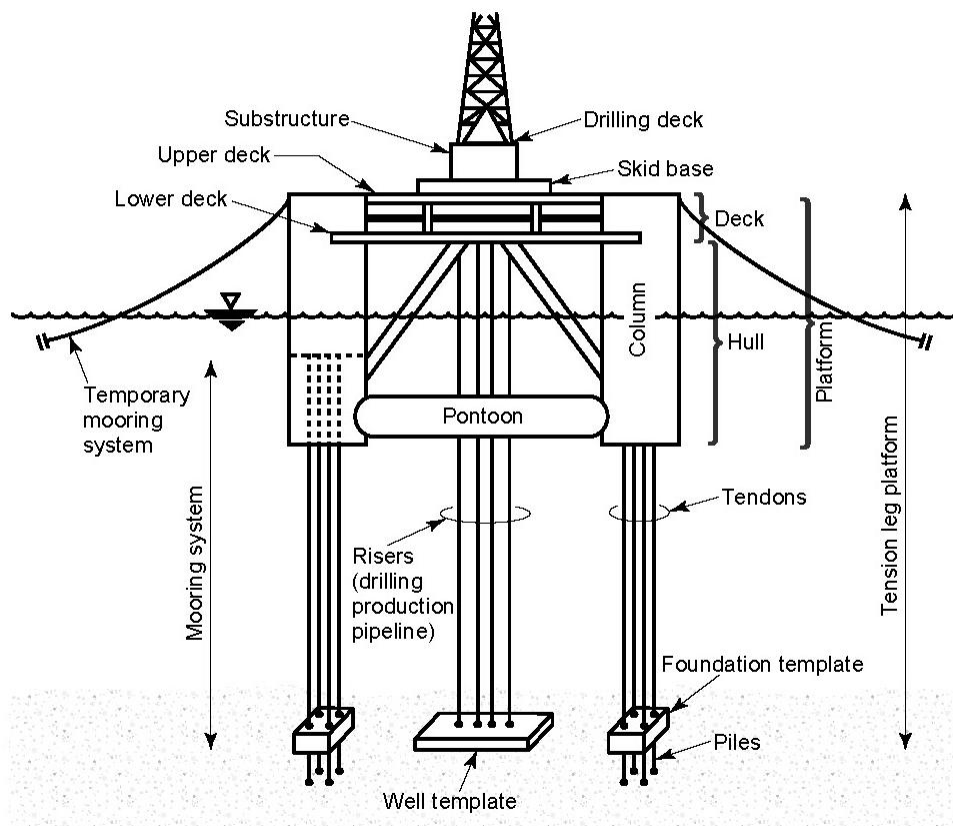


Figure 1—TLP Terminology

3.2 Acronyms and Abbreviations

AFFF	aqueous film-forming foam
B	platform buoyancy
CFD	computational fluid dynamics
DP	dynamic positioning
HDWL	high design water level
LDWL	low design water level
PR	riser pretension (at the top of riser, where attached to platform)
PT	tendon pretension (at the top of the tendon where attached to the platform)
RAO	response amplitude operator

SCR	steel catenary riser
TLP	tension leg platform
VIV	vortex-induced vibration
VCG	vertical center of gravity
WB	weight of ballast in platform
WDC	weight of deck structure
WDP	weight of all equipment in or on deck
WHP	weight of all equipment and stored liquids in the hull
WHS	weight of hull structure
WM	miscellaneous weight

3.3 Symbols

A	projected area
A_c	projected area per unit length
A_y	amplitude of vortex-induced vibration
a_i	amplitude of i th wave component
C	damping matrix
C_A	added mass coefficient
C_D	drag coefficient
C_M	virtual mass coefficient (for fluid acceleration) $CM = CA + 1$
C_s	shape coefficient (may also account for shielding)
C_s	shape coefficient
D	member diameter
F	force vector
F	total force per unit length [Equation (9)]
f	vortex shedding frequency
f_n	natural frequency of vibration
F_D	drag force
F_d	drag force per unit length

$F_{\text{drag}}(t)$	dynamic viscous drag force
F_i	inertia force per unit length
F_w	wind force
$F_{\text{wind}}(t)$	dynamic wind force
$F_{\text{wd}}^{(2-)}(t)$	second-order time dependent drift force
$f_{\text{wv}}^{(1)}(t)$	first-order time dependent wave force
$F_{\text{wv}}^{(1)}(\omega_i)$	frequency dependent first-order wave exciting force per unit wave amplitude
$F_{\text{wv}}^{(2+)}(t)$	second-order time dependent springing force
$F(\omega)$	fourier transform of force vector
H	wave height
H/L	wave steepness
H_s	significant wave height
K	stiffness matrix
K	Keulegan-Carpenter number
k	wave number
k_a	$kD/2$
L	wavelength
M	inertial mass matrix
$P_{ij}^{(2-)}(\omega_i, \omega_j)$	real part of second-order difference-frequency quadratic force transfer function in bichromatic waves
$P_{ij}^{(2+)}(\omega_i, \omega_j)$	real part of second-order sum-frequency quadratic force transfer function in bichromatic waves
$P(x)$	probability density function
$Q_{ij}^{(2+)}(\omega_i, \omega_j)$	imaginary part of second-order sum-frequency quadratic force transfer function in bichromatic waves
$Q_{ij}^{(2-)}(\omega_i, \omega_j)$	imaginary part of second-order difference-frequency quadratic force transfer function in bichromatic waves

R_e	Reynold's number
S	Strouhal number
$S_{aa}(\omega)$	wave elevation spectrum
S_{ff}	wind force spectrum
S_{uu}	wind gust spectrum
$S_{xx}(\omega)$	response spectrum
t	time
T_f	incremental tension due to foundation mis-positioning and the instantaneous offset
T_i	individual tendon load sharing differential
T_l	incremental tension due to load and ballast condition/weight variations/design margin
T_m	incremental tension due to overturning moment from wind and current forces
T_{max}	design maximum tension
T_{min}	design minimum tension
T_o	design pretension at mean water level
T_P	spectral peak period
T_r	tension variation due to heave, pitch, and roll oscillations at their natural frequency (ringing and springing, including possible underdeck slamming loads)
T_s	incremental tension caused by setdown due to static and slowly varying offset (wind, wave drift, and current)
T_t	incremental tension due to tide/storm surge water level variation
T_v	tension-induced by vortex shedding responses of an individual tendon
T_w	tension variation from wave forces and wave-induced vessel motion about the mean offset (including any coupled tendon responses)
u	instantaneous water particle velocity (speed and direction)
u'	instantaneous velocity variation from sustained wind
$\dot{u}$	water particle acceleration
V_c	current velocity normal to member axis
V_c	water particle velocity (includes current)

V_r	reduced velocity
V_{wd}	instantaneous wind speed
V_z	mean wind speed
Y_{rms}	rms VIV motion amplitude
X	instantaneous displacement of body or component
χ_a	aerodynamic admittance
χ	aerodynamic admittance function (see 6.2.7)
$\dot{x}$	instantaneous velocity of body or component
$\ddot{x}$	instantaneous acceleration of body or component
ω	radian frequency
σ_x	standard deviation
ε_i	phase angle of i th wave component
ρ_a	mass density of air
ρ_w	mass density of seawater

4 Planning

4.1 General

4.1.1 Configuration Selection

Most TLP designs have certain basic common features. They include one or more columns and pontoons to provide buoyancy, and tendons to moor the platform to the seafloor. The following are some of the key factors that need to be considered when developing plans for a TLP.

- a) Purpose—Drilling, production, quarters, and/or other.
- b) Location—Environmental, seafloor, and regulatory conditions.
- c) Financial—Capital and operating costs, risk.
- d) Service life.
- e) Contracting strategy.
- f) Construction—Materials, methods, assembly, and installation.
- g) Operational requirements.

The configuration selection process focuses on selecting global design parameters and then maturing the design from conceptual design through detail design.

Recognition of the need for several iterations of the design process and operational requirements may be important in planning and scheduling the design. Time is often needed to evaluate the effects of parameter variations before rational design decisions can be made.

Due to the sensitivity of a TLP to weight and buoyancy issues, a weight, buoyancy, and center of gravity control procedure for the entire system should be incorporated into the design process at the very earliest stage. The control procedure should be one that can be used throughout the design, construction and operational life.

4.1.2 Exposure Categories

TLPs can be categorized by various levels of exposure to determine criteria for the design of new structures and the assessment of existing structures that are appropriate for the intended service of the structure.

The levels are determined by consideration of life-safety and consequences of failure. Life-safety considers the maximum anticipated environmental event that would be expected to occur while personnel are on the platform. Consequences of failure should consider the following factors:

- a) historical experience;
- b) the planned life and intended use of the platform;
- c) the possible loss of human life;
- d) prevention of pollution;
- e) the financial loss due to platform damage or loss including lost production, cleanup, replacing the platform and redrilling wells, etc.

New or relocated TLPs used for oil production, oil handling, and/or drilling should be considered as having a high consequence of failure.

Lower consequences of failure and reduced exposure to life-safety may support the use of oceanographic criteria with a shorter return period. Potential applications where such reduced criteria might be applicable are as follows:

- unmanned structures; and
- field support structures not used for oil production, oil handling, or drilling.

The only criteria contained in this publication are those related to the high consequence of failure categorization. Criteria for lower consequence of failure and reduced exposure to life-safety would have to be developed and supported on a case-by-case basis.

4.2 The Design Process

4.2.1 General

An understanding of the entire design sequence and its relationship to external constraints such as financial, scheduling, equipment, and manpower requirements is essential.

In planning the design process, it is important to recognize the operator's contracting strategy for engineering, fabrication, and installation. Depending on how the contracting is structured between the various parties

involved (e.g. engineering, hull fabrication, topsides fabrication, drilling, installation, etc.), different levels of project definition may be required at different stages of the project. In addition, there may be variability in the allocation of design work between the engineering and construction entities.

The design process should include plans and schedules for possible model testing of the platform. Hydrodynamic model testing may be required in the design process to verify the analytical results and/or provide other data necessary for the design.

4.2.2 Conceptual Design

Conceptual design translates the functional requirements into naval architectural and engineering characteristics during the initial design iterations. It embodies technical feasibility studies to determine such fundamental elements as length, width, depth, draft, hull shape, mooring system, and well and riser systems to satisfy the environmental criteria, functional requirements, and installation feasibility. The conceptual design includes initial lightship weight estimates and mooring pretension.

It is the designer's responsibility to select the most suitable buoyancy distribution, tendon geometry, and pretension that will achieve the operator's functional requirements.

On drilling structures, these arrangements are heavily influenced by the well system. Experience indicates that a very close designer/operator relationship is required during the entire design process in order to produce a satisfactory design.

The distribution of buoyancy is selected to minimize the net vertical oscillating wave force on the hull by taking advantage of hydrodynamic cancellation effects, thereby reducing oscillating loads on the tendons. Typically, some combination of a surface piercing vertical column or columns and submerged pontoons is selected to provide the optimal distribution of buoyancy.

The lateral stiffness of the tendon mooring system is generally designed to result in long natural periods in surge and sway (i.e. greater than the dominant periods of the wave energy), with the resulting beneficial compliance to dynamic motion.

The vertical stiffness of the tendon system is generally selected such that the heave, roll, and pitch periods of the TLP have low natural periods relative to the dominant periods of the wave energy, so as to minimize wave amplification.

Tendon pretension is selected such that the full length of all tendons is in tension for all loading conditions over the life of the facility. Under certain circumstances, a temporary loss of tension may be acceptable if it can be demonstrated that the resulting stresses, motions due to loss of tension and retensioning, and the latching mechanism are within design limits.

Alternative designs are generally considered parametrically during this phase to determine the most practical design solution. The selected concept is then used as a basis for obtaining approximate construction and installation costs and schedule, which often determine whether or not to initiate a preliminary design.

4.2.3 Preliminary Design

Preliminary design further refines the characteristics affecting cost and performance. Certain controlling factors such as platform geometry, number, and type of wells, mooring pretension and payload should not change significantly after completion of this phase. Additionally, an associated base-case installation plan for the selected configuration is developed at this stage. Completion of preliminary design provides a precise definition that will furnish the basis for development of project plans and specifications.

4.2.4 Final Design

The final design stage yields a set of plans and specifications that form an integral part of the fabrication contract. This stage delineates precisely features such as hull shape, dynamic response, structural details,

use of different types of steel, spacing and type of frames and stringers. Paramount among the final design features are weight and center-of-gravity determination. The final general arrangement is also developed during this stage. This fixes the overall volumes and areas for consumables, machinery, living and utility spaces, and handling equipment. Depending on how the project contracting is structured, installation engineering input may become significant at this stage.

The specifications developed or adopted at this stage delineate quality standards of hull and outfitting and the anticipated performance for each item of machinery and equipment. They describe the tests and trials that shall be performed successfully to have the TLP considered acceptable.

4.2.5 Detail Design

The last stage of design is the development of detailed fabrication drawings and construction specifications. These are the installation and construction instructions to yard tradesmen and are subject to the approval of the designer. Platform operation and inspection plans are also developed at this project stage.

4.3 Codes, Standards, and Regulations

A determination of the applicable codes, standards, and regulations should be made at the commencement of a project. Differences between such requirements or standards should be identified immediately, and a project decision or agreement with the responsible regulatory organization expedited.

4.4 Operational Requirements

4.4.1 Function

A TLP can perform a variety of functions such as drilling, producing, storage, materials handling, living quarters, or some combination of these. The platform configuration should be determined by integrating the equipment layouts on the decks with those aspects of system design that assure hydrodynamic and aerodynamic performance, stability, weight considerations, and constructability. The platform configuration should also allow for internal and external inspection programs consistent with the operational life of the facility.

4.4.2 Site Considerations

Environmental conditions depend on geographic location, and within a given geographic area, the foundation conditions may vary as will such parameters as design wave height and period, currents, tides, and wind speeds.

Accurate data on water depth and tidal variations are needed to fabricate tendon components so that the TLP operates at its design draft. Estimates of reservoir compaction and seafloor subsidence over the life of an oil field's depletion are also needed for the same reasons, as well as for setting deck elevation above still water.

The orientation of a platform refers to its position referenced to true north. Orientation will be controlled by the directions of prevailing and extreme design waves, winds, and currents and by operational requirements. Platform orientation also needs to be considered within the context of the full-field architecture and may involve other issues such as subsea tie-ins, onsite floating storage and/or production units, tanker offloading facilities, and marine traffic routes.

4.4.3 Arrangements

Due to the interaction between the many variables affecting arrangements, platform operations, and the human factors involved, the use of project risk assessments is recommended. Such assessments can be used to help identify potential hazards associated with installation, field start-up, and ongoing operations.

Layout and weight of equipment for mooring, drilling and/or production, consumables, and other payload items should be carefully accounted for in the design and operation. Weight and weight distribution affect both

the steady and dynamic tensions in the tendons. Consideration should be given to future operations such as gas and/or water injection.

Plans for handling personnel and materials should be developed at the start of the platform design. The type and size of supply vessels and the mooring system required to hold them in position can affect the platform. The number, size, and location of boat landings, if required, should be determined. The type, capacity, number, and location of the deck cranes should also be determined. If equipment or materials are to be placed on a lower deck, adequate hatches should be provided on the upper decks. The use of helicopters should be established and adequate facilities provided.

The location and number of stairways, access routes, and boat landings should be controlled by both safety and operational requirements.

Fire protection systems, including firewalls and safe-havens, should be provided for the safety of personnel and equipment. The systems selected should be suitable for the anticipated hazards (e.g. electrical or hydrocarbon fire) and should conform to all applicable regulations.

Emergency equipment such as launchable lifeboats or survival capsules should be provided for personnel evacuation. The types of equipment and evacuation methods should meet all applicable regulations.

Provision should be made for handling spills and potential contaminants. A deck and process vessel drainage system that collects and stores liquids for subsequent handling should be provided. The drainage and collection system should meet applicable regulations.

The platform should be provided with systems for transferring ballast water to or from hull compartments (ballast system), for monitoring tank contents, and for permitting safe access to tanks and void spaces. Compartmentalization of the hull will be required to limit the effects of damage, leakage or other unintended water ingress. Such compartments may be useful for temporary ballast to control draft and stability before and during installation. Access for inspection should be provided in the design.

4.5 Environmental Considerations

4.5.1 General

Winds, currents, waves, and tides cause steady and oscillatory lateral movements, variations in tendon loads, and/or distributed loadings on the structure and its elements. The resulting TLP response requires the use of dynamic analysis methods in the design. Environmental data consistent with the analysis technique should be used.

4.5.2 Design Considerations

The design of all systems and components should anticipate extreme and normal environmental conditions that can be experienced at the site. In addition, postulated damaged conditions occurring at the time of the environmental events should be considered. Environmental loading and platform response are important design considerations for several subsystems including foundations, tendons, risers, hull, and deck equipment.

Extreme environmental conditions are those that produce the extreme response that have a low probability of being exceeded in the lifetime of the structure. For metocean events, a minimum return period of 100 years for the design event should be used unless the consequences of failure are such that a shorter recurrence interval for design criteria can be justified. The design of the structure and its key subsystems shall be such that they will be capable of withstanding the extreme metocean events in a safe condition without damage.

For earthquakes, the two-tier strength level event (SLE)/ductility level event (DLE) criteria as used for fixed offshore platforms are also applicable to TLPs (refer to API 2A-WSD). SLE and DLE criteria should be developed using a probabilistic seismic hazard assessment (PSHA) consistent with the seismic risks at the site.

Tsunami effects can generally be neglected since the kinematics velocities developed in such events tend to be much lower than design currents in deepwater.

Normal environmental conditions are those that are expected to occur frequently during the service life. Since different environmental parameters and combinations affect various responses and limit operations differently (e.g. installation, crane usage, etc.), the designer should consider the appropriate environmental conditions for the design situation.

A matrix, or scatter diagram of fatigue sea states should be developed covering the entire range of environments expected during the service life. The environments should be discretized into a convenient number of bins, identifying relevant environmental parameters and number of occurrences for each bin.

Environmental conditions associated with transportation and installation of the TLP should be considered during the structure design.

4.5.3 Environmental Data

Selection of the environmental data required is the responsibility of the operator. The dynamic nature of the TLP requires that the platform designer work closely with a meteorological-oceanographic specialist to develop data and interpretations in the form needed for the particular design/analysis methods to be used.

Recognized statistical methods and models should be applied in the assessment of extreme and normal environmental conditions. All data used should be carefully documented. The estimated reliability and the source of all data should be recorded, and the methods used in developing available data into models should be described. Sensitivity of design to poorly established parameters/distributions in statistical models should be recognized.

Selection of specific environmental conditions for design should be based on factors related to risk. Section 5.5 contains specific guidance on the choice of environmental parameters for design. API 2A-WSD gives a general discussion of most of these parameters and their specific use in design analysis for fixed platforms.

As a result of Hurricanes Ivan, Katrina, and Rita, the industry reviewed metocean requirements for the Gulf of Mexico. The result was a change to the recommended minimum 100-year return period wave heights and associated winds. Refer to API 2INT-MET for updated metocean criteria to be used in the Gulf of Mexico.

4.6 Seafloor Characteristics

4.6.1 Seafloor Surveys

The purpose of a seafloor site survey is to provide data for a geologic assessment of foundation soils and the surrounding areas and helps plan subsequent detailed geotechnical programs. It is also used to identify seafloor irregularities that could be operational hazards such as pockmarks, shallow gas, near-surface faults, debris flows, diapirism, and hard grounds.

Conventional three-dimensional 3D seismic data (marine streamer) can be used for reconnaissance geohazards mapping. However, these data are not typically processed for seafloor and near-seafloor imaging and suffer from low-resolution, high-noise, and acquisition artifacts. 3D seismic data that has been processed or reprocessed specifically for site investigation purposes (i.e. optimized lateral and vertical resolution of the seafloor and near-seafloor) can be used to supplement (or in some cases in lieu of) conventional site survey methods. These specialist 3D seismic volumes yield detailed images of seafloor and near-seafloor morphology, structure, and depositional patterns.

Useful mapping products derived from these data sets include bathymetry, seafloor renderings (artificial illumination), seafloor amplitude (surficial lithology, hydrocarbon seeps), near-seafloor isopach and structure maps, as well as cross-sectional and 3D perspective views. Higher resolution engineering surveys are typically needed to select the final TLP location and evaluate subsea flowline corridors.

This information can be gathered by deep tow survey equipment or from autonomous underwater vehicles (AUVs). These tools are outfitted with high-resolution sub-bottom profilers or frequency modulated chirp systems, sidescan sonar and swath bathymetry. Ideally the geophysical data from 3D, deep tow or AUV is confirmed with seabed geotechnical information from cores, and piezocone penetration tests, vane and/ or T-bar in-situ tests.

4.6.2 Site Investigation

Site-specific geotechnical investigations should be performed to define the various soil strata (e.g. thickness, lateral extent) and their corresponding physical and engineering properties. If practical, the soil sampling and testing program should be defined after reviewing the seafloor geophysical survey. The foundation investigation for pile supported structures should yield at least the soil test data necessary to predict axial capacity of piles in tension and compression, axial and lateral pile load deflection characteristics (including long-term creep under tendon pretension), and mudmat penetration vs resistance.

4.6.3 Seafloor Instability

Large movement of the seafloor may be caused by waves, earthquakes and soil loads (including shallow water flow). Such soil movement can impose significant lateral and vertical forces against foundations. The scope of geotechnical site investigations in areas of seafloor instability should be sufficient to develop design criteria for the effects of soil movement.

4.6.4 Scour

Scour is removal of seafloor soils caused by currents and waves, and can result in removing vertical and lateral support for foundations. Where scour is a possibility, it should be accounted for in design to avoid failure or overstressing of foundation elements.

4.7 Systems Design

4.7.1 Platform

4.7.1.1 There are several variations of platforms that can be distinguished by platform use (i.e. production-only, drilling-only, or drilling/production). Some example variations are shown in the following.

- a) Production well platform without drilling capability—This type of structure should be considerably smaller and lighter than a drilling/production platform. Production risers generally are attached to the deck structure. Wells may be pre-drilled using a semisubmersible or may be tied back to the facility from subsea completions.
- b) Drilling platform without production facility capability—This wellhead type of structure should also be considerably smaller and lighter than a drilling/production platform. Drilling risers generally are attached to the deck structure.
- c) Drilling/production platform with drilling at deck level through a well bay—This type of platform includes facilities for both drilling and production. Its size may be large to support the associated weight requirements.

4.7.1.2 Many functional requirements of a platform require special attention during the planning stages of design. In all cases, personnel and material requirements should be considered in relationship to the safety and efficiency of the platform. The following critical requirements will significantly impact the design and layout of the platform.

- a) Drilling facilities—The number, type, weight, and location of drilling rigs should be ascertained prior to commencement of design.

- b) Production facilities—The weight, area, and center-of-gravity of the production facilities should be determined insofar as possible prior to commencement of design of the platform. Because platform design is sensitive to the values of weight, area, and center of gravity, these values should not be permitted to deviate beyond specified tolerances, otherwise redesign may be required.
- c) Drilling/Production risers—Sufficient clearance should be provided between risers and adjacent structural members to avoid interference during severe environmental conditions.
- d) Well systems—The number of platform wells, completion and workover method, minimum well spacing, and well bay location have a direct influence on the size and layout of the deck structure and the hull. These features should be determined prior to commencement of preliminary platform design.
- e) Hull compartmentation—Hull damage from falling objects, boat collision, or other means should be considered during the design. The subdivision of the hull should allow for accidental flooding of at least one watertight compartment. Damage control procedures should be developed during the design phase and included in the operating manual. Bulkhead configurations, tank layouts, and tank access openings should be designed to facilitate periodic internal tank inspections.
- f) Airgap—The minimum clearance between the lowest deck and any underdeck temporary maintenance equipment and a wave crest is an important parameter in the design of the TLP. The airgap has an effect on the center of gravity and in turn the maximum and minimum tendon tensions. The designer has two general options: provide a minimum deck clearance or allow for wave impact in the design of the platform.
- g) Installation procedures—The floating stability of the hull prior to the installation of the tendons is a critical element of the installation process.

4.7.2 Tendon System

The tendon system consists of the tendons, and ancillary components needed for operation, including load measurement systems and inspection or monitoring apparatus.

The tendon system restrains motion of the platform in response to wind, waves, current, and tide to within specified limits. The tendons connect points on the platform to corresponding points on a seafloor foundation. By restraining the platform at a draft deeper than that required displacing its weight, the tendons are ideally under a continuous tensile load that provides a horizontal restoring force when the platform is displaced laterally from its still water position. Generally very stiff in the axial direction, the tendon system limits heave, pitch, and roll response of the platform to small amplitudes while its softer transverse compliance restrains surge, sway, and yaw response to within operationally acceptable limits.

The number of tendons is determined by the platform configuration, loading conditions, and design philosophy, including intended service requirements and redundancy considerations based on sound engineering design practice. The designer should allow for the possibility of material deterioration during the service life of the platform and provide a means of detecting and repairing such defects.

The tendons may take one of several forms as described in the following.

- a) Tubular Members with Connectors—The members may be designed to be completely void, partially void, or fully flooded. They may be fabricated as one piece or constructed from separate tubular body and end connectors by welding or otherwise fixing the end connectors to the tubular. The members may be made of metal or composite fiber reinforced resins (e.g. carbon fiber/epoxy composites), with either integral or metallic connectors.
- b) Tubular or Solid Rod Members with Welded Connections—The tubulars are fabricated from seamless or rolled and welded steel and are designed to be welded together, prior to or during offshore installation, to form a continuous tendon element.

- c) **Tendon Strand**—These tendons are fabricated from small diameter high tensile strength wire or fiber strands and are formed into bundles. These tendons are designed to be installed offshore using a continuous one-piece spooling operation to minimize the need for intermediate connectors.

Investigating items such as coupled tendon/platform motions, vortex-induced vibrations (VIVs), and the fatigue life of complex mechanical and welded connections requires a high level of technical sophistication. The designer is encouraged to make use of modern but proven equipment and analytical methods.

Critical tendon components, because of their lack of previous use or complexity, may warrant extensive engineering development and prototype testing to determine the fatigue, fracture, and corrosion characteristics and the mechanical capabilities of the components.

The time required to fabricate the tendons may be comparable with the duration required to construct the hull and deck structure. Consideration should be given to the fabrication lead-time requirement of the tendons to avoid unnecessary delays in installation. Tendon fabrication specifications, including material, welding and NDE requirements, also need to be established early in the project.

Installation of the tendons may require the use of large capacity lifting and handling equipment. Installation procedures and their implication to the design should be considered early in the planning stages. Onboard storage area, if required for the tendons during installation, can affect the layouts of the deck and hull and warrants early attention during design.

4.7.3 Foundations

There are several types of foundations that may be utilized for a TLP. Examples include:

- a) a foundation consisting of individual piles, to which individual tendons are directly connected;
- b) a foundation consisting of a foundation template anchored to the ocean floor by piles (driven or suction), which carry both lateral and tensile loads from multiple tendons connected to the template;
- c) shallow foundations such as non-piled gravity foundations (e.g. concrete caisson foundations) to which the tendons are directly attached;
- d) combination of items a) and b) with a template for each leg or one template common to all legs;
- e) auxiliary foundations consisting of anchor piles, deadweight clumps, drag anchors, or other types of anchors to which a catenary mooring system is attached for use during installation or operation.

Three commonly used types of piles for TLPs are the driven pile, suction pile, and suction/gravity pile. Other pile types that can be considered, but as of this writing have not been used for TLPs, are drilled and grouted and combination driven-drilled and grouted piles. The type most appropriate for a particular foundation will depend on the soil conditions at the site and the pile performance, as well as on the installation equipment available. Further discussion on these pile types can be found in API 2A-WSD.

4.7.4 Well Systems

The design of a well system should achieve cost effective safety and reliability in the containment, control, and transmission of produced fluids from the oil or gas reservoir to the processing system. While risers are an integral part of the well system, they can also be used for other functions, such as for pipeline connections. Systems will commonly be capable of being run and retrieved by vertical deployment from the deck.

Integration of the design of the well systems into the design of the TLP should be an early priority. The selection of well riser tension levels, the platform motion effects, the effect of thermal loads when wells and tendons are congruent, and riser/hull clearances are examples of items requiring close coordination. The weight and size of the well system equipment will have a significant impact on hull size and cost.

Different types of risers between the platform and seafloor may be utilized, including integral and non-integral risers, and risers integral to the tendons. Drilling blowout preventers (BOPs) and well completion systems may be located either at the platform deck level or subsea. Anticipated workover frequency and wellhead maintenance will influence the decision as to surface or subsea completions. Anticipated changes in future operation (e.g. gas lift or water injection) might require the need for flexibility within components selected.

Well component design and selection should be primarily based on reliability and safety of the system. Field proven technology and equipment should be used where possible. Design reliability should include redundancy, backup procedures, and fail-safe designs whenever practical. Component and well system reliability studies could be useful in determining the consequences of failure, and identifying those components needing a higher degree of reliability. Identification of those components that cannot be retrieved to the surface, the consequences of such components being damaged, and how to mitigate the consequences should be considered. In all cases, consideration should be given to an acceptable means of stopping the well flow near the seafloor in the event of an accident.

4.7.5 Facilities

The planning and selection of facilities involve many problems that are unique to compliant structures. The selection and design of the facilities should consider the platform motions. Facilities will have interfaces between individual systems and the overall structure, including dynamic load input from drilling rigs, sharing of utilities between drilling/production systems and hull systems, and escape means for various damage states. Such loads and interfaces should be identified and considered.

TLP facilities design should recognize the highly interactive nature of the design process, and the importance of proper coordination and integration of drilling rig, production, hull systems, and structural needs. Specific definition of all facilities criteria and requirements early in the design process should prevent changes in the platform resulting from changes in facilities. There should be close coordination between the facilities and structural designers throughout the design project to ensure that routine interactions, changes, and interfaces are properly addressed.

Facilities and drilling layouts should be considered in the initial stages of design when the development of the overall configuration is being made. Layouts should initially be guided by the overall function of the platform and should include the influences of well location(s), production systems needs, accommodation requirements, and area classification considerations. Facilities construction, whether fully integrated, semi-integrated, or modular, will affect the layout and weight as well. Damage control, personnel safety and evacuation, and spillage/containment requirements also influence the facilities layout. It may be beneficial to examine a variety of facilities layouts.

Weight, center of gravity (CG), and space requirements should be managed to develop a facility efficient in cost and operation. Weight management is the key to controlling parameters that affect the stability and global performance of a floating structure.

The design process should consider the use of “growth allowances” in the form of weight and space factors, which can help in two respects. First, platform facilities have a tendency to grow during the design process with potentially detrimental implications. Thus, realistic allowances for weight and space growth during the design process should help to prevent major design recycling at late stages. Second, experience has shown that the originally intended operational parameters for offshore facilities frequently are no longer adequate once the facility has been in operation for several years. Accordingly, it is appropriate to utilize space and weight growth allowances as a means of allowing flexibility in future operations. Operational growth scenarios should also include examination of the weight or space flexibility that may be gained by the removal of certain facilities at later stages in the operation.

Benefits may result from keeping the design growth and operational growth allowances separate during design. Operational growth allowances can easily be preempted by unexpected design problems, but the implications to future facility operation should be considered.

Both design growth allowances and operational growth allowances should recognize the impact of weight and space on floating facilities.

4.8 Fabrication and Installation

4.8.1 Fabrication Methods

The method of platform fabrication should be considered as part of the preliminary design since the method selected will significantly affect not only structural design but also the feasibility of fabrication at a chosen site.

There are four basic methods of platform fabrication as described in the following.

- a) Deck floatover—With this method, the deck is constructed in one piece separately from the hull, floated (usually by barge) over the hull and lowered and mated to it using controlled ballast and jacking procedures. Outfitting of the deck is usually completed prior to deck mating.
- b) Modules—With this method, the deck facilities are installed in the form of stacked modules on top of the hull. This is generally done at a final outfitting facility prior to final tow to the installation site. Modules may be designed to carry global loading between columns, or to “float” on sliding supports. In the latter case, a structural frame connecting the columns should carry the global loading between columns.
- c) Integral deck and hull—With this method, the deck is constructed integrally with the hull. A sufficiently deep dry dock or a convenient, sheltered deepwater site is a prerequisite for this type of construction. Outfitting of the deck may be completed together with the construction of the deck subassemblies (as in modular construction) or may take place subsequent to deck and hull construction.
- d) Deck lifting—The deck is constructed in one piece and is lifted and integrated offshore.

4.8.2 Fabrication Site Selection and Preparation

The proper selection and preparation of the fabrication site is instrumental to the successful construction. Important considerations are as follows:

- a) Coastal site—The fabrication yard should have a deepwater dry dock or means for transferring the hull into the water. It may be skidded onto a submersible barge or launched directly into the water. If the dry dock does not have sufficient depth, the use of auxiliary buoyancy and/or stability modules to support the hull during construction may be acceptable.
- b) Sheltered offshore construction area—Deepwater construction facilities may be located offshore, away from the fabrication yard, and in sufficiently deep and sheltered waters to allow convenient access for either floatover deck mating or integral deck construction.
- c) Deepwater channel—For wet tow, a deepwater channel should be available to permit towing the completed structure to sea. The minimum channel depth should be sufficient to allow the platform to be towed at a draft commensurate with specified stability criteria. Alternatively, for dry tow, a site which allows placement of the structure on a dry tow transport vessel is required.

4.8.3 Transportation

Precautions should be taken during transportation to sea to avoid damage to the structure. Transportation can be either by towing or by carriage on a mobile heavy-lift vessel. Escort tugboats to provide protection against damage should be considered. Stability criteria for transportation should be selected as appropriate for the time, duration, and location of the route as well as for the degree of damage protection and control afforded. The ability to either outrun (i.e. avoid storms) or to seek a safe harbor during a storm will have a significant effect on the motion requirements for the transportation. Specific transportation requirements will depend on whether or not the vessel is manned.

4.8.4 Installation Equipment

The function, type, and size of the major equipment selected for installation can affect the design and should be considered during the planning stages of design. For example, the response of the platform will change considerably during the transition from freely floating to vertically restrain; therefore, the temporary restraining equipment should be sized accordingly.

4.8.5 Installation

In planning the installation of subsea well and mooring template(s), due consideration should be given to avoiding interference with seafloor returns of well cuttings and grout. These factors should also be considered in design of the connection equipment and methods to be used for the risers and tendons. The final design of production template(s), well system, temporary mooring system, foundation templates, and the piles will depend on the installation methods and equipment selected.

4.9 Materials, Welding, and Corrosion Protection

4.9.1 Materials

Selection of the strength and quality levels for steel, cement grout, concrete, and other materials for the platform, foundation, and other components will generally follow the criteria commonly used for offshore structures. This publication emphasizes steel as the primary structural material but specifically does not preclude the consideration of other materials. Future revisions of this recommended practice (RP) will cover these other materials as appropriate.

Critical locations in the platform may require specification of steel with enhanced properties consistent with predicted loadings. Strength, toughness, and fatigue resistance of the specified platform materials shall be consistent with expected fabrication practices and the inspectability of each critical location during service.

Steel for the tendons may be higher strength structural steel and will affect the method of tendon fabrication and inspection as well as tendon type and service. The tendons operate under high cycle fatigue stresses superimposed on the mean stress tensile load in a seawater environment. The material should have acceptable properties in the final condition to meet the requirements of strength, toughness, and resistance to corrosion and corrosion fatigue. The material should possess adequate fracture toughness so as to withstand the largest nonrejectable weld flaw allowed by the tendon fabrication specification at design maximum loads and minimum exposure temperatures. Resistance to stress corrosion cracking under operating conditions is critical since detection of such cracks is difficult during service. In-service inspection requirements, intervals, and methods of determining allowable defect size should be considered.

4.9.2 Welding and Inspection

Selection, qualification, and application of welding and weld inspection procedures will generally follow criteria used for offshore platform fabrication where applicable (e.g. platform, foundation templates, etc.).

Where welding is prescribed in the fabrication of tendons, the resulting weldments should have strength properties exceeding those of the tendon parent material. Fabrication procedures should be followed which assure the required properties in the installed tendon. These properties may be more difficult to obtain in a weldment than in the parent steel, especially as the strength level increases. Consideration may be given to fabricating the tendons without any weld, however, the effect on cost, availability and fabrication lead-time should be accounted for.

The inspection method should be sufficient to detect and locate all potentially damaging flaws. This requires consideration of the local geometry as well as the toughness of the material and the applied stress. Inspection methods should be designed and tested to demonstrate an adequate ability to detect, resolve, and size defects.

4.9.3 Corrosion Protection

Steel materials should be protected from the effects of corrosion by the use of a corrosion protection system that is in accordance with DNV-RP-B401, or NACE SP0176. The corrosion protection systems include coatings, cathodic protection, corrosion allowance, and corrosion monitoring. Overprotection that may cause hydrogen embrittlement and coating damage should be avoided.

4.10 Safety and Reliability

The design should maximize the safety of personnel and the protection of property within a framework of efficient, cost effective design. Safety and reliability depend on the ability of a facility to survive the loads anticipated over the installed life. The designer should examine not only the intact facility and structure, but also examine the structure under damaged conditions and ensure that the remaining strength, fire resistance, and escape means are adequate.

Qualitative reliability analyses of certain systems such as the tendon system are possible. Such analyses can help to understand the differing degrees of reliability among designs utilizing different numbers of tendons, different types of connectors, and/or end terminations, etc. Such analyses can help assess reliability versus system cost, and pinpoint critical elements deserving special attention.

Hull damage state scenarios should be developed with the implications of compartment flooding. Facilities design should consider damaged state scenarios and possible implications upon the deck structural system. Personnel escape routes should be designated for damaged states, and alternate routes provided. Damage control systems, including firefighting means, ballast redistribution capabilities, and backup power supplies should all be selected considering the need for reliable operation during periods of severe service. Redundant means of monitoring major platform functions, such as trim, ballast condition, etc., should be considered.

4.11 Operating and In-service Manuals

4.11.1 Overview

The designer should provide manuals that communicate to the operator the correct practices to be used for safe and efficient operation of the platform. These manuals describe the practices and procedures necessary for normal operations; maintenance, in-service inspection and emergency procedures for damage state conditions and other emergency situations. Operating personnel should be required to review and understand the operating and in-service manuals. A description of information typically included in the manuals is noted in 4.11.2 through 4.11.10.

4.11.2 TLP Overview

Typical information includes a description of the TLP system and its function, including its location and orientation, the general overview of platform (hull, deck, tendons, foundations, risers and facilities). Information on certification, operational modes, global performance characteristics, and allowable deck loading plans should also be included.

4.11.3 Operation of Marine Systems

Information on the ballast and bilge system, hull hydraulic systems, hull ventilation, vents and sounds, oily drain pumps, marine instrumentation and load monitoring (both tendon tensions and weight management) should be included for safe operation of the TLP.

4.11.4 Support Operations

Procedures for handling supply boat operations, crew shift changes, helicopter operations, collision avoidance, and preparation of daily reports should be included. Operating and in-service manuals should document the sizes and classes of support equipment (e.g. helicopters and supply boats) for which the facility is designed.

4.11.5 Extraordinary Operations

Procedures for extraordinary operations, such as tendon removal, should be clearly identified prior to installation of the TLP. Associated monitoring requirements for such operations should also be prescribed.

4.11.6 Emergency Operations

Procedures for emergency operations should be clearly identified prior to the installation of the TLP. Critical procedures may include how to react to the following:

- a) loss (or significant change) of tendon tension,
- b) flooded hull compartment,
- c) tendon damage (including flooding),
- d) adverse weather/currents (e.g. hurricane abandonment) and the time necessary to carry out the planned operations,
- e) foundation failure,
- f) pollution incident,
- g) man overboard,
- h) emergency evacuation plan,
- i) emergency fire protection plan,
- j) platform abandonment,
- k) loss of instrumentation for load management system and guidance on manual estimation of tendon tension based on last known conditions and hand calculations,
- l) drifting mobile offshore drilling unit (MODU)/vessel nearby.

4.11.7 Load Management and Allowable KG

The safe operation of the TLP requires an effective load management procedure. A careful explanation of the program used for load management should be included. This should include an overview or procedures for evaluating the following:

- a) vertical loads acting on the TLP (e.g. lightship weight, tendon and riser tensions, ballast, other variable loads, etc.);
- b) base configuration of the TLP;
- c) summary of approved lightship weight and CG;
- d) allowable deck loading;
- e) capacity of cranes;
- f) capacity of derrick, if applicable;
- g) tank tables;

- h) stability and compartmentation;
- i) tendon tension calculations;
- j) apparent weight calculations;
- k) ballast adjustments;
- l) tendon tension reconciliation;
- m) allowable KG (vertical center of gravity with respect to keel).

Effects on TLP global response and load management due to weather and subsidence should be described.

4.11.8 In-service Inspection Plan

A continuing in-service inspection program is required to ensure the proper long-term maintenance of the platform and its components. Typical issues addressed in the inspection plan are as follows:

- a) annual inspection,
- b) hull tanks,
- c) welded joint inspection,
- d) hull gauging,
- e) watertight integrity,
- f) hull corrosion control,
- g) underwater survey,
- h) tendon and foundation,
- i) risers,
- j) inspection sheets.

4.11.9 Construction Manual

An overview of the fabricated TLP structure should be included as documentation for offshore personnel and for long-term management of the asset. Information on repair procedures, structural steel materials used, material certifications and welding procedures should be included.

4.11.10 Reference Drawings and Arrangements

Generally the manuals include a full set of reference drawings and arrangements. The following is a typical list that should be included:

- a) general arrangements,
- b) fire plans,
- c) hull structural plans,

- d) lifesaving equipment plans,
- e) deck structural plans—primary,
- f) deck structural plans—secondary,
- g) hull systems P&IDs,
- h) electrical area classifications,
- i) emergency power system one-lines,
- j) tank capacity plans,
- k) deck load plan.

5 Design Criteria

5.1 General

This section defines the criteria commonly needed for the design of a TLP. The format of the design criteria is consistent with Section 6, and those sections that deal with the design of the various subsystems.

Design and analysis of a TLP and the associated subsystems require that a series of design load cases be specified and checked. This requires that each phase of construction, transportation, installation, and operation be coupled with appropriate design environmental events and associated safety factors. These design environmental events and safety factors are selected based on a calibration of the design code equations or as part of a probabilistic design analysis. Specification of the load cases also requires establishing the detailed condition, including the allowable range of weight and center of gravity variations of the platform.

Other environmental conditions, including long-term data for fatigue analyses, etc., are also needed for various design activities.

This publication is based on working stress design (WSD) principals. There have been efforts over the past 20 years to address load and resistance factor design (LRFD) principals in tension leg platforms, but these have been abandoned because of the dynamic nature of platform response wherein the final extreme response cannot reasonably be broken down into the component responses to individual load components. However, one significant advance in achieving more uniform risk levels which is included in this publication has been to include the concept of response-based criteria, wherein the variability and uncertainty of response to a multi-parameter environment is addressed in the specification of the design environment.

5.2 Safety Categories

5.2.1 General

The design checking procedures described herein are based on safety categories being applied to load cases. A safety category includes a specification of environmental conditions and safety factors that together are used to check the overall reliability and adequacy of a design. There are four different types of safety categories used in this recommended practice.

5.2.2 Category A—Operational Conditions

This category is used to assure that the structure meets criteria for operational capabilities. Considerations for this safety category include the acceptability of deflections and vibrations.

5.2.3 Category B—Extreme Conditions

This category is used to determine the serviceable strength of a structure. Category B applies to conditions that will occur only rarely in the life of the structure. The structure is designed to survive conditions without significant probability of its subsequent serviceability being compromised. Platform conditions to be covered include intact, damaged, and tendon removed cases.

5.2.4 Category S—Survival Conditions

This category is used to determine reserve strength of a structure to overload conditions, which are expected to occur very rarely during the life of the structure. The TLP should be designed to survive these conditions without loss of life, damage to the environment or total loss of the platform. Depending on the nature of the design, the yielding or failure of components or local areas of structure may be acceptable, provided no progressive failure is initiated.

For the TLP, the survival category also includes, at a minimum, required global load cases for deck clearance and minimum tendon tension, which are specified to ensure that the structure is inherently robust in its ability to deal with rare conditions. Inclusion of hull structural strength checks in survival conditions is not explicitly recommended, but is at the option of the operator.

5.2.5 Category C—Fatigue Conditions

This category is intended for the design of the structure against fatigue failure. This applies principally to components whose fatigue life will limit the service life of the overall structure. The structure will generally be designed such that its components have a minimum fatigue life greater than the structure's required service life, with adequate margin of safety to account for uncertainties such as material properties, fabrication tolerances, inspection practices, ability to access for inspection, maintenance and repair, and criticality of the consequences of failure. The structure will be designed to facilitate the inspections appropriate to assure against premature failures. Easy inspection and repair or replacement may justify the use of particular components with an expected fatigue life that does not have a high probability of exceeding the service life of the structure.

5.3 Operational Requirements

Design criteria dictated by operational requirements should be reviewed during each iteration of the design. The cost and weight consequences of these requirements should be fully established for the operator before a final design decision is made.

Examples of such requirements may involve:

- limiting motions to meet requirements of facilities,
- simultaneous drilling and production,
- consumables resupply procedure and frequency,
- inspection and maintenance procedures and schedule,
- manning schedule and rotation.

5.4 Stability Requirements

5.4.1 General

Stability should be established for relevant in-place operating and pre-service conditions, for both intact and damaged states of the structure.

5.4.2 In-place Condition

The in-place TLP is a compliant structure. 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 and moments. Traditional measures of hydrostatic free floating stability (i.e. metacentric height without mooring stiffness) are not appropriate in the in-place condition of a TLP, but are replaced instead by the global performance minimum and maximum tension criteria based on a full dynamic analysis, and by serviceability limits on pitch and roll motions. Global performance load cases to demonstrate adequacy of design ensure that the system is sufficiently constrained by the tendon system in the intact, damaged, and tendon removed conditions, and is safe from overturning in all environmental conditions considered.

Hull damage scenarios to be considered, however, should be, at a minimum, the same as for damaged stability requirements for column stabilized MODU as prescribed in the applicable code [e.g. International Maritime Organization (IMO), class or coastal state regulations], including extent of damage and all pertinent definitions.

NOTE Unlike a MODU, the waterline of a TLP is affected by tide, storm surge, seabed subsidence, and draw-down (setdown) due to environmental loading. The vertical extent of damage should be adjusted accordingly.

5.4.3 Pre-service Conditions

The intact and damaged stability in all free-floating conditions prior to final installation (e.g. float-off, deck integration, wet tow, prior to initial tendon tensioning) should, in general, satisfy requirements applicable to column stabilized mobile offshore drilling units, as promulgated by the U.S. Coast Guard in the United States. In other locations, IMO MODU Code, or coastal state requirements, along with class society rules, may apply.

Marginal stability may be accepted for marine operations of short duration operation such as during deck integration at quay side or platform installation at the offshore site, provided that in these marginal stability conditions controlled transient ballasting, provision of reliable weather forecasts, limited weather windows, and close monitoring of the system status are used to provide and demonstrate an adequate safety level.

During installation or transient ballasting down conditions, it may not be practical to provide reinforcement against collision over the full range of waterlines. In such cases, rigorous procedures should be developed to ensure that such flooding will not occur. These should include consideration of collision, leakage through the ballast system and other systems and/or structure, reliability and redundancy in pumping arrangements and redundancy of power supply.

Planning and risk assessment should also include the definition of restricted criteria, and a procedure to return to the reinforced waterline should the installation operation be aborted.

Pre-service stability requirements can have a substantial influence on bulkhead placement and general arrangements of the hull. Care should be taken to review the applicable stability rules before entering the conceptual design phase. Hull sizing and arrangements should consider the ability to recover from damage, and carry sufficient ballast weight margin to accommodate unexpected growth in vertical center of gravity, which will adversely impact stability in pre-service conditions.

5.4.4 Weight Control

All TLP design and construction should include careful weight control procedures. This includes the following:

- a) a detailed breakdown of component and module estimates during design;
- b) weighing or accurate estimation of components during construction;
- c) tracking of weights during assembly and commissioning;
- d) an inclining test of the completed TLP, when possible.

The final weight condition of the platform includes weight, vertical and lateral center of gravity, and estimates of the mass moments of the system. An example of a good reference for weight control procedures can be found in ISO 19901-5.

5.4.5 Inclining Tests Weight and CG Determination

An inclining test should normally be conducted when construction is as near to completion as practical, to accurately determine the platform weight and the position of the center of gravity. Changes of on board load conditions after the inclining test and during service should be carefully accounted for.

5.4.6 Alternate Weight and CG Determination

Some platform configurations are not stable in the free-floating condition as a fully assembled configuration. With such systems it may not be possible to perform a traditional inclining test of a reasonably complete portion of the platform. In other cases, the TLP may be integrated on location with deck structure or modules being installed on an installed hull. In cases where an inclining test is not utilized, alternate means of determining the weight and center of gravity of the TLP may be utilized. Such alternate 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 CG of the completed system.

5.5 Environmental Criteria

5.5.1 General

Environmental criteria should be associated with the safety category being considered. Philosophically, the environments specified for use in this publication are response-based, i.e. a 100-year design event is an environment that is expected to lead to 100-year responses. This is achieved either by use of traditional design criteria (independent of TLP sensitivity) supplemented by a probabilistic design analysis, or by an environmental scanning process to determine appropriate criteria for the TLP system, again supplemented by a probabilistic design analysis. The probabilistic analysis or scanning process can be performed as a calibration for a class of TLPs in a given environment, or can be performed for an individual project.

There can be different design events at a given return period that can govern different responses of the TLP.

NOTE TLPs are sensitive to a number of different environmental loadings and the extreme responses of TLPs are not necessarily produced by the highest wave or highest wind conditions.

Because of its compliant and dynamic nature, criteria for design of a TLP require a reasonably complete specification of the environment, including wave significant height, period, and spectral form, wind velocity and spectrum, current profile, and water level (tide and storm surge). Directional distributions are sometimes significant. In general, detailed site-specific conditions, rather than generic regional conditions, should be used for floating systems. Selection of the actual data needed should be made only after consultation with both the platform designer and meteorological/oceanographic specialists.

For the Gulf of Mexico, the collection and analysis of metocean data should also follow the recommendations in API 2INT-MET.

Available statistical data and/or realistic statistical and mathematical models should be utilized to develop the description of environmental conditions. Considerations include:

- operating environmental conditions are important both during the construction and during the service life of a platform,
- extreme and survival conditions are important in formulating platform design loadings.

All data used should be documented in project design reports as to source, analysis methods, and assumptions in interpretation. The quality and the source of all data should be recorded. The methods

employed in developing data into the desired environmental values should be reported as part of project documentation.

The following sections briefly describe the environmental parameters that should be specified for use in design. For guidance on actual values to use in design, the designer should refer to data collected at the intended site, to appropriate oceanographic numerical models, and to API 2INT-MET.

5.5.2 Wind

Wind is significant in TLP design and analysis. Both steady wind and fluctuating wind components should normally be used. A wind spectrum is normally used to represent fluctuating wind components, although use of gust values is acceptable if these are shown to provide an equivalent response to use of a full wind spectrum. API 2A-WSD provides guidance on wind gust modeling and wind spectra.

5.5.3 Waves

Wind driven waves are a major source of environmental forces on offshore platforms. Such waves are irregular in shape, can vary in height and length, and may approach a platform from one or more directions simultaneously.

Because of the random nature of the sea surface, the sea state is usually described in terms of statistical wave parameters such as significant wave height, spectral peak period, spectral shape (including spectral width), and directionality. Other important sea state parameters which may affect TLP response are the maximum up and down crossing wave height and the maximum crest height.

The statistical maximum crest height that a platform may experience has been shown to depend on the plan view size of the platform. Forristall ^[142] describes methods for predicting local maxima based on traditional point statistics. This procedure was adopted in API 2INT-MET.

5.5.4 Current

Current data collected at the site should be included in the design criteria if available. Currents should include wind driven, tidal, and background circulation components. In deepwater the currents might produce large system loads. Near boundary currents such as the Gulf Stream and loop current, currents due to meanders and eddies should be considered. Deep current profiles have been identified in the Gulf of Mexico and elsewhere, and should also be included if likely to occur. Recent descriptive names of such currents include cold core eddy, submerged current, and submerged jets. Bottom boundary currents in some areas such as the Sigsby Escarpment have also been identified. Current profiles over the entire water column are important to calculation of loads on, and VIV of, tendons and risers.

5.5.5 Tide and Water Level

Tidal components for design include astronomical, wind, and pressure differential tides. A high design water level (HDWL) and low design water level (LDWL) should be established for each design event. The tidal range will affect the required tendon pretension (minimum tension) and will contribute to maximum tension.

5.5.6 Joint Statistics

Environmental data such as wind, tide, wave, and currents can have specific relationships regarding their interaction and joint occurrences. A commonly used assumption of taking the combined maximum of each parameter might not always produce the worst design condition, or may be excessively conservative. When collecting data or performing analytical work, the various relationships should be included if possible. Of particular importance are wind/wave, wave height/wave period, wave/current, wind/current and wave/tide relationships.

5.5.7 Physical Properties

Various seawater physical properties, such as temperature, salinity, and oxygen content, may be important for steel requirements, corrosion, and buoyancy calculations. Further guidance can be found in API 2A-WSD. In areas where substantial density differences may occur, the ranges should be accounted for in design load cases.

5.5.8 Ice

In far northern or far southern climates, floating ice or atmospheric icing can affect the loading on the platform (refer to API 2N).

5.5.9 Earthquakes

Seismic accelerations should be considered for areas that are determined to be seismically active. Both vertical and horizontal accelerations are important for TLP design. The horizontal accelerations excite tendon transverse modes, while vertical accelerations directly excite heave, pitch, and roll responses of the TLP. Soil liquefaction leading to foundation failure is also a concern. The degree of risk for seismic activity in the United States is shown in API 2A-WSD. Local regulations and conditions should be considered and may result in more stringent requirements.

5.5.10 Marine Growth

The type and accumulation rate of marine growth at the design site should be evaluated for determining design allowances for weight, hydrodynamic diameters, and drag coefficients. Refer to API 2A-WSD for appropriate guidance.

5.6 Design Load Cases

5.6.1 General

Defining a design load case requires selection of the following parameters:

- project phase,
- platform condition,
- environment and safety factors.

5.6.2 Definition of Loads Acting on Structure

All appropriate load types shall be quantified and included for each design case. Load types and design parameters are discussed in the following sections. Table 1 shows how the parameters may be combined to define design cases. This table is intended only to provide an example and is not necessarily complete. Other environmental criteria may be used if properly justified.

5.6.3 Project Phase

5.6.3.1 General

This describes the phase of the platform or component, e.g. hull construction, deck transport, platform in-place. The construction, float-out, load-out and transportation phases have various loading conditions that should be examined. These conditions are described by the stage of construction, draft during tow, or stage of load-out.

5.6.3.2 Fabrication

Loading conditions imposed on the hull and deck during fabrication could control the structural design of some components. Intact and damaged stability of the freely floating hull shall be ensured at all phases of the fabrication.

Table 1—Project Design Load Cases

Design Load Case	Safety Category	Project Phase	Platform Configuration ^e	Design Environment	Annual Probability of Exceedance
1	A	Construction	Various		
2	A	Load out	Intact	Calm	
3	B	Hull/deck mating	Intact	Site specific	
4	B	Tow/transportation	Intact/damaged	Route	Varies
5	A	Installation	Intact	Installation	Varies
6	A	In place	Intact	One-year normal	≤1
7	B	In place	Intact	100-year extreme	0.01
8	S	In place	Intact	1000-year extreme	0.001
9	B	In place	Damaged—no compensation	One-year normal	≤ 0.01 ^a
10	S ^{b c}	In place	Damaged—no compensation	10-year reduced extreme	≤ 0.001 ^a
11	B	In place	Damaged—compensation	10-year reduced extreme	≤ 0.01 ^a
12	S ^{b c}	In place	Damaged—compensation	100-year extreme	≤ 0.001 ^a
13	B	In place	Tendon removed (planned)	10-year reduced extreme	≤ 0.01 ^a
14	S ^{b c}	In place	Tendon removed (planned)	100-year extreme	≤ 0.001 ^a
15	C	In place	Intact	Annual scatter diagram	1
16	SLE ^d	In place	Intact	SLE seismic	Varies
17	DLE ^d	In place	Intact	DLE seismic	Varies

NOTE This table is indicative of the types of load cases to be checked, and is not intended to imply adequate number of load cases.

^a Probability of exceedance includes nominal probability of damage or tendon removal occurring.

^b Pile check, if performed, in survival conditions uses reduced safety factor.

^c Survival check with damage or tendon removed is against disconnect (not zero tension) and may be response-based.

^d See Section 4 and API 2A-WSD for definition of SLE, DLE.

^e In all cases, platform configuration should consider both minimum weight and maximum weight variations.

5.6.3.3 Transportation

The freely floating platform behaves like a semisubmersible during transportation to the installation site. Since it is free to pitch and roll, lateral deck accelerations can be larger than after installation. Since it is free to heave, and heave resonant periods tend to be short, adequate deck clearance with the waves should be verified.

Alternately, the hull, deck, or complete TLP can be transported on a barge or heavy lift vessel. In this case, the motions of the combined barge/TLP component shall be used in determining accelerations, loads, and clearances.

5.6.3.4 Installation

The stiffness and mass properties change as the platform is transformed from a freely floating vessel to a vertically moored platform, thus changing the dynamic response characteristics. The tendons and their handling equipment should be designed for loading conditions representative of the various installation phases.

5.6.4 System Condition

5.6.4.1 General

This section describes the condition of the platform or component.

5.6.4.2 Intact

The platform or component is as designed.

5.6.4.3 Damaged Hull

Damaged conditions should be checked for various project phases. The transport barge or floating component should be checked with one compartment flooded.

In the in-place condition, the platform should be capable of withstanding damage in a normal condition (one-year storm) with no ballast adjustment, or a reduced extreme condition (10-year storm) with ballast adjustments.

Flooded compartments to consider, extent of damage, and associated definitions should be in accordance with that prescribed for column stabilized MODU in the applicable code (e.g. IMO, class, coastal state regulations). Within a range of 5 m (16.4 ft) above and 3 m (10 ft) below any in-place waterline, any watertight flats, or bulkheads shall be considered damaged. The location of the waterline for a TLP will vary with tide, storm surge and seafloor subsidence. This means the distance between horizontal flats will be considerably greater than the minimum prescribed for semisubmersibles in MODU codes (e.g. +5 m/-3 m). In addition, consideration should be given to the dimensions of typical supply boats used in the region of operation, and any hazards that may require an increase in vertical spacing.

At a minimum, damaged scenarios should include any single compartment adjacent to the sea, any two adjacent compartments at the waterline, any horizontal flats located in the damage zone as defined above, any compartment containing ballast pumps or machinery cooled by seawater.

5.6.4.4 Tendon Removed

For TLPs with more than one tendon per corner, it is recommended that the TLP be designed on the basis that tendons can be removed for inspection, maintenance, or replacement. In this tendon-removed condition, the TLP should be designed for combinations of static, environmental, motion induced and construction loads. This condition is a planned maintenance or construction condition, and would include appropriate ballast to maximize performance in this condition. The platform has reduced capacity while in a tendon removed

condition, and careful monitoring of environment and operational weight to ensure optimum configuration and response is recommended. The platform should be capable of withstanding a reduced extreme condition (10-year storm) with Category B safety factors with one tendon removed. The platform shall be shown to survive the extreme response condition (100-year storm) without loss of the platform in the tendon-removed configuration (i.e. Safety Category S). This case is intended to be a true survival case, and is not limited to the zero tension recommendation. Because of the nature of this condition as a reduced capacity/damaged condition case with full planning and preparation, special conditions such as pinning a connector to prevent disconnect upon slack condition are acceptable in meeting survival condition requirements. The tendon-removed condition as discussed herein is not a broken tendon case.

5.6.5 Design Environments

5.6.5.1 General

5.6.5.1.1 Design environmental conditions are associated with each safety category. The important aspect of the environmental design condition used to evaluate the design response is that it be the same environment used in the calibration of the safety factors. In the context of this recommended practice, environmental conditions are also associated with response return periods, and are referred to as “design environments.”

5.6.5.1.2 The selection of the design environments should be based on either general or specific TLP response characteristics. The designer/owner is responsible for selecting appropriate design environments. Guidance on a probabilistic analysis method for selection of appropriate design environments may be found in Section 7. Further information on the sensitivity of the TLP system to selection of environment for Gulf of Mexico locations may be found in the Conoco Model Code reports (Banon, et al. 1994 [95]; Jefferys and Banon 1993 [162]; Leverette, API TAC-93-20 [176]; Spillane and Leverette 1988 [224] and 1991 [225]; Leverette and Rashedi, 1995 [178]. General methods for establishing response-based criteria are described in Schaudt, et al. 1992 [218]; Wen and Banon, 1995 [242]; Forristall et al. 1991 [141]; Spillane, et al. 1999 [226]. Traditional design environments determined as extreme n -year return wind, wave, and current events should be used for areas with insufficient environmental database to generate appropriate response based design environments. In such cases, the designer is encouraged to examine appropriate sensitivity cases to ensure that sufficient consideration is given to possible onerous combinations of events.

5.6.5.1.3 The design environment should be defined quantitatively in terms of wind (speed, direction, spectrum), wave (H_S , T_P , spectral shape, direction), current (speed and direction as function of depth), and water level (tide, storm surge).

5.6.5.1.4 The various safety categories include different return periods for the design environments. Typical design environments include the following.

5.6.5.2 Extreme Environments

Extreme environmental conditions are those that produce TLP responses having a low probability of being exceeded in the lifetime of the structure. A minimum return period of 100 years for the design response should be used for Safety Category B criteria for the intact condition unless risk analysis can justify a shorter recurrence interval.

The structure and its key subsystems shall be designed such that they will be capable of withstanding extreme environmental conditions in a safe operable condition. Similar extreme environments may be combined with damaged cases to assess the ability of the structure to survive without further damage.

5.6.5.3 Normal Environment

Normal environmental conditions are those that are expected to occur frequently during the construction and service life. Since different environmental parameters and combinations affect various responses and limit

operations differently (e.g. installation, crane usage, etc.), the designer should consider the appropriate environmental conditions for the design situation.

5.6.5.4 Reduced Extreme Environment

Reduced extreme environmental conditions are those that have a low probability of being exceeded in combination with other low probability events (e.g. when the hull is damaged or a tendon is removed). Joint statistics may be used to determine a return period which, combined with the probability of damage, produces a risk level equal to that of the extreme environment. A return period of 10 years is typically used for damaged or temporary reduced capacity conditions of the TLP. For removed tendon conditions, a 10-year annual storm condition is recommended with no restriction on season for removing a tendon.

5.6.5.5 Survival Environment

Survival environmental conditions as described in this publication are those that produce TLP responses having a very low probability of being exceeded in the lifetime of the structure. A minimum return period of 1000 years for the design response should be used for Safety Category S criteria for the intact condition, unless risk analysis can justify a shorter recurrence interval. Survival conditions are used for evaluating minimum tension and deck clearance.

5.6.5.6 Calm Environment

Some operations are performed only during calm conditions. Where such a choice is available the design case is permitted to use calm conditions.

5.6.5.7 Transportation, Installation, and Marine Operations Environments

For pre-service conditions, including float-off, integration, dry or wet transport to site, and installation, the return period of environmental conditions to be considered should be related to the duration of the marine operation and the appropriate risk level. As a general guidance, the criteria in Table 2 may be applied.

Table 2—Return Period of Environmental Conditions

Duration of Use	Environmental Criteria
Up to three days	Special weather window
Three days to one week	One-year return seasonal
One week to one month	10-year return seasonal
One month to one year	50-year return seasonal
More than one year	100-year return all year

5.6.5.8 Operation Duration

5.6.5.8.1 For weather-restricted operations, there should be a margin between the design criteria and the operation criteria. As a guideline, a ratio of 0.8 for wind speed and 0.75 for wave height may be used to derive the operational criteria from the design criteria. Weather restricted operations may be divided into sequences where the operation may be aborted and brought to a safe condition (safe haven) within the remainder of the existing weather window.

5.6.5.8.2 The point of no return (PNR) should be defined as the last point in time (or a geographical point along a route) at which an operation could be aborted or returned.

5.6.5.8.3 For the critical period between any PNR and the structure reaching a safe condition, the reliability of weather window is crucial. The window duration shall have necessary margins for the following:

- a) inaccuracy in operation schedule,
- b) technical/operational delays, and
- c) inaccuracy of weather forecast timing.

5.6.5.8.4 Generally, the forecast window duration shall be in excess of the total critical operation schedule. This, however, needs to be evaluated on background and consequences as given in the following guidelines:

- a) operations with vulnerable/critical equipment need extra allowance,
- b) operations with time schedule based on previous similar operations need less allowance,
- c) operations in areas/time of the year where weather is difficult to predict need extra allowance.

5.6.5.9 Weather Forecast

5.6.5.9.1 Weather forecasts should be obtained before and during all marine operations. The forecast shall be issued at regular intervals, e.g. every 12 hours. For weather-restricted operations, the forecasters should preferably be present at site to provide regular weather briefing.

5.6.5.9.2 The weather forecast should be in writing and include relevant parameters such as:

- a) synopsis, barometric pressure, temperature;
- b) wind direction and velocity;
- c) waves and swell: significant and maximum wave height, direction and period;
- d) visibility, rain, snow, sleet, etc.

5.6.5.9.3 Other environmental conditions such as current, tide and surge, may also be of utmost interest for certain operations. Such conditions need real time measurements as well as regular forecast, both prior to start of and during operation.

5.6.5.9.4 Normally the weather (environmental) forecast should cover the following period 0 to 12 hours, 12 to 24 hours, 24 to 36 hours, 36 to 48 hours, 48 to 72 hours, and outlook beyond 72 hours. Any weather forecast shall give a level of confidence.

5.6.5.9.5 Transportation cases should use appropriate conditions for the transportation route.

5.6.5.9.6 Consideration should be given to possible delays in overall project when designing a major marine operation for a specific season. Criteria for partially installed systems (such as preinstalled tendons) should make allowances for possible delays, such as those due to weather, current conditions, or project schedule, in installing the rest of the system. Experience has shown that potential delays can be several months. Selected criteria should be representative of specific project conditions and factors.

5.6.5.10 Seismic

The TLP should be designed with strength and stiffness to ensure no significant structural damage occurs for the level of earthquake shaking which has a reasonable likelihood of not being exceeded during the life of the structure. The two-tier SLE/DLE criteria as used for fixed offshore platforms are also applicable to TLPs (refer to API 2A-WSD). SLE and DLE criteria should be developed using a probabilistic seismic hazard assessment (PSHA) consistent with the seismic risks at the site.

5.6.6 Safety Factors

The safety categories described above are associated with matched sets of design environments and safety factors. The safety factors are a means of ensuring an adequate level of safety above and beyond the return period of the design environment, and for accounting for other sources of variability and uncertainty. The safety factors are based on a target annual probability of exceedence level. Different safety categories generally have different target safety levels.

The safety factors for global responses are given in Section 7. The safety factors for allowable stress for the various components are given in their respective sections or in the annexes.

5.6.7 Load Types

Loading type categories are described in Table 3. The combination and severity of loads should be consistent with the likelihood of their simultaneous occurrence.

Table 3—Loading Type Category Descriptions

Load Type	Description
Dead loads	Nonvariable static weight of the platform structure and any permanent equipment that does not change during the life of the structure.
Live loads	Variable static loads that can be changed, moved or removed during the life of the structure. Maximum and minimum payloads should be considered.
Environmental loads	Loads on the structure due to the action of wind, wave, current, tide, earthquake, or ice.
Inertial loads	Motion induced loads that are consequences of the environmental loads.
Construction loads	Loads built into the structure during the fabrication and installation phases.
Hydrostatic loads	Buoyancy of, or submerged pressure on, submerged members.
Combined loads	The combination and severity of loads should be consistent with the likelihood of their simultaneous occurrence.

6 Environmental Forces

6.1 General

The purpose of this section is to describe methods for calculating forces which act on an in-place TLP due to environmental effects, such as waves, winds, currents, ice, earthquakes, etc. Forces due to platform motion responses are also significant and are discussed herein. Environmental parameters needed for these calculations are defined in Section 5. The emphasis in this section is on calculating the forces on individual

members or local forces. Methods for calculating global environmental forces and platform responses caused by these environmental forces are described in Section 7.

Environmental forces should be calculated at four distinct frequency bands to evaluate their effects on the system. The four frequency bands are as follows.

- a) Steady forces such as mean wind, current, and wave drift are constant in magnitude and direction for the duration of interest.
- b) Low-frequency cyclic loads can excite the platform at its natural periods in surge, sway, and yaw by waves, wind and current (oscillating body in a steady current produces an oscillating force); typical natural periods are in excess of one minute.
- c) Wave frequency cyclic loads are large in magnitude and are the major contributor to platform member forces and tendon system forces. Typical wave periods range from 5 to 30 seconds.
- d) High-frequency cyclic loads can excite the platform at its natural periods in heave, roll and pitch: typical natural periods range from 1 to 5 seconds.

6.2 Wind Forces

6.2.1 General

The wind conditions used in a design should be determined with appropriate means from wind data collected in accordance with Section 5 and should be consistent, in terms of joint probabilities of occurrence, with other environmental parameters assumed to occur simultaneously. A TLP has long natural periods in surge, sway, and yaw which may be excited by energy in the wind spectrum. The effects of the complete wind spectrum, including sustained and fluctuating winds, should be considered in determining the wind induced platform loads and responses. Such analyses may require knowledge of the wind turbulence intensity, spectra, and spatial coherence. These items are addressed below.

6.2.2 Wind Properties

6.2.2.1 General

Wind speed and direction vary in space and time. On length scales typical of even large offshore structures, statistical wind properties (e.g. mean and standard deviation of velocity) taken over durations of the order of an hour do not vary horizontally, but do change with elevation (profile factor). Within long durations, there will be shorter durations with higher mean speeds (gust factor). Therefore, a wind speed value is only meaningful if qualified by its elevation and duration. A reference value is the one-hour mean speed at the reference elevation of 10 m (32.8 ft).

6.2.2.2 Mean Profile and Gusts

A wind profile defines the vertical variation of wind speed, given a reference wind speed as defined in 6.2.2.1. Applicable mean wind profiles and gusts are defined in API 2A-WSD. Therefore, once the reference wind speed is defined, the wind speed at any elevation is also defined.

Wind gust speeds can be calculated from an hourly mean speed. The conversion equations are specified in API 2A-WSD.

6.2.2.3 Wind Spectra

As with waves, the frequency distribution of wind speed fluctuations can be described by a spectrum. Due to the large variability in measured wind spectra, there is no universally accepted spectral shape. In the absence of data indicating otherwise, the simple shape given by API 2A-WSD is recommended.

6.2.2.4 Spatial Coherence

Wind gusts have 3D spatial scales related to their durations. For example, three-second gusts are coherent over shorter distances and therefore affect smaller elements of a platform superstructure than 15-second gusts. The wind in a three-second gust is appropriate for determining the maximum static wind load on individual members; five-second gusts are appropriate for maximum total loads on structures whose maximum horizontal dimension is less than 50 m (164 ft); and 15-second gusts are appropriate for the maximum total static wind load on larger structures. The one-minute sustained wind is appropriate for total static super-structure wind loads associated with maximum wave forces. In frequency domain analyses of dynamic wind loading, it can be conservatively assumed that all scales of turbulence are fully coherent over the entire superstructure.

The variable nature of the wind field can alternatively be described by two components: a sustained component (V_z) and a gust component (u'). The calculation of the total wind speed is shown in Equation (1).

$$u = V_z + u' \quad (1)$$

where

- u is the instantaneous wind velocity (speed and direction);
- V_z is the mean (or sustained) wind velocity;
- u' is the instantaneous velocity variation from sustained wind.

6.2.3 Wind Force Relationship

6.2.3.1 The instantaneous wind force on a TLP can be calculated by summing the instantaneous force on each member above the water line. This should be calculated by an appropriate equation as shown in Equation (2).

$$F_w = \frac{1}{2} \rho_a C_s A |V_z + u' - \dot{x}| (V_z + u' - \dot{x}) \quad (2)$$

where

- F_w is the wind force;
- ρ_a is the mass density of air;
- C_s is the shape coefficient (may also account for shielding);
- A is the projected area of object;
- V_z is the mean wind speed;
- u' is the instantaneous speed variation from sustained wind;
- $\dot{x}$ is the instantaneous velocity of structural member.

6.2.3.2 For all angles of wind approach to the structure, forces on flat surfaces should be assumed to act normal to the surface and forces on vertical cylindrical objects should be assumed to act in the direction of the wind. Forces on cylindrical objects that are not in a vertical attitude should be calculated using appropriate formulas that take into account the direction of the wind in relation to the attitude of the object. Forces on

sides of buildings and other flat surfaces that are not perpendicular to the direction of the wind shall also be calculated using appropriate formulas that account for the skewness between the direction of the wind and the plane of the surface.

6.2.3.3 The total wind force on the structure may also be calculated using the total exposed area of the structure with appropriate coefficients determined by model tests or some other appropriate method.

6.2.3.4 When using the wind spectrum, it is common to linearize the force for spectral and frequency domain calculations (Simiu and Leigh, 1983 [222]; Kareem, 1980 [164]).

$$F_w = \frac{1}{2} \rho_a C_s A V_z^2 + \rho_a C_s A V_z u' \quad (3)$$

where

F_w is the wind force;

ρ_a is the mass density of air;

C_s is the shape coefficient (may also account for shielding);

A is the projected area of object;

V_z is the mean wind speed;

u' is the instantaneous speed variation from sustained wind.

The first term in Equation (3) is the constant or steady force, and the second term is linear in the fluctuating velocity. The higher-order term, which is neglected in this approximation, is generally small. It does contribute a small amount to the steady force.

6.2.4 Steady Wind Force

6.2.4.1 The first term of Equation (3) is the steady wind force. V_z should correspond to the mean wind speed used in generating the wind spectrum.

6.2.4.2 Commercial software programs are available for estimating the steady wind forces on a complex structure that contains many small dimensioned and spatially separated elements.

NOTE 1 This software is highly dependent on modeling parameters; having an understanding of wind tunnel tests is recommended when using and tuning these programs.

NOTE 2 Validation of the software on a similar platform type is recommended.

6.2.4.3 In addition to producing steady wind forces, steady wind can also induce vibrations of slender structural members (see 6.4 for more details on VIV).

6.2.5 Fluctuating Wind Force

The fluctuating wind force may be calculated in the time or frequency domains. In the time domain, the total wind force is calculated from a time series of the instantaneous total wind velocity using Equation (2). In frequency domain calculations, Equation (3) may be used with the wind spectrum to derive the wind force spectrum as shown in Equation (4):

$$S_{ff}(f) = \chi^2(f) S_{uu}(f) (\rho_a C_s A V_z)^2 \quad (4)$$

where

S_{ff} is the wind force spectrum;

f is the frequency;

χ is the aerodynamic admittance coefficient;

S_{uu} is the wind gust spectrum;

ρ_a is the mass density of air;

C_s is the shape coefficient (may also account for shielding);

A is the projected area of object;

V_z is the mean wind speed.

In lieu of full spectral analysis, a quasistatic analysis using one-minute mean wind speed and Equation (2) can be used, if it can be demonstrated that the results (such as extreme TLP offset, etc.) are similar for both methods.

6.2.6 Shape and Shielding Coefficients

The shape coefficients in Table 4 are recommended for perpendicular wind approach angles.

Table 4—Shape Coefficients for Perpendicular Wind Approach Angles

Shape Coefficient	Object
1.5	Beams of various cross section shapes
1.5	Sides of rectangular sections
0.5	Cylindrical sections
1.0	Overall projected area of platform (should be confirmed by model testing)

Shielding coefficients may be used when the proximity of a second object relative to the first is such that it does not experience the full effect of the wind (Simiu and Scanlan, 1978 ^[221]; DNV-RP-C205; Hoerner, 1965 ^[153]; Meyers, Holm, and McAllister, 1969 ^[191]).

6.2.7 Aerodynamic Admittance

Wind gusts measured at two locations become uncorrelated as the distance between the two locations increase. When the lateral dimensions of a structure are large, the reduction in gust forces can be accounted for by an aerodynamic admittance factor. Simiu and Scanlan, 1978 ^[221], present data on transverse gust correlations which can be used to determine admittance factors. The aerodynamic admittance coefficient χ modifies the force equation as shown in Equation (5)

$$F_w = \frac{1}{2} \rho_a C_s A V_z^2 + \rho_a \chi C_s V_z u' \quad (5)$$

where

F_w is the wind force;

ρ_a is the mass density of air;

C_s is the shape coefficient (may also account for shielding);

A is the projected area of object;

V_z is the mean wind speed;

χ is the aerodynamic admittance coefficient;

u' is the instantaneous speed variation from sustained wind.

The admittance coefficient is frequency dependent, is smaller for higher frequencies, and varies between 0 and 1. A value of $\chi = 1.0$ is conservative and appropriate for low-frequency wind oscillation, and should be used for high frequencies when data is not available to establish a lower value.

6.2.8 Wind Tunnel Data

6.2.8.1 Wind pressures and resulting forces may be determined with properly executed wind tunnel tests on representative models. An example of tests for a semisubmersible is given in Macha and Reid (1984) [184]. Such tests may be suitable for a similarly shaped TLP.

6.2.8.2 In wind tunnel test, special attention should be paid to model scale, boundary layers thickness and test Reynolds number. The model should be as large as possible within the limitations of the testing facility.

6.2.8.3 In lieu of exhaustive wind tunnel test, software calibrated to model test on the same or similar structures can be used to estimate wind forces.

6.3 Current Forces

6.3.1 General

The current velocity used in design should be determined by the means described in 5.5.4 and should be consistent (as to return period) with other design parameters such as wave height and wind velocity. The joint statistics of current and other environmental events should be considered.

Ocean currents can cause two major effects on TLP members—drag force and vortex induced vibration or VIV.

6.3.2 Current Drag

The drag force exerted on a bluff cylindrical member by a current is proportional to the square of the current velocity. The drag force acts in the direction of the component of current that is normal to the member axis. The drag coefficient should be based on the best empirical data available. Drag force can be determined using the formula in Equation (6).

$$F_d = \frac{1}{2} \rho_w C_D \int A_c (V - \dot{x}) |V - \dot{x}| dl \quad (6)$$

where

F_d is the drag force;

ρ_w is the mass density of water;

C_D is the drag coefficient;

A_c is the projected area per unit length;

V is the current velocity;

$\dot{x}$ is the instantaneous velocity of structural member.

The current effect is not limited to producing steady drag forces. Current can also produce low-frequency excitation and damping. The damping effect is especially important in low-frequency range where damping from other sources is small. The current induced damping should be considered for all low-frequency motion analyses.

The current drag coefficient of the hull should be obtained by model testing.

6.4 Vortex-induced Vibrations (VIV)

6.4.1 General

6.4.1.1 When a flow, either air or fluid, passes a blunt body, vortices are shed around the body. The normal shedding pattern of the vortices is asymmetric and alternating between the two sides of the body. As a result, the alternating vortices generate an alternating lift (normal to the direction of flow) force and a drag (parallel to the flow direction) force. Normally, these forces are randomly distributed along the body. The net force on the body is of little or no consequence. If, however, the body is capable of vibrating, the vortices are in phase along a significant segment of the body, and the vortices are being shed at or near one of the body's natural frequencies, the body may be excited to vibrations of significant amplitude. The vibration induced by the lift force is called transverse VIV and that induced by the drag force is called in-line VIV.

6.4.1.2 Currents acting with nearly uniform speed over a substantial portion of the body are more likely than waves to excite such vibration. Wind also can generate VIV on slender structural members.

6.4.1.3 The VIV response of a structure, either a rigid hull or a flexible member such as a tendon or a riser, is normally function of vortex shedding frequencies, properties of the structure such as natural frequency, mode shapes and damping, current profile etc.

6.4.1.4 Unlike other forced vibrations, VIV is a self-limiting phenomenon—the vibration amplitude is normally limited to a few (rarely more than two times) structure diameters. Although the amplitude is relatively small in many cases, the fatigue damage caused by VIV can be very severe if the structure is not properly designed.

6.4.1.5 Tendon VIV can affect tendon fatigue, hull fatigue if hull vibration is excited by the tendon VIV and hull accelerations, which could limit topsides operations.

6.4.1.6 The consequence of tendon VIV response can be:

- tendon structural fatigue,
- increase of drag loading on the tendon, and
- hull vibration induced by tendon VIV.