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Petroleum and natural gas industries — Floating offshore structures —

Part 1:
Ship-shaped, semi-submersible, spar and shallow-draught cylindrical structures

Industries du pétrole et du gaz naturel — Structures en mer flottantes —

Partie 1: Unités monocoques, unités semi-submersibles et unités spars

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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 7, *Offshore structures*.

This second edition cancels and replaces the first edition (ISO 19904-1:2006), which has been technically revised. The main changes compared to the previous edition are as follows:

— title has been modified by replacing 'monohulls' with 'ship-shaped' and adding 'shallow-draft cylindrical structures';

— list of normative references (Clause 2) has been expanded;

— some definitions have changed and some new terms and definitions (Clause 3) have been added;

— subclause on planning requirements (5.3) has been expanded by addressing inspection and maintenance philosophy (5.3.5), documentation (5.3.6), extreme weather preparedness (5.3.7), and disconnectible floating platforms (5.3.8);

— subclause on use for project application (5.4.2) has been expanded with a paragraph regarding documentation for disconnectable floating platforms;

— new subclause on topsides arrangement and layout (5.5.9) has been added;

— subclause on air gap (8.10) has been renamed to air gap and wave crest assessment, and a new subclause addressing wave crest effects (8.10.2) has been added;

— subclause on material (9.9) has been expanded by addressing cement grout (9.9.5) and elastomeric materials (9.9.6);

— subclause on corrosion protection of steel (9.10) has been rewritten substantially;

— subclause on fabrication and constructions (9.11) has been expanded by addressing fabrication details (9.11.3) and welding (9.11.4);

— subclause on general aspects of fatigue analysis and design (10.1) has been expanded by adding a discussion on fatigue strength and actions;

— subclause on general aspects of ship-shaped structures (11.1) has been expanded;

— subclause on sloshing (11.2.3) has been expanded by addressing general configuration of tanks and resonance due to sloshing;

— subclause on green water (11.2.4) has been expanded;

— subclause on structural strength (11.3) has been expanded by elaborating on the evaluation of hull girder strength (11.3.1) and local strength and details (11.3.4);

— subclause on general design critera for semi-submersibles (12.2) has been expanded;

— new clause addressing shallow-draft cylindrical structures (Clause 14) has been added;

— subclause on watertight and weathertight appliances (16.4) has been expanded;

— subclause on hull systems (17.2) has been expanded by addressing atmospheric tanks (17.2.5.2) and water displaced tanks (17.2.5.3), elaborating on inert gas systems (17.2.6) and addressing production vent/flare system (17.2.8) and electical systems (17.2.9);

— subclause on import and export systems (17.3) has been expanded by elaborating on general aspects (17.3.1), alongside transfer (17.3.3.3.3) and tandem transfer (17.3.3.3.4) and addressing direct transfer (17.3.3.3.5);

— clause on stationkeeping systems (18) has been expanded by addressing disconnectable structures (18.4);

— subclause on structural integrity management system philosophies (19.2) has been expanded by elaborating on general aspects, including the addition of a figure (19.2.1);

— new clause addressing assessment of existing floating structures (Clause 20) has been added;

— additional information and guidance (Annex A) has been modified with additions and changes in line with modifications to the main text;

— the list of informative references (Bibliography) has been updated and expanded as needed.

A list of all parts in the ISO 19904 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The International Standards on offshore structures prepared by TC 67 (i.e., ISO 19900, the ISO 19901 series, ISO 19902, ISO 19903, the ISO 19905 series and ISO 19906) constitute a common basis covering those aspects that address design requirements and assessments of all offshore structures used by the petroleum, petrochemical and natural gas industries worldwide. Through their application, the intention is to achieve reliability levels appropriate for manned and unmanned offshore structures, whatever the type of structure and the nature or combination of materials used.

It is important to recognize that structural integrity is an overall concept comprising models for describing actions, structural analyses, design rules, safety elements, workmanship, quality control procedures and national requirements, all of which are mutually dependent. The modification of one aspect of design in isolation can disturb the balance of reliability inherent in the overall concept or structural system. The implications involved in modifications, therefore, need to be considered in relation to the overall reliability of all offshore structural systems.

The International Standards on offshore structures prepared by TC are intended to provide wide latitude in the choice of structural configurations, materials and techniques without hindering innovation. Sound engineering judgement is therefore necessary in the use of these documents.

This document was developed in response to the offshore industry's demand for a coherent and consistent definition of methodologies to design, analyse and assess floating offshore structures of the class described in Clause 1. Further applicable requirements are found in national and international codes and standards, and RCS rules.

Some background to, and guidance on, the use of this document is provided in informative Annex A. The clause numbering in Annex A is the same as in the normative text to facilitate cross-referencing.

Petroleum and natural gas industries — Floating offshore structures —

Part 1:
Ship-shaped, semi-submersible, spar and shallow-draught cylindrical structures

1 Scope

This document provides requirements and guidance for the structural design and/or assessment of floating offshore platforms used by the petroleum and natural gas industries to support the following functions:

— production;

— storage and/or offloading;

— drilling and production;

— production, storage and offloading;

— drilling, production, storage and offloading.

NOTE 1 Floating offshore platforms are often referred to using a variety of abbreviations, e.g. FPS, FSU, FPSO (see Clauses 3 and 4), in accordance with their intended mission.

NOTE 2 In this document, the term "floating structure", sometimes shortened to "structure", is used as a generic term to indicate the structural systems of any member of the classes of platforms defined above.

NOTE 3 In some cases, floating platforms are designated as "early production platforms". This term relates merely to an asset development strategy. For the purposes of this document, the term "production" includes "early production".

This document is not applicable to the structural systems of mobile offshore units (MOUs). These include, among others, the following:

— floating structures intended primarily to perform drilling and/or well intervention operations (often referred to as MODUs), even when used for extended well test operations;

— floating structures used for offshore construction operations (e.g. crane barges or pipelay barges), for temporary or permanent offshore living quarters (floatels), or for transport of equipment or products (e.g. transportation barges, cargo barges), for which structures reference is made to relevant recognized classification society (RCS) rules.

This document is applicable to all possible life-cycle stages of the structures defined above, such as:

— design, construction and installation of new structures, including requirements for inspection, integrity management and future removal,

— structural integrity management covering inspection and assessment of structures in-service, and

— conversion of structures for different use (e.g. a tanker converted to a production platform) or re-use at different locations.

The following types of floating structure are explicitly considered within the context of this document:

a) ship-shaped structures and barges;

b) semi-submersibles;

c) spars;

d) shallow-draught cylindrical structures.

In addition to the structural types listed above, this document covers other floating platforms intended to perform the above functions, consisting of partially submerged buoyant hulls made up of any combination of plated and space frame components. These other structures can have a great range of variability in geometry and structural forms (e.g. tension leg platforms) and, therefore, can be only partly covered by the requirements of this document. In other cases, specific requirements stated in this document can be found not to apply to all or part of a structure under consideration.

NOTE 4 Requirements for topsides structures are presented in ISO 19901-3.

In the above cases, conformity with this document requires the design to be based upon its underpinning principles and to achieve a level of safety equivalent, or superior, to the level implicit in it.

NOTE 5 The speed of evolution of offshore technology often far exceeds the pace at which the industry achieves substantial agreement on innovation in structural concepts, structural shapes or forms, structural components and associated analysis and design practices, which are continuously refined and enhanced. On the other hand, International Standards can only capture explicit industry consensus, which requires maturation and acceptance of new ideas. Consequently, advanced structural concepts can, in some cases, only be partly covered by the requirements of this document.

This document is applicable to steel floating structures. The principles documented herein are, however, considered to be generally applicable to structures fabricated in materials other than steel.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13702, *Petroleum and natural gas industries — Control and mitigation of fires and explosions on offshore production installations — Requirements and guidelines*

ISO 19900, *Petroleum and natural gas industries — General requirements for offshore structures*

ISO 19901-1, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 1: Metocean design and operating considerations*

ISO 19901-3, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 3: Topsides structure*

ISO 19901-6, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 6: Marine operations*

ISO 19901-7, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units*

ISO 19902, *Petroleum and natural gas industries — Fixed steel offshore structures*

ISO 19906, *Petroleum and natural gas industries — Arctic offshore structures*

International Maritime Organization. IMO MARPOL, International Convention for the Prevention of Pollution from Ships

International Maritime Organization. IMO International Code on Intact Stability

International Maritime Organization. IMO International Convention on Load Lines

International Maritime Organization. IMO Crude Oil Washing Systems

IMO MEPC/Circ. 406, Guidelines for application of MARPOL Annex 1 requirements to FPSOs and FSUs as modified by Resolutions MEPC.139(53) and MEPC.142(54)

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
abnormal value
value of an environmental parameter used in accidental limit state verification in which a *structure* (3.59) is not expected to suffer significant loss of integrity

Note 1 to entry: Abnormal situations are used to provide robustness against events with an annual probability of exceedance typically between 10^{-3} and 10^{-4} to avoid, for example, excessive deformations.

Note 2 to entry: In ALS verification, all the partial factors are set to 1,0.

[SOURCE: ISO 19901-1:2015, 3.1, modified]

3.2
accidental event
event involving exceptional conditions of the *structure* (3.59) or its exposure

EXAMPLE Impact, fire, explosion, local failure or loss of intended differential pressure (e.g. buoyancy).

3.3
action
external load applied to the *structure* (3.59) (direct action) or an imposed deformation or acceleration (indirect action)

EXAMPLE An imposed deformation can be caused by fabrication tolerances, differential settlement, temperature change or moisture variation.

Note 1 to entry: An earthquake typically generates imposed accelerations.

[SOURCE: ISO 19900:2013, 3.3]

3.4
action combination
values of different *actions* (3.3) considered simultaneously in *verification* (3.61) of the *structure* (3.59)

3.5
action effect
effect of *actions* (3.3) on a *structure* (3.59) or on *structural components* (3.57)

EXAMPLE Internal force, moment, stress, strain, rigid body motion or elastic deformation.

[SOURCE: ISO 19900:2013, 3.4, modified — "on a structure or" has been added to the definition and examples have been added.]

Note 1 to entry: Can be used interchangeably with the word "response".

3.6
air gap
clearance between the highest water or ice surface that occurs during abnormal metocean or ice conditions and the lowest exposed part of the *topsides* (3.60) not designed to withstand wave or ice impingement

[SOURCE: ISO 19900:2013, 3.5, modified — Definition has been rephrased.]

Note 1 to entry: Minimum values of air gap are normally specified for ULS and ALS (abnormal) situations.

3.7
basic variable
one of a specified set of variables representing physical quantities which characterize *actions* (3.3), environmental influences, geometrical quantities, or material properties, including soil properties

[SOURCE: ISO 19900:2013, 3.7]

3.8
characteristic value
value of a *basic variable* (3.7), an *action* (3.3) or a strength model associated with a prescribed probability of not being violated by unfavourable values

Note 1 to entry: In some design situations, a variable can have two characteristic values, an upper and a lower value.

[SOURCE: ISO 19900:2013, 3.10, modified — Definition and Note 1 to entry have been rephrased.]

Note 2 to entry: In the case of actions and related properties, the characteristic value normally relates to a reference period.

3.9
classification
class
process by which a classification society defines a vessel's type and permitted use, determines necessary certification, and specifies associated inspection and survey regimes

Note 1 to entry: Vessels that have been subject to this process and that obtained the corresponding certificate are referred to as being in 'class'.

3.10
design criteria
quantitative formulations that describe the conditions to be fulfilled for each *limit state* (3.30)

[SOURCE: ISO 19900:2013, 3.15]

3.11
design format
mathematical description for *verification* (3.61) of non-exceedance of a *limit state* (3.30)

Note 1 to entry: In this document, both partial factor and working stress design (WSD) formats are permitted.

3.12
design service life
assumed period for which a *structure* (3.59) is to be used for its intended purpose with anticipated maintenance, but without substantial repair being necessary

[SOURCE: ISO 19900:2013, 3.16, modified — 'to be' has been added.]

3.13
design situation
set of *actions* (3.3) and combination of actions representing real conditions during a certain time interval, for which relevant *limit states* (3.30) are not exceeded

3.14
design value
value of a *basic variable* (3.7), an *action* (3.3) or a strength model derived from its *representative value* (3.41) for use in *verification* (3.61)

[SOURCE: ISO 19900:2013, 3.18, modified — Definition has been rephrased.]

Note 1 to entry: For action variables, the design value is found by multiplying the representative value by a partial action factor while for strength variables, the design value is found by dividing the representative value by a partial resistance factor.

Note 2 to entry: For FLS, SLS or ALS verification in accordance with the partial factor design format, all partial factors are equal to unity so that, in these cases, a design value is equal to the representative value.

Note 3 to entry: For verification in accordance with the working stress design format, all partial factors are equal to unity so that, in these cases, a design value is equal to the representative value. Appropriate global safety or utilization factors are applied in verification.

Note 4 to entry: In the case of actions and related properties, the value can relate to a reference period.

Note 5 to entry: For yield strength, the design value is equal to the representative yield strength.

3.15
disconnectable floating structure
floating structure (3.24) capable of discontinuing production and rapidly disconnecting from its ancillary components (e.g. risers, moorings, well systems, umbilicals), in response to the occurrence of a threshold event

Note 1 to entry: Threshold event is a hazardous event that triggers the start of disconnection.

3.16
dynamic action
action (3.3) that induces acceleration of a *structure* (3.59) or a *structural component* (3.57) of a magnitude sufficient to require specific consideration

[SOURCE: ISO 19901-7:2013, 3.8]

3.17
dynamic positioning
DP
stationkeeping technique consisting primarily of a system of on-board thrusters, which generate appropriate thrust vectors to counter the mean and slowly varying induced actions

3.18
environmental action
effect of wind, wave, current, ice and seismic actions on a *structure* (3.59)

Note 1 to entry: In general terms, environmental actions include those due to seismic actions but, for historical reasons, in several places in this document, seismic actions are treated separately from other environmental effects.

3.19
exposure level
classification system used to define the requirements for a *structure* (3.59) based on consideration of life-safety and of environmental and economic consequences of *failure* (3.21)

[SOURCE: ISO 19900:2013, 3.20, modified — Definition has been rephrased.]

3.20
extreme value
value of a parameter used in ULS verification in which a *structure's* (3.59) global behaviour is intended to stay in the elastic range

Note 1 to entry: Extreme values and events have annual probabilities of exceedance of the order of 10^{-2}.

3.21
failure
insufficient strength or inadequate serviceability of a *structure* (3.59) or *structural component* (3.57), or, in limit state verification, a condition in which a structure or component thereof does not fulfil its limit state requirement

3.22
fit-for-service
fitness-for-service
meeting the intent of a standard although not meeting specific requirements of that standard in local areas, such that *failure* (3.21) in these areas cannot cause unacceptable risk to life-safety or the environment

Note 1 to entry: "Fit-for-service" is an adjective and "fitness-for-service" is a noun.

[SOURCE: ISO 19900:2013, 3.21, modified — Definition has been rephrased.]

3.23
flag state
country under whose laws a vessel is registered or licensed

Note 1 to entry: 'Flagging' is the process by which such registration is accomplished.

3.24
floating structure
structure (3.59) where the full weight is supported by buoyancy

[SOURCE: ISO 19900:2013, 3.23]

Note 1 to entry: The full weight includes lightship weight, mooring system pre-tension, riser pre-tension and operating weight.

3.25
freeboard
distance measured vertically between the upper edge of the weathertight deck, at a given draught, and the mean water surface

3.26
green water
water that overtops a deck causing *slamming* (3.49) and pressure actions on the deck and to *structures* (3.59) on the deck

3.27
hazard
potential source of harm

EXAMPLE Large waves, strong winds, hurricanes, earthquakes, icebergs, unstable foundation, excessive topside weight, vessel collision, corrosion, and repetitive actions.

Note 1 to entry: Harm is typically differentiated between harm to personnel, harm to the environment, or harm in terms of costs to organisation(s) or society in general.

3.28
hazardous event
instance of a *hazard* (3.27) acting on a *structure* (3.59)

EXAMPLE Wave impact, iceberg impact, excessive topside weight added to the structure, landslip near structural anchors (piles).

3.29
hull
primary structure or structural subsystem providing buoyancy for a *floating structure* (3.24)

Note 1 to entry: For semi-submersibles, the hull generally consists of columns and pontoons. For spars and shallow-draught cylindrical structures, the hull consists of a single column.

3.30
limit state
state beyond which the *structure* (3.59) or *structural component* (3.57) no longer satisfies the relevant *design criteria* (3.10)

[SOURCE: ISO 19900:2013, 3.28, modified — 'or structural component' has been added.]

3.31
marine operations manual
MOM
document that defines the operational characteristics, procedures and capabilities of an offshore platform and associated essential systems

[SOURCE: ISO 19900:2013, 3.33, modified — 'marine' has been added to the term.]

3.32
metocean action
effect of wind, wave and current on a *structure* (3.59)

Note 1 to entry: The determination of these effects includes the influence of marine growth, tide, surge, and related processes, as appropriate.

3.33
mobile offshore unit
MOU
structure (3.59) intended to be relocated to perform a particular function

3.34
nominal value
value of a *basic variable* (3.7), *action* (3.3) or strength model determined on a non-statistical basis, typically from acquired experience or physical conditions

[SOURCE: ISO 19900:2013, 3.29, modified — Definition has been rephrased.]

EXAMPLE Value published in a recognized code or standard.

Note 1 to entry: Values of yield strength specified in steel standards and specifications are nominal values

3.35
operator
representative of the company or companies leasing the site

Note 1 to entry: The operator is normally the oil company acting on behalf of co-licensees.

[SOURCE: ISO 19900:2013, 3.32]

3.36
owner
representative of the company or companies owning or leasing a development

[SOURCE: ISO 19900:2013, 3.34]

3.37
platform
complete assembly of structural and non-structural systems for development and production of petroleum and natural gas fields

Note 1 to entry: For floating offshore structures, the structural system generally includes the hull, topsides structure, and stationkeeping system including anchors, while the non-structural systems includes topsides equipment (including accommodation), piping and risers.

Note 2 to entry: The structural system does not include soils.

3.38
recognized classification society
RCS
member of the international association of classification societies (IACS), with recognized and relevant competence and experience in *floating structures* (3.24) used in petroleum or natural gas activities, and with established rules and procedures for *classification* (3.9)/certification of *platforms* (3.37) located at a specific site for an extended period of time

[SOURCE: ISO 19901-7:2013, 3.23, modified — Definition has been rephrased, first and second preferred terms have been swapped.]

3.39
regulator
authority established by a national governmental administration to oversee the activities of the offshore petroleum and natural gas industries within its jurisdiction, with respect to safety of life and protection of the environment

Note 1 to entry: The term "regulator" can encompass more than one agency in given territorial waters.

Note 2 to entry: The regulator can appoint other agencies, such as marine classification societies, to act on its behalf, and in such cases, regulator as it is used in this document includes such agencies.

Note 3 to entry: In this document, the term "regulator" does not include any agency responsible for approval to extract hydrocarbons, unless such agency also has responsibility for safety and environmental protection.

[SOURCE: ISO 19902:2007, 3.40, modified — 'oil' has been changed to 'petroleum'.]

3.40
reliability
ability of a *structure* (3.59) or *structural component* (3.57) to fulfil the specified requirements

[SOURCE: ISO 19900:2013, 3.37]

3.41
representative value
value of a *basic variable* (3.7), *action* (3.3) or strength model, for *verification* (3.61) of a *limit state* (3.30)

[SOURCE: ISO 19900:2013, 3.38, modified — Definition has been rephrased.]

Note 1 to entry: The representative value can be a characteristic value, a nominal value, or other rationally determined value.

Note 2 to entry: For actions, this can relate to upper or lower characteristic values, dependent on which causes the more onerous condition. In combinations, it can involve multiplying the chosen value by a factor greater or less than unity.

3.42
resistance
capacity of a *structure* (3.59), component or cross-section of a component to withstand *action effects* (3.5) without *failure* (3.21)

[SOURCE: ISO 19900:2013, 3.39, modified — 'structure' has been added.]

3.43
return period
average period between occurrences of an event or of a particular value being exceeded

Note 1 to entry: The offshore industry commonly uses a return period measured in years for environmental events. The return period in years is equal to the reciprocal of the annual probability of exceedance of the event.

[SOURCE: ISO 19900:2013, 3.40]

3.44
riser
piping connecting the process facilities or drilling equipment on the *floating structure* (3.24) with the subsea facilities or pipelines, or with a reservoir

Note 1 to entry: Possible functions include drilling and well intervention, production, injection, subsea systems control and export of produced fluids.

3.45
robustness
ability of a *structure* (3.59) to withstand accidental and abnormal events without being damaged to an extent disproportionate to the cause

[SOURCE: ISO 19900:2013, 3.42]

3.46
semi-submersible
floating structure (3.24) normally consisting of a deck structure with, typically, three or more widely spaced, large cross-section, supporting columns connected to submerged pontoons

Note 1 to entry: Pontoon/column geometry is usually chosen to minimize global motions in a broad range of wave frequencies.

3.47
shallow-draught cylindrical structure
floating structure (3.24) having a cylindrical or near cylindrical geometry with a draught comparable to the diameter

3.48
ship-shaped structure
floating structure (3.24) having a geometry similar to that of ocean-going ships or barges

3.49
slamming
impulsive action with high pressure peaks that occurs during impact between a portion of the *structure* (3.58) and water

Note 1 to entry: Slamming can, for example, be due to emergence and re-entry of a lower section of the hull into the water or to wave impact on a structural component.

3.50
sloshing
impact action on the internal surface(s) of partially filled compartments due to internal fluid motion

3.51
spar
deep-draught, small water-plane area cylindrical *floating structure* (3.24)

[SOURCE: ISO 19901-7:2013, 3.32, modified]

3.52
special area
area identified by the designer as being of critical importance to the structural integrity and safety of the *structure* (3.59)

3.53
splash zone
part of a *structure* (3.59) that is intermittently exposed to air and to sea water

[SOURCE: ISO 19900:2013, 3.44, modified — 'immersed in the sea' has been changed to 'to sea water'.]

3.54
stability
hydrostatic stability
ability of a *floating structure* (3.24) to generate restoring moment after deviation from an equilibrium floating position

Note 1 to entry: Generally, verification of stability applies to both intact and damage conditions.

3.55
static action
action (3.3) that does not cause significant acceleration of a *structure* (3.59) or of a *structural component* (3.57)

3.56
stationkeeping system
system capable of limiting the excursions of a *floating structure* (3.24) within prescribed limits

[SOURCE: ISO 19901-7:2013, 3.34]

3.57
structural component
physically distinguishable part of a *structure* (3.59)

[SOURCE: ISO 19900:2013, 3.46, modified — Example has been omitted.]

3.58
structural system
combination of *structural components* (3.57) acting in such a manner that the components function together

3.59
structure
organized combination of connected components designed to withstand *actions* (3.3) and provide adequate rigidity and *stability* (3.54)

[SOURCE: ISO 19900:2013, 3.49, modified — 'and stability' has been added.]

3.60
topsides
structure (3.59) and equipment placed on a *hull* (3.29) to provide some or all a of *platform's* (3.37) functions

Note 1 to entry: For a ship-shaped structure, the deck is not part of the topsides.

Note 2 to entry: A separately-fabricated deck or module support frame is part of the topsides.

[SOURCE: ISO 19900:2013, 3.52, modified — Definition has been rephrased, Note 2 to entry has been removed.]

3.61
verification
examination made to confirm that an activity, product or service is in accordance with specified requirements

[SOURCE: ISO 19901-7:2013, 3.39]

3.62
watertight
capable of preventing the penetration of water into or through the *structure* (3.59) with a water pressure head corresponding to that for which the surrounding structure is designed

3.63
weathertight
capable of preventing the penetration of water into the structure during temporary exposure to water

Note 1 to entry: A watertight closing appliance is also considered weathertight.

4 Symbols and abbreviated terms

4.1 Symbols

A accidental action

A_v area, or area per unit length, in square metres (m^2), or metres (m)

a_v vibration amplitude, in metres

B moulded breadth, in metres (m)

b width, in millimetres (mm)

C coefficient (non-dimensional unless otherwise specified)

D fatigue damage ratio throughout life cycle of platform or duration of particular operational phase

d component diameter, in metres

E material (Young's) modulus, in newtons per square metre (N/m^2)

E_e environmental action

F action per unit length, in newtons per metre (N/m)

F_d design value of action effect

f frequency, in hertz (Hz)

f distribution factor (non-dimensional)

G permanent action

K_s stability parameter for VIV

L length between perpendiculars

M bending moment or representative bending strength, in newton metres (Nm)

m constant related to the slope of an S-N curve

m_e effective mass per unit length (kg/m)

N total number of cycles

P pressure, in newtons per square metre (N/m^2)

P_e annual probability of exceedance

Q variable action

Q_s is the maximum representative still-water shear force, in newtons (N)

Q_u is the representative ultimate shear strength of the hull girder, in newtons (N)

Q_w is the maximum representative wave shear force, in newtons (N)

R strength, in newtons per square metre (N/m^2)

r strength, in newtons per square metre (N/m^2)

S stress, in newtons per square metre (N/m^2)

T time or duration, in years

T_R return period, in years

t thickness, in millimetres (mm)

V volume, or volume per unit length, in cubic metres (m^3), or square metres (m^2)

v velocity, in metres per second (m/s)

γ partial action or resistance factor

δ logarithmic decrement of damping

ξ fraction of critical damping

η allowable utilization factor

κ curvature, 1/m

ρ density, in kilograms per cubic metre (kg/m^3)

4.2 Abbreviated terms

ACFM alternating current field measurement

ACPD alternating current potential drop

ALP articulated loading platform

ALS accidental limit state

AP aft perpendicular

BOD basis of design

CALM catenary anchor leg mooring

CBM	conventional buoy mooring
COW	crude oil washing
CP	cathodic protection
CVI	close-up visual inspection
DP	dynamic positioning
EC	eddy current
FE	finite element
FLP	floating loading platform
FLS	fatigue limit state
FMD	flooded member detection
FP	forward perpendicular
FPS	floating production structure
FPSO	floating production, storage and offloading structure
FSU	floating storage unit
GVI	general visual inspection
HAZID	hazard identification
IMO	International Maritime Organization
MMS	minerals management service
MOM	marine operations manual
MOU	mobile offshore unit
MODU	mobile offshore drilling unit
MPI	magnetic particle inspection
MPM	most probable maximum
MWL	mean water level
NDT	non-destructive test
NPSH	net positive suction head
RAO	response amplitude operator
RCS	recognized classification society
ROV	remotely operated vehicle
SALM	single anchor leg mooring
SCIP	structural critical inspection point

SCF	stress concentration factor
SIM	structural integrity management
SLS	serviceability limit state
STL	submerged turret loading
TLP	tension leg platform
TOFD	time-of-flight diffraction
TM	thickness measurements
UCW	ultrasonic creeping wave
ULS	ultimate limit state
VIM	vortex-induced motions
VIV	vortex-induced vibrations
VLCC	very large crude carrier
VOC	volatile organic compound
WI	weld inspection
WSD	working stress design

5 Overall considerations

5.1 General

Clause 5 presents the general requirements for the floating structures described in Clause 1 when used to support the petroleum and natural gas industries functions also listed in Clause 1.

5.2 Safety requirements

Key guiding principles of the activities of the petroleum and natural gas industries are safety of life, environment and property. Within the framework of this document, these principles shall be enforced through the following:

- verification of the floating structure's ability to withstand environmental and other external actions that are likely to occur during the design service life or any extension thereof;
- a robust structural form so that local damage does not lead to complete loss of integrity of the structure;
- definition of safe operating procedures so that risks of injury to personnel are identified and minimized;
- identification and assessment of possible accidental events, as summarized in ISO 19900, and mitigation of their consequences;
- performance of a hazard assessment to ensure that possible malfunctions do not pose a danger to life, to the environment, or to the structure's integrity.

The implications of the above items shall be incorporated in the floating structure's design philosophy and in the development of the operational philosophy as reflected in the MOM.

Some of the items in the above list are usually performed as part of a formal risk assessment, which is an appropriate general procedure for identifying hazards, quantifying the associated risks and determining approaches for the mitigation of their consequences.

For methods used to protect against fires and explosions, the selection of a suitable approach depends upon the function of the platform. Procedures shall conform to ISO 13702. National or regional requirements also apply, where they exist.

Requirements for personnel safety set by flag states and coastal state authorities can have a substantial effect on the design of a floating structure.

5.3 Planning requirements

5.3.1 General

Planning shall be undertaken in the initial stages of the design process to obtain a safe structural solution for performing the desired function.

5.3.2 Exposure level

Offshore platforms can be categorized by various levels of exposure to determine criteria that are appropriate for the intended service, its design and its quality management. This applies to the design of new structures and to the assessment of existing structures. The level relevant for a given platform shall be determined in accordance with the requirements of ISO 19900.

This document (i.e. ISO 19904-1) provides requirements for L1 structures only.

5.3.3 Basis of design

At the outset of the design process, a document (basis of design - BOD) should be created to summarize

— definition of design practices,

— exposure level,

— applicable limit states, design situations and design criteria (see ISO 19900),

— fabrication, transportation and installation philosophy,

— inspection and maintenance philosophy,

— service and operational philosophy, and

— platform removal philosophy.

5.3.4 Design practices

Regulations, codes, standards and RCS rules (collectively referred to as "standards" hereafter) applicable to the design and construction of the floating structure shall be clearly identified at the commencement of the project – see 5.4.2.

Mixing of standards should, in general, be avoided. When more than one standard is utilized in the design process, differences in the standards shall be identified and a decision made concerning the appropriate measures to be undertaken. Such a decision shall be based upon sound engineering practice.

The standards used in the design of structures shall be consistent and compatible with those utilized in the fabrication and in-service monitoring of the structure.

For innovative structural forms, or applications of unproven structural concepts where limited or no direct experience exists, appropriate analyses shall be performed to demonstrate that the safety level of the design is no lower than the safety level implicit in this document when applied to traditional structural forms or concepts.

5.3.5 Inspection and maintenance philosophy

At the planning stage, a philosophy for inspection and maintenance should be developed and documented, to ensure full consistency with the BOD of the floating structure and its components. The requirements for fatigue strength, corrosion control, material toughness, and inspection planning shall be consistent with the design service life of the floating structure established as part of the planning activities.

A critical assessment should be made of the ability to achieve the intended inspection and maintenance objectives. Relevant requirements related to inspection and maintenance requirements are given in Clause 19.

General requirements for inspection of structures are given in ISO 19900. For detailed considerations concerning in-service condition monitoring, see Clause 19.

5.3.6 Documentation

During the fabrication, erection, load out and installation phases, data related to the as-built configuration, inspection and maintenance of the platform shall be recorded as the project progresses and compiled in a form suitable for retention as a permanent record.

Any changes made to the design of a floating structure subsequent to the lightship survey and/or inclining experiment shall be accounted for and included in the final documentation and updated during service (see also 5.5.7 and 15.2).

A MOM, or equivalent, shall be prepared for use by personnel onboard the floating structure. The MOM should be as concise as reasonably practicable and shall contain pertinent information for safe operation, including all relevant limiting design criteria relating to global structural strength, compartmentation and stability. Marine operations staff on-board the structure should be trained to execute procedures to be followed for storm safe conditions and for extreme weather evacuation.

Different hull configurations can be sensitive to variations in total weight, weight/buoyancy distribution, hydrostatic stability or any combination thereof. The designer shall ensure that weight monitoring, distribution and control procedures are clearly identified in the MOM.

The MOM should be updated to reflect any changes to the marine operations identified by the results of any structural assessment.

Documentation noting any areas built with special steel should be onboard to identify any special welding requirements when carrying out emergency repairs.

5.3.7 Extreme weather preparedness

Advanced planning can assist in reducing extreme weather risks as well as improving post-event response. Owners should develop a written extreme weather preparedness plan describing general activities for their inventory of offshore structures as well as the plans for each specific structure. Checklists and platform-specific guides can assist, e.g. during an evacuation process. Structures with high life safety exposure and/or economic risk can require additional consideration.

5.3.8 Disconnectable floating platforms

Some floating platforms are designed to enable rapid disconnection of some or all the platform's stationkeeping systems and ancillary components to limit exposure to foreseeable hazardous events that could lead to exceedance of applicable limit states (e.g. severe metocean or ice conditions). Rapid disconnection allows the floating structure to move away from the hazard forecast at the installation site, protecting the structure and/or other components (moorings, risers, etc.) from the extreme actions that would be experienced if the platform remained connected.

The ability to forecast a threshold event, the frequency of such events, and the time required for the disconnection should be considered at the design stage when setting the disconnection criteria. These criteria shall be established and stated in the MOM. The means and/or procedures for verifying operability of the quick disconnect system throughout the platform's design service life shall be specified in the MOM.

5.4 Additional standards and specifications

5.4.1 General

The intent of this document is to state explicitly general principles and basic requirements. The designer is then directed, through appropriate references, to make use of existing design practices and standards.

Where the floating structure is to be flagged, the relevant flag state authority requirements also apply.

5.4.2 Use for project application

For a specific project application, the owner shall identify the complete list of standards (see 5.3.4), contractual agreements and company specifications whose requirements shall be met, clarifying areas of possible overlap and specifying the level of precedence in the enforcement of such requirements.

In the case of disconnectable floating structures, when disconnected, different requirements can apply depending on the type of structure. For self-propelled units, design practices additional to the standards identified in 5.3.4 can apply. For non-self-propelled units, tow requirements (see ISO 19901-6) are also applicable.

5.5 General requirements

5.5.1 Functional requirements

A floating platform's functional requirements are generally specified by the owner and shall be satisfied in conjunction with the principles stated in 5.2. Consequently, the structure of a floating platform (and its stationkeeping system) shall be designed to allow the platform to

a) fulfil its intended mission (production, drilling and production, etc.) for a specified length of time (design service life), and

b) meet specified minimum requirements for serviceability and operability, such as keeping platform motions within prescribed limits, for a specified fraction of time.

The platform shall also be designed to provide

— adequate comfort levels for personnel onboard,

— proper functioning of the topsides equipment,

— access to subsea facilities, where applicable, and

— clearances with respect to other subsea or surface facilities, where applicable,

while, at the same time

— maintaining floating stability,

— maintaining structural integrity,

— maintaining integrity and serviceability of drilling, production, export or other types of risers and

— ensuring platform survival in extreme, abnormal and accidental events.

Conformance of the floating structure design with these requirements shall be verified using the analysis methodologies and design criteria given in Clauses 8 to 16 and in Clause 18. Action effects, such as motions, accelerations, forces and stresses, shall be evaluated for all defined design situations, and shall be compared with the system and component strengths to ensure the existence of reserve against loss of stability, structural failure or other undesirable occurrences.

5.5.2 Structural design philosophy

The structural system, components and details of a floating platform shall be designed, constructed and maintained so that they are suited to their intended use.

The general requirements and conditions stated in ISO 19900 shall be fulfilled. Additionally, the following design principles apply:

— structural systems shall have ductile resistance unless the specified purpose or structural material requires otherwise;

— structures shall be designed to minimize stress concentrations and provide simple stress paths;

— structures shall be designed such that fabrication, including surface treatment, can be accomplished in accordance with accepted techniques and practices;

— heavy, concentrated actions on the structure shall be located such that proper framing to support these actions can be planned;

— effects of fabrication and offshore construction tolerances shall be taken into account;

— adequate allowance shall be made for corrosion when selecting materials, and corrosion shall be minimized by judicious design of structural details, selection of structural profiles and the use of suitable materials, coatings and cathodic protection systems;

— whenever practical, structures shall be designed to enable load redistribution.

A floating structure shall be designed with due consideration to minimizing the adverse effects of accidental events. Such events include fire/blast, collisions, compartmental flooding, mooring line failure, dropped objects, and fluid impacts such as green water or slamming. In this regard, consideration should be given to the layout and arrangement of facilities and equipment.

Cargo tanks and cargo systems shall be separated by oil-tight cofferdams from galleys, living quarters, below-deck general cargo spaces, boiler rooms and machinery spaces where sources of ignition are normally present. Cofferdams shall be adequately vented and wide enough to allow ready access. Ballast tanks or void spaces may be considered as cofferdams.

The floating structure shall be designed to maintain global integrity during abnormal and accidental events. Furthermore, the structure shall be designed so that if structural damage does occur, the damaged structure (possibly with temporary repairs, as applicable) is able to resist action combinations appropriate to these design situations without suffering extensive failure, free drifting, capsizing or sinking, and without causing extensive harm to the environment.

Emergency and other essential equipment (ballast pumps, generators, mooring winches, etc.), shall be designed to continue to operate at the platform attitudes resulting from an abnormal or accidental event. Low-pressure piping and bulkhead penetrations can provide conduits for downflooding (and siphoning) and shall be examined for integrity under the maximum hydrostatic pressure consistent with the damaged condition.

5.5.3 Design criteria

Criteria to be met by the structural design are usually directly related to specific design situations. For factors to be considered – see ISO 19900.

5.5.4 Hydrostatic stability and compartmentation

The floating behaviour of the platform shall be consistent with the requirements for stability in intact and damaged configurations, for both temporary and in-service conditions (see Clause 16).

When recognized standards are used to verify adequate stability, consideration shall also be given to the consequences of the accidental events identified as being relevant for the structure (see 7.5).

To mitigate the consequences of possible damage, the floating structure's hull shall be subdivided into compartments to facilitate meeting stability requirements and reduce risks of environmental pollution and loss of the platform (see Clause 16).

5.5.5 Weight control

The hydrostatic stability and the dynamic response of a floating platform are very sensitive to the magnitude and distribution of the mass. These parameters, and the location of the centre of gravity, shall be monitored during the entire life cycle of the platform.

During the design and fabrication process:

— the weight of the structure shall be evaluated;

— the centre of gravity of the structure, or part of the structure, shall be evaluated.

Regular weight and centre of gravity reports should be produced at various stages of the design and fabrication process, with appropriate contingency factors to allow for uncertainties connected with outstanding items to be fabricated or installed.

The weight database shall be updated to an as-built status, to provide accurate information for all pre-service temporary phases, including launch, transportation, upending and lifts.

The mass distribution of a floating platform as-built shall be verified to an appropriate degree of accuracy (see 16.2 for requirements for inclining tests).

The MOM shall contain appropriate provisions for handover of the design database to the operations team, and for the continuing in-service weight control process.

NOTE Further guidance on this topic can be found in ISO 19901-5[135].

5.5.6 Global response

The floating structure hull shall be designed so that, in conjunction with the effects of the stationkeeping system and the riser system, the predicted excursion and motion response stays within appropriate limits, set in conjunction with the requirements for

— serviceability of all types of risers,

— comfort levels for personnel onboard,

— serviceability of the drilling, production, or other types of equipment, as applicable, and

— maintaining minimum clearances with other surface facilities or subsea infrastructure.

5.5.7 Stationkeeping

The stationkeeping system, which in general consists of a combination of mooring lines, anchors and thrusters, shall be designed to restrain the platform maximum excursion to the envelope defined by the considerations identified in 5.5.6. See Clause 18.

Weathervaning stationkeeping systems, generally using internal or external turrets, are a common choice for ship-shaped structures and barges in moderate to harsh environments. These stationkeeping systems allow the platform to weathervane and reduce metocean actions and ice actions.

5.5.8 Materials

Suitable materials shall be specified. In addition to strength, due care shall be paid to ductility, toughness, weldability and corrosion resistance requirements.

Adequate ductility in the design of a structure shall be facilitated by

— meeting requisite material toughness requirements,

— avoiding failure initiation due to a combination of high stress concentrations and undetected weld defects in structural components and details,

— designing structural details and connections to allow a certain amount of plastic deformation, (avoiding “hard spots”), and

— arranging the scantlings of structures and their components to avoid sudden changes in structural strength or stiffness.

5.5.9 Topsides layout — safety considerations

Personnel safety is a key consideration in the layout and arrangement of the topsides process equipment. The following requirements or recommendations apply:

a) Personnel accommodation should not be located directly above or below

 1) produced oil and/or gas storage tanks,

 2) process vessels,

 3) surface trees and wellheads, and

 4) portions of risers located on the floating structure.

b) Personnel accommodation should be positioned as far away as possible from the process facilities and from the flare.

c) Process vessels, hydrocarbon storage tanks, or other items which could become a source of fuel in the event of a fire, should be located as far away as possible, or otherwise protected, from wellheads and potential ignition sources.

d) Arrangements and layout of the facilities, accommodation, control rooms, and life-saving appliances should be such that a fire in a process area, hydrocarbon storage area, wellhead area, or other classified areas does not prevent or impede the safe exit of personnel from the accommodation through designated escape routes to boat landings or lifeboat locations.

5.6 Independent verification

Independent verification that the floating structure’s design and construction conforms to the requirements of this document shall be carried out as a combination of independent calculations, document reviews and audits, surveys and inspections, etc., as appropriate. Emphasis shall be placed on the verification of structural systems and components significant to safety.

Verification activities shall be sufficiently detailed and extensive to clearly demonstrate that the design and construction are adequate. Appropriate documentation shall be maintained of the scope and extent of the verification, the procedures employed, and the relevant reports.

The above requirements can be satisfied in part, or in full, by classing by an RCS.

5.7 Analytical tools

Appropriate requirements for analytical tools are given in ISO 19900.

5.8 In-service inspection and maintenance

Comprehensive structural inspection and maintenance programmes shall be developed for the structure and emergency and other essential marine equipment (see Clause 19) to monitor the integrity of the floating structure throughout its design service life. Such programmes shall account for the frequency of inspection and the number of tanks open at any one time.

In-service inspection procedures shall be developed and undertaken to confirm that modifications, alterations, repairs, and maintenance are undertaken in conformance with appropriate design drawings, specifications, and procedures.

Tanks that contain hazardous materials, e.g. diesel, methanol, or tanks that contain potable water, should be designed to minimize inspection requirements. Tank piping shall be arranged to allow for the safe isolation of tanks prior to inspection.

5.9 Assessment, re-use and life extension

Various circumstances can lead to a requirement for an existing structure to be assessed – see ISO 19900 Clause 12.

In such cases, the existing structure shall be assessed for conformity with the requirements of Clauses 15 or 20, as appropriate. Where the structure or any of its components does not conform to the requirements of this document, adequacy may be demonstrated on a fitness-for-service basis.

6 Basic design requirements

6.1 General

In accordance with ISO 19900, structural design shall be performed with reference to a specified set of limit states. For each limit state, design situations shall be determined and an appropriate calculation model shall be established to ensure that critical action combinations for all main load-bearing structural components are evaluated. Each phase of construction, transportation, installation, operation, and removal shall be complemented by appropriate metocean and ice conditions. Significant effects occurring in one design phase that affect another phase shall be fully considered in the design process. Such effects could be, for example, built-in deflections or fatigue damage.

The reliability of floating structures is highly dependent upon the reliability of emergency and essential marine equipment. Risk assessments shall be conducted to demonstrate that such equipment realizes reliability levels compatible with that demanded for the structure and its components.

6.2 Limit states

6.2.1 General

Verification shall satisfy the limit state design requirements given in Clauses 7 to 14. In addition, for each limit state, watertightness and hydrostatic stability shall be ensured in accordance with Clause 16.

6.2.2 Limit states for floating structures

The following limit states shall apply:

— ultimate limit states (ULS), which generally involve verifying the floating structure's strength to resist extreme actions and action effects;

— serviceability limit states (SLS), which generally involve verifying the floating structure's performance under operational (normal) actions and action effects;

— fatigue limit states (FLS), which cover the structure's strength to resist cumulative effects of repeated actions;

— accidental limit states (ALS), which investigate the structure's ability to resist accidental and abnormal events, and the structure's resistance to the effects of specified metocean actions and ice actions after damage has occurred as a consequence of an accidental or abnormal event.

6.3 Design situations

6.3.1 General

Design situations include the service and operational requirements resulting from the intended use of the floating structure in conjunction with the environmental conditions affecting the floating structure's behaviour.

An environmental design situation consists of the set of actions induced by waves, wind, current, and, if applicable, earthquakes or floating ice, on the floating structure and on the mooring system, as appropriate, and is characterized by a given return period.

Criteria to be met by the design can be directly related to the specific formulation or modelling technique used to simulate the design situation. In such cases, design situations and design criteria form one whole and shall not be separated from one another. They are jointly specified in Clauses 8 to 19.

The definition of specific design situations for the floating structure shall be the responsibility of the owner. The requirements of a regulatory authority apply where one exists.

6.3.2 ULS situations

The design actions to be used in the various ULS are specified in Clause 7. The design strengths and the application of the ULS are specified in Clauses 9, 11, 12, 13 and 14.

For ULS conditions, representative metocean actions and ice actions shall be established with the intention to identify the most onerous associated action effects with a return period of 100 years ($P_e = 10^{-2}$). Different structural components can be affected to a different extent by the same design situations. Consequently, a range of design situations shall be used to ensure that the most onerous conditions for all types of structural components are identified.

6.3.3 SLS situations

The identification of SLS design situations for floating offshore structures shall be based on a number of considerations, including the following:

— unacceptable deformations can affect the efficient use of structural or non-structural components or the functioning of equipment relying on them;

— local damage (including corrosion, cracking, wear, deterioration of flex joints) can reduce the durability of the structure or affect the efficiency of structural or non-structural components;

— excessive motions, accelerations, vibrations or noise can cause discomfort to personnel and interfere with their capability to discharge their duties;

— motions, accelerations or vibrations can exceed the range of effective functionality of topsides equipment (e.g. roll and pitch angles can seriously affect the performance of separators, or the serviceability of drilling equipment).

The assessment criteria associated with SLS shall typically be based on motions, deflections or vibration limits during normal use.

The SLS criteria shall be defined by the owner of a structure, established practice, designers, or suppliers of motion-sensitive equipment, the primary aim being efficient and economical in-service performance without discomfort to onboard personnel or excessive routine maintenance.

The acceptable limits necessarily depend on the type, mission and configuration of the structure. Furthermore, in defining such limits, other disciplines such as equipment and machinery designers shall also be consulted.

6.3.4 FLS situations

FLS are addressed in Clause 10, covering methods, actions and resistances.

6.3.5 ALS situations

ALS are addressed in Clauses 9, 11, 12, 13 and 14, in respect of actions and in selecting both partial action factors and partial resistance factors. The main goal of ALS verification is to ensure that the structure incorporates robustness so, when exposed to specified accidental and abnormal events, the structure suffers, at worst, limited damage that

a) does not affect its overall structural integrity, stability and watertightness, and

b) enables it to maintain adequate structural integrity (residual strength), stability and watertightness for a sufficient period of time and under specified metocean and ice conditions to enable some or all the following activities, as applicable:

   — evacuation of personnel from the structure;

   — control over movement or motion of the structure;

   — temporary repairs;

   — firefighting;

   — control of outflow of cargo or stored material liable to cause environmental damage or pollution.

Different types of accidental or abnormal events can require different methodologies or different levels of the same methodology to assess adequacy of the structural resistance during and following such events.

Post-ALS design situations can include consideration of a reduced extreme environmental condition. This condition should be established with the intention of resulting in the most onerous action effects for, as a minimum, a return period of one year (see Table 1). For verification, intact components shall be checked to ULS-a and ULS-b combinations (see 9.7.3.2 and Table 3) while for damaged components or structure, recognized structural practices accounting for such damage can be utilized.

6.3.6 Temporary phases

During temporary phases, structural strength is generally limited as a result of partial levels of completion of the structure and/or application of action combinations that differ from those applicable to normal operation. The effects of design situations applicable to temporary phases shall be addressed during design to avoid exceedance of either ULS or SLS, and to assess contributions to FLS.

Detailed planning of erection sequences and construction methods is essential to ensure all critical conditions are identified.

Loadout, transportation, offloading and installation assessments should conform to the requirements of a qualified marine surveyor accustomed to advising on transportation of these types of structures (e.g. an insurance marine warranty surveyor) or equivalent (see 9.12).

When verifying the design of a floating structure during the transportation phase, representative metocean parameters and ice parameters should be established based on an assessment of the probability and consequence of encountering an event during the transportation phase that would cause the design limits of the structure and/or seafastening to be exceeded (see ISO 19901-6 and ISO 19902).

7 Actions and action effects

7.1 General

This clause addresses actions likely to be experienced by a floating structure during its life cycle and applicable methodologies for their evaluation. Some of the information provided below can be found in ISO 19900 but is included here for completeness.

7.2 Permanent actions (G)

Permanent actions (see A.7.2 for examples) are those likely to act throughout a given design situation and for which variations in magnitude with time, during the design service life of the structure

a) are small in relation to the mean value, or

b) attain some limiting value.

The representative value of a permanent action shall be taken as the mean value based on the density of the material, the volume of the structure or component based on its nominal dimensions, calculated reactions, and calculated effects of deflections and deformations, as appropriate.

In cases where the permanent action can have an upper or lower value, the representative value shall be taken as the value that produces the most unfavourable effects in the structure under consideration.

A procedure for monitoring the weight and position of the centre of gravity of the floating platform shall be incorporated into the design process. The mass distribution of a floating platform as-built shall be verified to an appropriate degree of accuracy (see 16.2 in connection with requirements to inclining tests). Monitoring of the weight and centre of gravity shall be performed during the life cycle of the floating platform.

NOTE For further guidance, see ISO 19901-5[135].

7.3 Variable actions (Q)

Variable actions generally vary in magnitude, position and direction during the life of the structure, and are usually related to operations and normal use of the platform. These actions are likely to act throughout a given design situation, but do not include environmental actions (see A.7.3 for examples).

The representative value of a variable action shall be taken as the maximum (or minimum) value that produces the most unfavourable effects in the structure under consideration. The value shall be determined either in the same manner as for permanent actions, i.e. mean or calculated, or as a specified value from a recognized source (e.g. RCS rules or national regulations).

Design local deck actions shall be documented on a load plan. This plan shall clearly show the design uniform and concentrated actions for all deck areas for each relevant mode of operation.

Design limits pertaining to tank capacities shall be documented on a capacity plan. As a minimum, the capacity plan shall clearly show tank layout, intended use of tanks, capacities, and the maximum design relative density of tank fluid.

Crane hook loads should be included in this category.

7.4 Environmental actions (E_e)

7.4.1 General

Environmental actions shall be derived from environmental information appropriate to the specific locations where the floating structure is to be fabricated, transported, installed and operated (see ISO 19901-1). The stochastic nature of environmental actions shall be adequately accounted for. Environmental actions can be repeated, sustained, or both repeated and sustained.

The representative value of an environmental action is the maximum or minimum value (whichever is the more unfavourable) corresponding to a prescribed probability of exceedance. Joint probability of occurrence of the various environmental actions may be taken into account if such information is available and can be adequately documented.

Global environmental actions are normally generated by appropriate structural analysis software or mapped from other software packages used to develop the actions, e.g. hydrodynamic software used to generate wave-induced pressures.

Actions arising from earthquakes are not normally of concern for the design of floating structures. However, it can be necessary to assess their effect, for example, on mooring systems particularly in shallow waters, utility systems and equipment, and communication equipment.

7.4.2 Environmental site-specific data

The phenomena and environmental characteristics listed in this subclause shall, where appropriate to the region, be taken into account in the design. These characteristics shall be described by physical parameters and, where available, statistics (see also ISO 19901-1). For the design of the structure, site-specific environmental conditions shall be selected in accordance with the requirements of ISO 19901-1.

a) **Wind**

Wind is usually characterized by the mean value of its velocity over a given time interval at a given elevation above the mean water level. The frequency content shall be taken into account by means of a wind spectrum as defined in ISO 19901-1. The variation with elevation (wind profile) and the spatial coherence should be considered.

b) **Waves**

Site-specific information shall be established to consider sea-state characteristics (wave height, period, duration, directions and spectra) and the long-term statistics of these characteristics, including wind- and swell-generated waves if appropriate for the location of interest.

c) **Water depth and sea level variation**

The water depth shall be determined together with the magnitude of the low and high tides, and positive and negative storm surges. The possibility of ground subsidence should be considered when determining the water depth. Tidal components for design include astronomical, wind, and pressure differential tides.

d) **Currents**

Phenomena such as tidal, wind-driven, global circulation, loop and eddy currents shall be considered. Currents shall be described by their velocity variation (in magnitude and direction) with water depth (current profile) and persistence. The occurrence of fluid motion caused by internal waves should be considered.

e) **Marine growth**

Marine growth shall be defined by its thickness, roughness, density and variation with depth. This information is usually provided by direct measurements and operational experience in the specific area of interest. Additionally, the marine growth thickness to be used in the design is influenced by operational strategy (e.g. regular cleaning, use of anti-fouling coating) as well as structural behaviour (e.g. less marine growth is normally found on slender structures with significant dynamic displacements).

The presence of marine growth causes an effective increase of the component dimensions, a consequent direct increase in structure weight, in hydrodynamic drag and in added mass, and alters the roughness characteristics of the surface. In structural design, therefore, the mass, buoyancy diameter and effective drag diameter shall be adjusted to account for the specified water depth variation of marine growth. In addition, the values of the hydrodynamic coefficients (drag, Cd, and inertia, Cm) should reflect the roughness associated with the marine growth.

The BOD and the MOM can include a specific provision for periodic marine growth cleaning or anti-fouling systems during the platform life, in which case the design assumptions shall be adjusted accordingly. Any such reliance shall be documented and the cleaning programme defined over the life of the platform. The consequences of not maintaining this programme should be determined and reported.

f) **Ice and snow**

Ice accretion on structural components from sea spray, snow, rain, and air humidity can cause increases of cross-sectional area (with consequent increase in mass and added mass) and surface roughness. These effects shall be considered when determining wind and hydrodynamic actions.

For floating structures, the effects of snow and ice accretion can affect the hydrostatic stability. Appropriate instructions concerning the need for removal of ice accretion shall be included in the MOM.

The accumulation of ice (icing) and snow on horizontal and vertical surfaces (thickness and density) shall be defined, together with the appropriate parameters for the other metocean phenomena (wind, waves and current) to be considered in conjunction with ice and snow accumulation. In addition, the possibility of ice build-up through freezing of sea spray, rain or fog shall be considered.

Sea ice and iceberg occurrences shall be considered when applicable.

g) **Temperatures**

The maximum, average and minimum air and sea temperatures at the site shall be determined.

h) **Local sea water characteristics**

Sea water properties such as oxygen content, salinity and density shall be provided.

i) **Geotechnical data**

Site investigations shall be performed to define physical and engineering properties of the soil strata and to identify potential hazards (earthquakes, mudslides, etc.).

7.4.3 Wind actions

7.4.3.1 General

Actions on a structure caused by wind shall be considered for both global analysis and local design.

Wind-induced actions shall be determined by means of wind tunnel tests and/or suitable analytical methods. Validated computational fluid dynamic methods may be used where appropriate.

The total wind velocity can be described as the sum of the mean wind component and a gust component.

7.4.3.2 Mean wind action

Mean wind actions on a floating structure can be estimated by calculating the mean wind actions on all exposed components of the structure and summing the contributions from each component. Mean wind actions on individual components can be calculated from Formula (1):

$$P_w = \frac{1}{2}\rho_a C_s v_z^2 \tag{1}$$

where

P_w is the mean wind pressure;

ρ_a is the mass density of air;

C_s is the shape coefficient, which shall be determined from appropriate sources (e.g. RCS rules or ISO 19902);

v_z is the mean wind velocity at height z above the mean water level.

If C_s is obtained from wind tunnel measurements, all the parameters in Formula (1) shall be used in a manner consistent with the derivation of the wind tunnel results.

The wind velocity is usually given at a reference height of 10 m above the mean water level. To obtain the mean wind velocity at a different elevation, z, this value should be adjusted according to the formulation provided in ISO 19901-1. Wind velocity should be averaged over an appropriate time interval, typically 3 s for a small standard component, 1 min for stability calculations, and 1 h for mean wind actions in conjunction with a frequency or time domain gust analysis.

Solidification effects shall be taken into account in cases where components are located close together in a plane normal to the wind direction.

Shielding effects may be taken into account if it can be adequately documented that the inclusion of such effects is justified.

When calculating wind actions, care shall be taken to decompose the global structure into components of sufficiently small size, so that the local wind velocity can be considered constant over the component without significant error.

For ship-shaped structures, additional information is given in A.7.4.3.

7.4.3.3 Dynamic wind actions

Wind-induced dynamic actions fall into three categories:

a) long-period variations in the wind intensity, which tend to engulf the whole platform and which can give rise to slow rigid body motions of the platform about its mean position;

b) medium-period fluctuations affecting large structural components or sub-assemblies, such as flare towers;

c) shorter-period variations associated with the shedding of vortices and aerodynamic instabilities.

Whenever appropriate data are available, aerodynamic admittance and spatial and temporal correlation of the gusts should be accounted for.

A dynamic analysis considering the time variation of wind actions and their effects shall be performed for the entire platform as well as for wind-exposed equipment and objects sensitive to varying wind actions, e.g. towers, flare booms.

The fluctuating gust component can be calculated in either the time domain or the frequency domain using an appropriate wind gust spectrum (see ISO 19901-1).

7.4.3.4 Wind-induced instability

Consideration shall be given to local aerodynamic instability. Examples of such instabilities (see ISO 19901-1) are atmospheric turbulence, gusts and squalls. Additionally, instabilities can arise due to interaction between the air flow and structural components, e.g. vortex-induced vibration of slender components (see 7.4.6) and galloping effects.

7.4.4 Current actions

Current actions on large-volume bodies like floating structures shall be determined by model tests, relevant empirical analytical tools, and/or appropriate sources. In determining the shape coefficients, appendages (bilge keels, strakes, etc.) shall be taken into account. Actions induced by steady currents on ship-shaped structure and semi-submersible structures can be determined by global coefficients, analogous to mean wind actions (see 7.4.3.2). In general, current actions on ship-shaped structures are much larger in shallow water (with small under-keel clearance) than in deep water.

Current actions on slender components can be determined using Formula (3) (see 7.4.5.3). Drag coefficients shall be determined from appropriate sources. In the absence of data indicating otherwise, the drag coefficients provided in ISO 19902 for unshielded circular cylinders are recommended, i.e. 0,65 for smooth surfaces and 1,05 for rough surfaces.

The effects of medium-term and long-term variations of current velocity on moored floating structures shall be considered.

For ship-shaped structures, additional information is given in A.7.4.4.

7.4.5 Wave actions

7.4.5.1 General

Actions caused by waves acting on a structure shall be considered for both global analysis and local design. Wave actions shall be determined by appropriate methods, taking into account all relevant parameters, including water depth, marine growth, type of structure, size, shape, and response characteristics.

The simultaneous effect of hydrostatic pressure, hydrodynamic local pressures, and the integrated (global) effect of still-water and wave actions shall be computed.

Adequate consideration shall be given to the relationship between the wave's dominant periods and the structure's natural period of motion or vibration. For example, for two different design situations, each having the same composite return period, it is possible that the situation characterized by lower wave heights, but a longer or shorter associated period, induces more severe action effects on some components.

Local hydrodynamic instability shall be investigated (see 7.4.6).

7.4.5.2 Actions on large-volume bodies

The total pressure acting on submerged structural components includes both static and dynamic contributions. The dynamic pressure at a point on the immersed surface of a structure is expressed as the superposition of the pressure associated with the following:

— incident and scattered waves;

— flow induced by the six degrees-of-freedom radiation potential due to the motion of the structure in still-water;

— the time-varying hydrostatic pressure due to heave, roll and pitch displacements of the structure from its mean position.

For structural components with dimensions of the same order of the wave length (where, typically, the ratio between the wave length and the diameter or other characteristic dimension is <5), the flow disturbance introduced by the large volume body cannot be neglected in the calculation of water particle kinematics. In this case, the current/wave/body interaction shall be considered when deriving resultant actions.

The transfer functions for linear wave actions can be determined by diffraction and radiation theory.

For simple geometrical shapes, analytical solutions may be used. For structural forms where the actions cannot adequately be described by state-of-the-art methods, model tests shall be undertaken.

Hydrodynamic interactions between large-volume components shall be accounted for.

7.4.5.3 Actions on slender components

The computation of the action on a cylindrical component caused by waves, or a combination of waves and currents, depends on the ratio of the wavelength to the component diameter. If this ratio is large (>5), the member does not significantly modify the incident wave. The action can then be computed as the sum of a drag component and an inertia component, as follows [see Formulae (2) to (5)]:

$$F = F_{\mathrm{d}} + F_{\mathrm{i}} \tag{2}$$

where

F is the local action vector per unit length acting normal to the component axis;

F_{d} is the vector for the drag action per unit length acting normal to the component axis in the plane of the component axis and v;

$$F_{\mathrm{d}} = \frac{1}{2}\rho_{\mathrm{w}} C_{\mathrm{d}} \left(v - \dot{x}\right)\left|v - \dot{x}\right| A_{\mathrm{v}} \tag{3}$$

F_{i} is the vector for the inertia action per unit length acting normal to the component axis in the plane of the component axis and $\partial v/\partial t$

$$F_{\mathrm{i}} = \rho_{\mathrm{w}} C_{\mathrm{m}} V \frac{\partial v}{\partial t} - \left(C_{\mathrm{m}} - 1\right)\rho_{\mathrm{w}} V \ddot{x} \tag{4}$$

where

C_{d} is the hydrodynamic drag coefficient;

C_{m} is the hydrodynamic inertia coefficient;

ρ_{w} is the mass density of water;

A_{v} is the projected effective dimension of the cross-sectional area normal to the cylinder axis per unit length based on an effective diameter that includes marine growth;

V is the effective displaced volume of the cylinder per unit length;

v is the component of the local water particle velocity vector (due to waves and current) normal to the axis of the component;

$\frac{\partial v}{\partial t}$ is the component of local water particle acceleration vector normal to the component axis;

$\dot{x}$ is the velocity of the cylinder normal to the axis of the component;

$\ddot{x}$ is the acceleration of the cylinder normal to the axis of the component;

$| \; |$ denotes the absolute value.

As presented here, Formula (2), in combination with Formula (3) and Formula (4), commonly (albeit incorrectly) referred to as Morison's equation, does not include hydrodynamic lift actions, slam actions and axial Froude-Krylov actions. If the above formulae are used for columns and pontoons (e.g. for semi-submersible hulls) appropriate additional terms shall be added to account for axial Froude-Krylov actions and added mass. The final analysis shall be performed using a diffraction analysis, in which case the drag effects shall be added.

The combined effect of simultaneous drag and inertia actions is obtained by vectorial addition.

The drag coefficient (C_d) depends on many parameters: Reynolds number, Keulegan-Carpenter number and roughness, amongst others.

For deterministic, global wave action calculations, the drag coefficient for circular cylinders shall not be less than the values provided in ISO 19902, i.e. 0,65 for smooth surfaces and 1,05 for rough surfaces, where the rough surface value shall be used for members with marine growth. The value of C_d can be affected by the occurrence of VIV (see 7.4.6). For fatigue assessment, higher values of C_d can apply, see ISO 19902.

Design assumptions on the absence of marine growth shall be supported by appropriate requirements in the MOM to ensure that the components in question are kept free of marine growth during the structure's life.

Solidification effects shall be taken into account in cases where components are located close together in a plane normal to the wave direction.

Shielding effects can be taken into account if it can be adequately documented that the inclusion of such effects is justified.

The inertia coefficient (C_m) for circular cylinders shall be taken to be no less than 2,0 for actions where the inertia component action is considerably higher than the drag component action. For other shapes, the inertia coefficient can be accurately determined from appropriate calculations and model tests.

The wave actions on structures composed of large-volume components and slender components are generally computed by a combination of wave diffraction and radiation theory and Morison's equation. The effects on water particle velocities and accelerations due to the large volumes shall be considered when using Morison's equation on adjacent slender components.

7.4.5.4 Slamming on slender components

Design of components in the wave zone shall include the effects of slamming (3.50).

For cylindrical members, the slamming actions can be calculated from Formula (5):

$$F_s = \frac{1}{2} \rho_w C_{sl} d v^2 \qquad (5)$$

where

F_s is the slamming action per unit length in the direction of the relative velocity vector;

ρ_w is the mass density of water;

C_{sl} is the slamming coefficient;

d is the component diameter;

v is the relative water particle velocity normal to the component axis.

The slamming coefficient C_{sl} can be determined using theoretical and/or experimental methods. For smooth circular cylinders, the value of C_{sl} should be assumed to be no less than 6,0 when performing a quasi-static analysis, and no less than 3,0 when performing a dynamic analysis.

7.4.5.5 Higher-order non-linear wave actions

Some hydrodynamic phenomena, generally represented by higher-order, non-linear numerical models, give rise to actions at frequencies close to resonant frequencies of the floating structure and its stationkeeping system. These actions shall be assessed and their effects investigated, as they can be important for the design of floating structures. The nature of these phenomena is addressed in A.7.4.5.5.

Examples of the effects due to higher-order hydrodynamics are:

— mean drift (mean second order action);

— slow drift (time varying action).

Wave drift and wave drift damping are affected by the wave/current interaction, which shall also be considered.

7.4.5.6 Wave enhancement effects

In the vicinity of large bodies, the free surface elevation can be enhanced by motions, diffraction, radiation, wave/current interaction effects, and other non-linear wave effects. These shall be accounted for, as appropriate, in the wave action calculation and used to estimate deck clearance and freeboard (see 8.10).

7.4.5.7 Shallow water effects

If the floating structure is located in a shallow water area (i.e. water depth less than half the wavelength), wave amplitude enhancements and/or wave refraction caused by the effect of the sea bottom shall be taken into account in estimating wave actions.

7.4.5.8 Slamming and green water actions

Wave slamming against the shell structure of the hull due to local wave action, water entry slamming and green water action caused by high relative motions of structure and wave surface are local wave action effects and are discussed in more detail in 9.8.

7.4.6 Vortex-induced vibrations and motions

A fluid flow (wind or current) past a slender component can cause unsteady flow patterns due to vortex shedding. At certain critical flow velocities, the vortex-shedding frequency coincides with, or is a multiple of, a natural frequency of the component, resulting in harmonic or sub-harmonic excitations normal to the longitudinal axis of the component. This phenomenon is generally referred to as vortex-induced vibrations (VIV).

The vibrations can be in-plane (in the plane of the flow velocity) or transverse (in a plane perpendicular to the flow velocity and the component axis). Transverse vibrations are usually of more concern for most structural components. The effects of VIV include:

— increased drag actions on individual components;

— fatigue damage of individual components.

Furthermore, for flow velocities in certain ranges, the vibrations can affect the platform (e.g. spar and potentially semi-submersible) as a whole and result in transverse rigid body motions, i.e. vortex-induced motions (VIM).

The potential for VIV/VIM shall be assessed. The focus of a VIV analysis is generally to evaluate if the fatigue resistance of the component or system is adequate. Accordingly, the simplified (and conservative) VIV analysis described in A.7.4.6 should suffice if the resulting fatigue damage is acceptable. If the simplified analysis indicates insufficient fatigue resistance, a more sophisticated and less conservative method may be applied to demonstrate adequate fatigue resistance.

The method should be chosen according to the specific case to be investigated. Recognized semi-empirical methods can be applied if the problem characteristics are well within the validity range. Otherwise, if the problem is of high complexity (e.g. riser bundles, varying diameters or surface waves), more refined assessment methods are required.

For disconnectable structures, calculation of the response of the turret buoy while disconnected shall include all low-frequency motion components, VIM and second-order wave-induced motions.

Waves, especially transverse to a current, can change VIM motions due to current only, dependent on wave frequency, so wave effects should be considered in a VIM analysis, if applicable.

7.4.7 Direct ice action

Where encounter with sea ice or impact with icebergs can occur, collision actions shall be determined through appropriate theoretical models, model laboratory tests or full-scale measurements.

When determining the magnitude and direction of actions, the following factors shall be considered:

— geometry and nature of the ice;

— mechanical properties of the ice;

— velocity and direction of the ice;

— geometry and size of the ice/structure contact area;

— ice failure mode as a function of the structure geometry;

— inertia effects for both ice and structure.

ISO 19906 shall be used for structures in ice conditions.

7.4.8 Temperature effects

Floating structures shall be designed for the most onerous temperature differences to which they can be exposed. This applies, but is not limited to:

— storage tanks:

— structural components exposed to radiation from the flare;

— structural components that are in contact with risers or process equipment.

The lowest anticipated sea or air temperature shall be the lowest one-hour average temperature associated with an annual P_e of 10^{-2}.

7.4.9 Tidal effects

For floating structures constrained by stiff mooring systems, tidal effects can significantly affect the mean tensions in the mooring components. Therefore, the choice of tide conditions for a static equilibrium analysis is important. Higher mean water levels tend to increase maximum mooring line tensions, hydrostatic actions, and current actions on the hull, while tending to decrease deck clearances.

The effects of tides can be taken into account by performing a static balance at the various appropriate tide levels to provide a starting point for further analysis, or by making allowances for the appropriate tide level in calculating extreme responses.

7.4.10 Geotechnical hazards

Geotechnical hazards, such as earthquakes, mudslides and other geotechnical phenomena, can affect anchors, mooring lines and risers, and should be considered (see also ISO 19901-7). Underwater earthquakes (seaquakes) can cause pressure waves the vertical components of which can, for floating structures located in the vicinity of the earthquake epicentre, damage mechanical systems and impair the performance of production systems, operational systems and safety systems.

7.5 Accidental actions (*A*)

7.5.1 General

Accidental actions relate to accidental events, abnormal operations or technical failure (see A.7.5.1 for examples).

Both a hazard identification (HAZID) and a risk assessment shall be carried out at the outset of the design of a floating structure to identify potential accidental events, their magnitudes and probabilities of exceedance, and the associated consequences. The methods adopted for the HAZID and for the risk assessment shall take into account the type of structure and the existing operational experience.

The structural configuration and equipment arrangements shall be such that damage resulting from an accidental action shall not lead to an escalation of undesirable events (e.g. as could occur if the flare tower were to be placed in the collision zone) or impair safety-critical functions.

The representative value of an accidental action shall correspond to a value with an annual probability of exceedance, P_e, equal to 10^{-4}.

Values of accidental actions with a P_e less than 10^{-4} may be disregarded.

Accidental events may be assumed to occur independently of extreme environmental design situations, see Table 1.

For temporary phases, accidental actions may normally be omitted from further design verification, provided a HAZID and risk assessment have been conducted to ensure all actions likely to occur during temporary design conditions have been identified and their potential consequences assessed.

7.5.2 Collision

Collision-induced actions shall be considered in the design of all structural components that can be affected by sideways, bow or stern collision with another vessel. The vertical extent of the collision zone shall be based on the depth and draught of the colliding vessel, and on the relative horizontal and vertical motions between the vessel and the floating structure. The magnitude of the collision-induced action shall account for added mass effects. Attention shall be given to collisions that can occur during offloading operations.

Structural components located in areas where marine vessels operate in close proximity to the floating structure shall be capable of absorbing the energy resulting from casual contact due to routine operations.

Emergency and essential marine equipment shall be placed away from possible collision zones.

7.5.3 Dropped objects

Accidental impact actions caused by dropped, swinging or sliding objects from cranes or other lifting devices shall be considered. Critical areas for dropped objects shall be based on the planned movement of crane lifts over the platform.

7.5.4 Fire and blast

As far as practicable, semi-enclosed locations where gas pockets can occur should be avoided in the design of a floating platform. Where this is not possible, for example in moonpool locations, the potential for gas accumulation shall be assessed and appropriate measures shall be taken to reduce the risk of explosion to an acceptable level.

Blast resistance requirements shall be addressed concurrently with fire resistance requirements, taking into account probability of occurrence, blast safety evaluation, layout and area of importance, venting system, access to escape, etc. The resistance to fire after blast shall also be addressed.

The fire/blast scenario shall be defined: for example, fire followed by blast followed by fire; or blast followed by fire. It should be demonstrated that blast wall fire insulation remains effective for the duration of the fire/blast scenario. The overall structural design shall prevent any escalation of the accidental event, including escalation events that could affect emergency and essential marine equipment and/or escape routes.

Structural support of blast walls and the transmission of the blast action into the main structural elements shall be taken into account. The effectiveness of connections and the possible outcome from the blast, such as flying debris, shall be evaluated.

7.6 Other actions

7.6.1 Stationkeeping actions

A floating structure can be kept on station by various methods, depending on site-specific criteria and operational goals. These methods include different types of stationkeeping systems, such as internal and submerged turret systems, external turret, catenary anchor leg mooring (CALM), CALM buoy and hawser, spread mooring, and dynamic positioning (DP), see Clause 18. Each type of stationkeeping system imposes specific actions on the hull structure. These actions shall be considered in the platform's structural design. Specific actions induced by the stationkeeping system on the hull structure shall be consistent with the practices described in ISO 19901-7.

7.6.2 Sloshing actions

Sloshing is the dynamic magnification of internal pressures acting on the boundaries of partially filled tanks due to internal fluid motion. Sloshing occurs if the natural periods of the fluid in a tank and of the motions of the structure are similar (see 9.8.4). In some cases, the fitting of swash bulkheads or other baffle devices can be necessary to minimize sloshing effects.

Sloshing-induced actions shall be considered in the structural design.

7.7 Repetitive actions

Repetitive actions, which can lead to significant fatigue damage, shall be evaluated. As a minimum, the following sources of cyclic action effects should be considered:

— waves, including actions caused by slamming and variable buoyancy;

— wind, especially in conjunction with vortex-induced vibrations;

— motion-induced accelerations;

— currents, especially in conjunction with vortex-induced vibrations;

— low cycle/high stress range variable action fluctuations, such as loading and discharging of cargo/ballast;

— sloshing;

— mechanical vibrations, such as those caused by operation of machinery;

— fluctuating actions imposed by the stationkeeping system.

7.8 Action combinations

The structure's resistance shall be investigated for a range of potential combinations of permanent, variable, environmental and accidental actions (see Clause 9).

Values of environmental actions to be used in design should always be established with the intention of resulting in the most probable maximum (MPM) (or minimum) response for the limit state under consideration. For different structural components, the most onerous response can arise from different design situations.

8 Global analysis

8.1 General

The combination of risers, stationkeeping system and the floating structure is a complex integrated dynamic system responding to environmental actions (wind, waves, current, etc.). Therefore, the global analysis of the floating structure cannot be separated from the analysis of the stationkeeping system, and overlaps substantially with this activity, which is covered in detail in ISO 19901-7. Accordingly, Clause 8 provides an overview of the general processes, issues and requirements to be fulfilled.

For floating structures, the typical action effects controlling the structure's overall geometry and configuration, as well as the design of the stationkeeping system include structure offset, structure motions, global structural forces, minimum and maximum mooring line and riser tensions, deck clearance (air gap, freeboard) and deck level motions and accelerations.

The representative values of these action effects are usually obtained from the results of global dynamic analyses and/or model tests.

Validation of numerical results by sensitivity studies with respect to key parameters should be performed.

8.2 Static and mean response analyses

8.2.1 General

The objective of static and mean response analyses is to determine the static equilibrium position of a platform with no wind, wave or current present, and, subsequently, the mean position due to steady metocean actions and ice actions on the platform. The mean position is then used as a basis for frequency domain analyses, or as the initial condition for time domain analyses.

8.2.2 Static equilibrium in still-water condition

The determination of the static equilibrium, or weight balance, in the "still-water" condition is fundamental to sizing of the floating structure and is the starting point for further analysis. A static equilibrium analysis shall be performed for each design situation.

Determination of the static equilibrium for each design situation shall include the following:

— the total platform weight;

— the total structure displacement (the total structure buoyancy) for each draught to be analyzed;

— any riser and mooring tensions acting on the structure;

— any applicable crane hook loads.

The structural weight shall include the weight of all structural components, permanent appurtenances, and all equipment permanently mounted on the platform. In addition, the platform weight shall include all weights appropriate to the design situation being analyzed. These variable actions shall include the weight of crude oil storage in various loading conditions (if applicable), temporary equipment, contents, consumable supplies, ballast, marine growth, ice, and any other appropriate temporary weights.

For floating structures with disconnectable moorings, design situations with and without loading from the moorings and risers shall be analyzed.

NOTE Different design situations can involve significant variations in temporary or removable weights and in actions to be included in the static equilibrium analysis.

8.2.3 Mean response analysis

The mean response is characterized by the position of the platform's centre of gravity, including setdown effects (as applicable), mean orientation of the platform (particularly for ship-shaped structures), and orientation of mooring and riser system.

The estimate of the mean response shall include the same components as the still-water condition discussed in 8.2.2, as well as, as a minimum, the following:

— the mean actions due to wind;

— the mean actions due to wave drift and current on the structure;

— current actions on risers and moorings.

Mean response calculations shall be repeated for a variety of design situations.

8.3 Global dynamic behaviour

8.3.1 General

While, for the analysis discussed in 8.2, the response of the system (floating structure, risers and moorings) can be approximated by a static or quasi-static analysis, dynamic analyses shall be performed when some natural period of the system or part thereof falls within the range of periods of steady-state actions, or when the structure is exposed to transient actions.

Dynamic effects can be important, for example, in connection with the following:

— wave frequency actions;

— low-frequency effects of wind and wave actions;

— wave slamming, sloshing in tanks, and other transient wave actions;

— mechanical impacts due to ships, icebergs or dropped objects;

— VIV and VIM;

— explosion actions.

Dynamic effects resulting from rigid body motions shall be adequately accounted for in the design process.

The effects of thrusters in terms of restoring forces and possible damping should be included.

Free surface effects in tanks shall be included, where relevant.

8.3.2 Analysis models

The metocean actions and ice actions on the platform are generally a function of both time and platform position. To allow a simple solution, a number of assumptions and linearizations are usually made.

A common simplifying assumption is to model the structure as a rigid body, excluding risers and moorings. The system then has six degrees of freedom. This approach is usually referred to as "uncoupled analysis" because it assumes no interaction between mooring and riser dynamic responses and the structure dynamic response (see 8.6).

More sophisticated and complex models can be developed by including a suitable number of degrees of freedom to simulate risers and moorings. Such models allow joint consideration of structure, mooring and riser dynamic behaviour and are suitable for deep water applications or when mooring lines/riser masses are a significant portion of the total system mass. This approach is usually referred to as a "coupled analysis" (see 8.7).

8.3.3 Mass

The total mass used in the analyses shall include

a) the mass of structural material,

b) the mass of equipment,

c) the mass associated with variable actions (including ballast and crude oil storage, if applicable), and

d) added mass effects associated with the submerged portion of the hull.

For uncoupled analyses, the mass of the moorings and risers may be accounted for in an approximate fashion.

For coupled analyses, moorings and risers shall be modelled with a sufficient number of degrees of freedom, and the total mass shall include

— the structural riser mass,

— the mooring line mass,

— the mass of any enclosed fluids and internal lines, and

— added mass.

8.3.4 Damping

Damping is important in limiting structure resonant responses, and can have significant contributions from wave radiation and drag on the hull, bilge keels, moorings and risers.

Roll damping effects should be carefully evaluated, particularly for ship-shaped structures, and included at the correct probability level in the hydrodynamic analysis.

Heave damping effects can be important for semi-submersibles.

For spars, riser friction damping can influence the structure's response.

8.3.5 Stiffness

The total stiffness shall contain contributions from:

a) the structure's hydrostatic characteristics,

b) geometric terms due to moorings/risers in combination with structure offset, and

c) elastic terms introduced by the mooring and riser systems.

8.3.6 Action classification

The time-varying actions on a floating platform are often categorized by their period ranges relative to the natural periods of the platform/moorings/riser system, as follows:

a) nearly steady actions that can be considered static because they vary with periods much longer than any platform natural periods;

b) slowly varying actions, with periods near the surge, sway and yaw natural periods (these responses typically have periods in the range of less than one minute to several minutes), and with roll and pitch natural periods for spars falling within a similar range;

c) actions at wave periods.

8.3.7 Turret moored systems

Analysis of turret moored systems presents some unique features:

a) The collinear environment (wind, wave, and current all coming from the same direction) is not always the most critical design case. Thus the metocean and ice parameters and the associated directionality should be carefully assessed to capture the most critical design situations. A shift in the wave heading from head-on to an oblique heading angle can significantly increase the metocean actions.

b) The prediction of the mean heading of the floating structure is of critical importance to the prediction of the maximum mooring line tensions or maximum structure offset. The sensitivity of the floating structure dynamic responses to the predicted mean heading should be assessed by undertaking parametric studies.

c) The accurate prediction of the yaw response in the dynamic simulation is critical in predicting the total system response. The prediction of yaw response by some analysis tools does not always receive the same degree of benchmarking as other degrees of freedom (e.g. pitch, surge, and sway response). Care should, therefore, be taken in determining yaw response.

8.4 Frequency domain analysis

Frequency domain analysis, in this context, refers to the solution of the equations of motion of a floating structure by harmonic analysis or by Laplace and Fourier transforms. The result of a frequency domain analysis is a description of the variables of interest (platform motions, platform accelerations, mooring forces, etc.) in terms of amplitudes and phases as functions of frequency. The method is naturally suited to the analysis of systems subjected to random excitations because it provides a clear and direct relationship between the input spectrum (in this case, the metocean actions) and the system response spectrum. The system response spectrum can then be used to estimate the short-term statistics of the variable of interest.

8.5 Time domain analysis

The time domain analysis method consists of a numerical solution of the rigid body formulae of motion for the platform, subject to external actions due to environmental phenomena, the platform stationkeeping system and other possible actions. Since a direct numerical integration of the formulae of motion is performed, any non-linearities can be directly included, such as drag-induced actions, finite motion, finite wave amplitude effects, and non-linear characteristics of the stationkeeping system. The capability of dealing with higher modelling complexity comes at the expense of increased computing time.

When the input to the analysis is represented by a deterministic, periodic wave, the analysis shall be carried out for a long enough simulation time to achieve a steady-state response.

When the input is represented by a wave spectrum, which is then converted into a time history of the water surface elevation, the analysis shall be performed long enough to achieve stationary response statistics. Several such analyses shall be performed, with different water surface elevation time histories obtained from the same input spectrum, and the response characteristics shall be combined to achieve a meaningful set of response statistics. Similarly, several different wind speed time histories should be investigated when the time-varying wind-induced action effects are significant.

8.6 Uncoupled analysis

Uncoupled analysis is generally used to compute the system (structure, moorings and risers) response using a two-step approach.

In the first step, the structure's rigid body response to static, low-frequency and wave-frequency metocean actions and ice actions is computed. The risers and mooring system are represented by their static restoring force characteristics and a constant low-frequency viscous damping. Assessment of the low-frequency damping is important for the low-frequency floating structure motion analysis. Contributions from current direct action on mooring lines and risers may be represented by a constant external action on the structure.

In the second step, the moorings and risers are analyzed, considering wave- and current-induced actions on the slender members, and imposing the structure's wave-frequency (or wave-frequency and low-frequency) motion response as forced dynamic excitation.

8.7 Coupled analysis

In a coupled analysis, all interactions between floating structure motions and slender structure response can be accounted for by creating a model of the total system, including hydrodynamic action modules for both large-body and slender components, including all mooring lines and risers. This approach yields dynamic equilibrium between the actions on the structure and the slender structure response at every time instant. Consequently, there is no need for assessment of the low-frequency damping from the slender structure, as this contribution is accounted for by the slender structure dynamics.

8.8 Resonant excitation and response

Non-linear mechanisms can generate actions and action effects that interact with particular natural frequencies of the total system normally not excited by wave frequency actions. As these resonant actions are often present in conjunction with low damping levels, care shall be taken to accurately model these effects. The amplitude of the response at resonance is very sensitive to the damping estimates. Model tests should be used in complex situations for validating analytical computations.

8.9 Platform offset

Generally, to ensure riser integrity and serviceability in ULS and SLS design situations, the global platform motions shall be limited within appropriate motion envelopes.

The platform offsets shall be computed in accordance with ISO 19901-7.

8.10 Air gap and wave crest assessment

8.10.1 Air gap

When assessing air gap, the following effects shall be considered:

— wave crest elevation, including wave asymmetry;

— wave/structure interaction effects (wave enhancement, run-up, etc.);

— global rigid body motions (including dynamic effects);

— effects of interacting systems (e.g. mooring and riser systems);

— maximum/minimum operating draughts.

Accounting accurately for these phenomena is computationally challenging so model tests should be used for final verification of air gap adequacy.

Structures, parts of structures, secondary structures, equipment and supports that are not designed for the effects of direct wave action (wave impact, slamming, etc.) or direct ice action shall be located at an elevation that provides an air gap >1,5 m in ULS design situations.

For ALS (abnormal) design situations, the air gap shall be greater than zero.

All structural components (including secondary structure) and other platform components and equipment that do not conform to these minimum requirements shall be designed to withstand the effect of direct wave or ice actions.

8.10.2 Wave crest effects

As a consequence of random field effects, the wave crest elevation at a point within the boundaries of a platform can be higher than the average value within the boundary. A wave staff at any point of a hypothetical platform grid records similar statistics; however, the expected maximum of all points within the grid is higher than the estimated maximum at a single point. Over a typical platform size area and for directional wave spectra in tropical cyclonic events, the maximum crest can be 10 % to 14 % higher than the average. Additionally, with a platform in place, up-wave measurements are about 10 % higher than down-wave measurements. Consequently, the maximum wave crest elevation within the boundary of a platform can be 15 % higher than the calculated value for the platform location.

In consideration of the localized nature of the effect described above, the calculation of global wave actions may omit consideration of the 15 % increase in crest elevation. However, structures and other platform components and equipment that lie at elevations between the crest and the crest plus 15 % plus air gap should be designed for local wave actions. When calculating air gap as described above, the 15 % enhancement of crest height may be ignored.

Risers, appurtenances, and localized components exposed to local increases in wave pressure due to irregularity of waves and proximity to columns should be designed accordingly. Values of local wave pressure used for the design of risers and appurtenances shall not be less than those used for global structure design anywhere at the same elevation.

For any equipment and other platform components (e.g. utilities, instruments, communications, control systems, power generation, drains) positioned below the recommended elevation, consideration should be given to arrangements and preventive measures that would minimize disruption of platform operability even in presence of water in the lower decks.

8.11 Platform motions and accelerations

The platform motions and accelerations shall be verified with respect to the serviceability restrictions of the topsides facilities and equipment. Large motions and accelerations can affect, among others:

a) efficiency of process equipment;

b) operability of cranes or rotating equipment;

c) comfort levels, cognition, postural stability for the personnel on board;

d) habitability of facilities;

e) operability of heliports;

f) power generation capabilities;

g) maintenance and serviceability;

h) functionality of safety-critical equipment.

8.12 Model tests

Estimates of the structural response to be used for design can be obtained by model tests. Model tests can also be used either to calibrate analytical predictions or to determine responses not directly or reliably calculable. The objectives of such model tests shall be clearly defined (see A.8.12) and, because during tests extraordinary or unexpected behaviour can occur, consideration should be given to the provision of continuous monitoring equipment to record such behaviour.

When comparing the results of model tests with analytical predictions, the following potential sources of discrepancies should be considered:

a) scale effects, such as those affecting Reynolds number, fluid interface and turbulence;

b) viscous effects (Reynolds number-dependent fluid drag and lift components) in both model tests and analytical predictions;

   NOTE In computer simulations, these coefficients can be varied to study their effects.

c) wave reflections from side walls induced by radiated and reflected incident waves;

d) finite dimensions of the model test basin and scaling difficulties;

e) limitations on the accuracy of modelling physical properties, parameters and dimensions;

f) limitations on the accuracy of the test results resulting from finite record lengths, finite sample rates, and numerical accuracy of the data analysis procedures;

g) assumptions made in the development of the numerical model.

NOTE An example is the assumption of linearity of the responses with respect to wave height, which is almost always made in the frequency domain analysis. This can cause significant discrepancies between the numerical and test results for very steep waves or in situations where viscous forces play an important role.

In some cases, the instrumentation itself can affect the responses. The effect of instrumentation on the model should be minimized whenever possible.

For moored floating structures, a static load deflection curve in calm water shall be measured and checked against computations to verify the accuracy of the modelling of physical properties and instrumentation.

When the objective of the test is to assess impacts and associated action effects, the measurements should be recorded at an appropriate sampling rate.

When planning model tests, transportation and installation conditions should also be considered, as these can control the design of significant portions of the structure.

8.13 Structural analysis

8.13.1 General

The structure of a floating platform shall be designed for the action combinations that produce the most severe action effects on the structure. Representative values of metocean actions and ice actions and action effects for design purposes can be obtained by a long-term response analysis which uses a short-term response analysis as part of the methodology.

8.13.2 Short-term response analysis

Select a suitable set of ULS and ALS situations, as identified in 6.3, expected to produce the most severe action effects. The combination of extreme wave, maximum storm current and maximum tide does not necessarily produce the maximum action effects. Similarly, a design situation can provide the most severe values for some action effects and not for others.

Accordingly, care shall be taken to ensure that the selected short-term sea states yield the MPM action effects that correspond to the target return period.

8.13.3 Long-term response analysis

A full long-term analysis involves calculating responses to the entire suite of possible metocean and ice conditions. Statistical analysis of these responses is then performed to predict the MPM values for each action effect.

8.13.4 Design wave analysis

The methods described in 8.13.2 and 8.13.3, based on a stochastic approach, can provide extreme or abnormal values for the variables of interest, but without regard to phase relationships.

One way to retain the phase information is to use a design wave (quasi-static or time domain) approach, in which the extreme or abnormal values computed from the methods above are used to identify one or more design wave. By using the design wave approach, the simultaneity of responses of global and local action effects can be accounted for.

9 Structural modelling, analysis and design

9.1 General

This clause provides general requirements and guidance for the structural strength analysis and design of floating structures constructed in steel, while Clause 10 provides the corresponding general requirements and guidance for their fatigue analysis and design.

General requirements and conditions are specified in Clauses 5 and 6. Requirements and guidance concerning actions and global behaviour are given in Clauses 7 and 8, respectively. More specific requirements for ship-shaped structures, semi-submersibles, spars and shallow-draught cylindrical structures are given in Clauses 11, 12, 13 and 14, respectively.

Structural design shall be based on either the partial factor design format, see 9.7.3, or the working stress design (WSD) format, see 9.7.4. Background on these two formats is given in A.9.7.1.

9.2 Representative values of actions

9.2.1 General

Representative values of actions shall be used in both the partial factor and the WSD formats. Unless specific exceptions apply, as documented within this document, the representative actions specified in 9.2.2 and 9.2.3 shall apply to operating and temporary phases, respectively.

For combinations of simultaneous global and local actions, representative values may be determined based upon consideration of their joint probability of occurrence.

Where variable actions, metocean actions and ice actions occur simultaneously, representative values may be determined based on their joint probability distribution.

For floating structures that are designed so that they can be relocated, metocean and ice conditions shall be established for each location envisaged and the response shall be checked for the most onerous design situation.

9.2.2 Representative values of actions for operating phases

For operating phases and for each relevant limit state, representative values of permanent, variable, metocean and ice and accidental actions shall be as specified in Table 1.

For ALS, two conditions shall be assessed. These are denoted in Table 1 as pre-ALS and post-ALS. The two accidental limit state conditions represent the structure at the time of the ALS event and in the damaged condition respectively.

Table 1 — Representative values of actions for operating phases

Action category	Representative value				
	Limit state — Operating phases				
	ULS-a	ULS-b	ALS		SLS
			pre-ALS	post-ALS	
Permanent (*G*)	MC	MC	MC	MC	MC
Variable (*Q*)	MC	MC	MC	MC	MC
Metocean and Ice	SV	$T_R = 100$, $P_e = 10^{-2}$	NA	$T_R = 1$, $P_e = 10^0$	SV
Abnormal action – metocean and ice (*A*)	NA	NA	$T_R = 1\ 000$ to $10\ 000$ $P_e = 10^{-3}$ to 10^{-4}	NA	NA
Accidental action (*A*)	NA	NA	$T_R = 10\ 000$, $P_e = 10^{-4}$	NA	NA

Key

SV: Specified Value

NA: Not Applicable

MC: Mean or Calculated value

NOTE 1 ULS-a and ULS-b are defined in 9.7.3.2.

NOTE 2 See 7.2 and 7.3 for definitions of mean and calculated values of permanent actions (*G*) and variable actions (*Q*), respectively.

NOTE 3 The units for T_R are years.

NOTE 4 Additional damage tolerance requirements apply to semi-submersibles — see 12.2.3.

9.2.3 Representative values of actions for temporary phases

For temporary phases and each relevant limit state, representative values of permanent actions, variable actions, metocean actions and ice actions shall be as specified in Table 2. Where specified values are adopted, they should be selected dependent upon the measures taken such that the required safety level is obtained. Such specified values should consider the actual location, season of the year, weather forecast and consequences of failure.

ALS design situations need not be formally considered for temporary phases, but consideration should be given to the possibility of accidental events and their mitigation.

Table 2 — Representative values of actions for temporary phases

Action category	Representative value		
	Limit state — Temporary phases		
	ULS-a	ULS-b	SLS
Permanent (G)	Mean or calculated value	Mean or calculated value	Mean or calculated value
Variable (Q)	Mean or calculated value	Mean or calculated value	Mean or calculated value
Metocean and ice	Specified value	Specified value	Specified value
NOTE 1 ULS-a and ULS-b are defined in 9.7.3.2.			
NOTE 2 Appropriate specified values of metocean parameters can be found in, e.g. ISO 19901-6.			

The required safety level for any temporary phase should be specified by the owner or be consistent with those specified for operating phases in Table 1. For temporary phases that do not involve risk of life, injury to personnel, or environmental consequences, metocean actions and ice actions with a shorter return period than that specified in Table 1 may be utilized.

9.2.4 Actions at interfaces

Structural analysis shall include consideration of actions occurring at interfaces of all relevant systems and components. Such actions can result, for example, from

— topsides systems (including drilling and production),

— topsides components (including helidecks and accommodation blocks, as applicable),

— mooring systems, or

— riser systems.

Individual actions at interfaces shall be combined in a logical manner.

9.3 Scantlings

The scantlings used in modelling and analysis are a function of floating structure type and exposure to corrosion. Deductions for corrosion should be directly related to the corrosion margins used for structural integrity management (Clause 19), normally a function of the environment to which the structure is exposed. The external corrosion deduction should be the same for all types of floating offshore structure operating in a similar environment.

In cases where pitting corrosion poses a risk for loss of containment (e.g. the bottom of oil storage tanks), a higher corrosion deduction can be necessary than for where generalized corrosion is a risk for loss of strength.

The actual corrosion experienced can be dependent on the effectiveness of the applied corrosion protection system (see 9.10), but the corrosion additions/allowances shall, as a minimum, be in conformity with the requirements of RCS rules or equivalent.

9.4 Modelling

9.4.1 General

Linear elastic structural models should normally be used to determine response for ULS design verifications. Non-linear structural models may be used for ULS verification, assessment of ALS events and ALS verification. See 9.5.3.2 and 9.5.3.3 for ULS and ALS analysis, respectively.

Space frame structures consisting of slender components should be analyzed using a 3-D frame analysis to calculate internal component forces and moments. The effects of joint eccentricity and flexibility, where significant, should be accounted for.

Structures composed of large-volume components, such as plate and shell structures, should be analyzed using three-dimensional shell models, in combination with frame models as appropriate. Where plate and/or shell panel buckling can reduce cross-sectional effectiveness, this shall be reflected in the model. When the accuracy of deflection calculations is important, the effect of shear lag on cross-sectional stiffness shall be incorporated in the model.

The structural response of a floating platform can generally be considered as being divided into two broad categories:

— global response, which requires global structural models that simulate the effects of global actions on the structure, evaluate the structural response of the primary structure and identify controlling load cases for local analysis models;

— local response, which normally requires local structural models that simulate the effect on the structure of local actions, such as hydrostatic pressures, tank pressures and concentrated actions.

Specific requirements and guidance for global and local models are included in 9.4.2 and 9.4.3, respectively. The model extent should, however, be defined such that boundary conditions and actions can be imposed at well-defined, or well-understood, interfaces. Appropriate extrapolation techniques should be used to provide information of stress levels at element boundaries.

Structural components that participate in a load path shall be explicitly modelled. The level of modelling detail is dependent on the intended purpose of the particular component in a model. Models should be checked to ensure that the stiffness of the structure is adequately simulated and that they accurately identify the controlling design situation. Particular attention should be given to the structural evaluation of areas surrounding critical interfaces and abrupt changes of section.

For local structures that can be significantly affected by global structural stiffness and/or response or conversely, in the case where local structures significantly affect the global stiffness and/or response, such effects shall be adequately considered when developing the structural analytical model. A combined global or local structural model can be necessary. See also 9.4.3.

Assumptions upon which the model is based shall be well documented.

9.4.2 Global models

Global models should generally include the entire floating structure, for which a restraint system is normally required.

Global models can comprise equivalent beams, space frame models or combined shell element/beam element models, as appropriate. Models should accurately represent the global stiffness of the floating structure and the relative stiffness of the major structural components.

9.4.3 Local models

Actions applied to local models shall be derived from consideration of global model responses and local actions resisted by the structure. Where local structural response is controlled by local actions alone, the application of global analysis actions may be omitted.

Global action effects on local models shall be accounted for by

— integration of the local model into the global model, or

— mapping of actions (or responses) from the global model to the local model (sub-modelling) by the application of, for example, displacement or force boundary conditions obtained from the global analysis, or

— superimposing responses from the global model on the local model responses.

The number of design situations to be evaluated by local models can be less than the full set of situations where a relevant screening process has been performed.

Shell (plate) or volume (solid) elements shall be used for all areas of interest of local models when determining the response of structural components critical to the integrity of a floating structure. Volume (solid) elements shall be used for highly detailed local models in which through-thickness variations in stress are important. In such cases, the size of the elements should normally be of the order of the plate thickness.

9.4.4 Response evaluation

The effects of factored actions derived from an analysis shall be used to check structural adequacy. The following specific limit states are usually evaluated:

— yielding (ULS);

— global and local buckling instabilities (ULS);

— fatigue failure (FLS), see Clause 10.

Artificially high (or low) stress gradients can occur due to modelling simplifications, typical examples of which are listed in A.9.4.4. The model should not normally be considered as acceptable at such locations and another model should be developed to analyse such locations where necessary.

ULS design verifications typically consider average stress levels over panels where buckling can occur. However, for panels with large stress gradients, the effect of the gradient shall be considered in the buckling evaluation. When evaluating buckling strength, mid-plane (membrane) element stress data shall be used. The effect of pressure on such stresses shall be accounted for, as appropriate.

9.4.5 Model verification

Model verification shall be performed throughout the structure's life cycle. Such verification falls into two categories:

a) quantitative verification;

b) qualitative verification based on engineering judgement and experience.

Quantitative verification should ensure that the model is consistent with the actual structure, including

— geometry,

— material properties,

— section properties,

— actions, and

— boundary conditions.

Displacements, restoring forces and action sums should be used to verify modelling of the system. Reactions at constrained boundaries should be used to confirm accurate application of actions and to verify system balance. When hydrodynamic actions are mapped onto the structure, global balancing of pressure, inertia and restoring forces shall be verified.

When local models are used to evaluate structural response for design situations identified from global models, force summations at local model boundaries in the global model should be used to verify accurate action transfer.

Qualitative verification shall review the adopted modelling strategy for consistency with previous experience in structural modelling.

Analysis results shall be demonstrated to be consistent with expectations of sound engineering judgement and previous experience. Results that deviate from expectations should be investigated to understand the discrepancy.

The final (as-built) drawings for a structural component shall be reviewed to ensure they accurately reflect the structural model geometry. The effects of deviations from the analysis model shall be evaluated.

9.5 Structural analysis

9.5.1 General principles

Action effects shall be determined by recognized methods that take adequate account of the temporal and spatial variations of the actions, the motions of the structure and the limit state to be verified. General principles associated with this process are the following:

a) The floating structure shall be analyzed for all governing design situations using appropriate computational methods.

b) Analysis models and techniques shall be selected that adequately represent the simultaneous global and local actions and provide the action effects needed for the assessment of the different limit states.

c) Analysis models shall adequately describe the relevant properties of actions and structural stiffness, and shall satisfactorily account for the local and system effects of time dependency, damping and inertia.

d) Non-linear and dynamic effects associated with actions and structural response shall be accounted for, where relevant.

e) If model uncertainties are particularly high, conservative models shall be selected. Normal uncertainties in the analysis model are expected to be taken care of by the partial action and resistance factors or safety factors.

f) Where geometric deviations/imperfections have a significant effect on safety, conservative geometric parameters shall be used. Initial deformations assumed in design should be consistent with tolerances used in construction (see 9.11).

g) The relevance of changes to a design as a result of alterations in design parameters and assumptions throughout the life cycle of the structure, including the design phase (for example, in respect to weight and centre of gravity estimates from weight control, changes in structural scantlings, positioning of openings) shall be assessed, as necessary.

9.5.2 Linear analysis

A linear elastic procedure shall normally be considered as appropriate when conducting an analysis for a ULS evaluation.

For ALS, simplified linear methods may be used. However, because the range of applicability of linear methods to ALS assessment is normally limited, their use in such cases shall be justified.

Consideration shall be given in the structural evaluation to amplification of bending response resulting from axial forces caused by, for example, rigid body motions or elastic deformations.

9.5.3 Non-linear analysis

9.5.3.1 General

Non-linear analysis may be applied to determine the ultimate capacity of structural components, substructure or the complete structure.

A non-linear analysis should include appropriate models for all significant non-linear effects, including elastoplastic behaviour, large deflections and criteria for rupture. Geometrical imperfections and residual stresses should be modelled when they have a significant effect on the structural response, such as for plating subjected to compression or tension and all compressed components susceptible to buckling. The methods and computer software adopted to execute non-linear analysis should be verified by comparison with test results, observed full-scale structural behaviour, known analytical solutions, or other well-documented computer software solutions.

When using non-linear analytical models, the effects of action history shall be addressed. It shall be demonstrated that the least favourable action history has been used.

When exploiting a non-linear finite element analysis, appropriate consideration shall be exercised in choosing finite element types and meshes and applying boundary conditions and restraints.

Where non-linear analysis is used to verify a design and the determined failure modes involve plastic hinge mechanisms, the structure shall be shown to have sufficient ductility to develop such failure mechanisms, so that no large plastic deformations or failures occur as a result of repeated yielding.

For structural components subjected to cyclic or repetitive actions, such actions shall be demonstrated not to lead to low-cycle fatigue failure, cyclic incremental collapse or other failure modes, e.g. shakedown.

9.5.3.2 ULS analysis

When non-linear analysis is used for ULS verification, significant departures from traditional design approaches shall be carefully and clearly justified.

9.5.3.3 ALS analysis

Non-linear analysis is generally deployed to determine the response of structures or their components to accidental actions in a manner similar to that applicable to intact structures. Such analysis can also be used for the post-damage assessment. In such cases, its applicability shall be demonstrated when the effects of the accidental actions have not first been assessed using the same analysis, and the results thereof retained as the starting point of the analysis of the damaged condition.

Simplified non-linear methods may also be used to assess the response of structures or their components to an accidental or abnormal event. The use of simplified methods to determine the effects of accidental actions can normally be justified on the basis of the large uncertainties associated with such actions. Such methods should be based on plastic hinge or yield-line mechanisms that account as necessary for in-plane behaviour. They should recognize the possibility of premature rupture. Simplified methods can also be used for the post-damage assessment of structures and their components.

9.5.4 Vibration analysis

Vibration analysis shall be executed for all structural components subjected to major sources of dynamic excitations (e.g. the thruster foundations and other heavy rotating machinery).

9.6 Structural strength

9.6.1 Representative strength values

Structural design verifications shall proceed using representative values of structural strength.

The representative value of strength shall equate to a characteristic value, nominal value or other rationally determined value. A characteristic value shall be based on reliable data and appropriate statistical techniques using recognized methods of testing.

If the representative strength reflects great uncertainty or cannot be determined with reasonable accuracy, tests shall be carried out to provide results from which a representative value can be rationally derived.

When evaluating the resistance of structural cross-sections, the following items should be among those taken into consideration:

— the strength of the net section at cut-outs and openings;

— shear lag effects;

— buckling strength including shear buckling;

— effect of buckling on cross-sectional stiffness.

For ULS, SLS and ALS conditions, the characteristic strength value shall normally be the 5th percentile of test results.

9.6.2 Yield strength

The measured value of yield strength from a tensile test shall be taken to coincide with the smaller of:

— yield strength at 0,2 % offset;

— 83,3 % of the minimum tensile strength.

The representative value of yield strength is normally the nominal value taken from RCS rules or equivalent, or the nominal value taken from the material standard or specification. Tensile tests shall be used to confirm the material conforms with its standard or specification.

Shear yield strength should normally be taken as $\left(1/\sqrt{3}\right)$ times the yield strength.

9.6.3 Buckling strength

Buckling strength shall be based upon RCS rules or equivalent code formulation.

When a state of stress cannot be defined by a single reference stress, the code formulation shall include appropriate interaction formulae.

9.7 Design verification

9.7.1 General

Verification shall be undertaken using either the partial factor design format (see 9.7.3) or the WSD format (see 9.7.4). In both cases, it shall be satisfactorily demonstrated that the design action effects (resulting from factored actions in the case of the partial factor format) do not exceed the design resistance criteria (including the appropriate resistance or utilization factors) for the limit state under consideration. Structural design may also be undertaken using reliability-based methods (see 9.7.5). Both the partial factor and the WSD formats are based upon the assumption that design values for responses and resistances are calculated separately. In cases where non-linear analysis is used and responses and resistances are calculated simultaneously, care should be taken to ensure that equivalent levels of safety to those implicit in this document are obtained.

When considering different modes of operation for a floating structure, all realistic variations in action combinations shall be determined to ensure the maximum (or minimum, if more onerous) action effects, whether alone or in combination, are identified.

9.7.2 SLS deflection limits

When conducting the SLS design verifications described in 9.7.3 and 9.7.4, the resulting deflections shall be checked for acceptability. A.9.7.2 provides guidance for deflection limits for both main load carrying components and non-main load carrying components.

9.7.3 Partial factor design format

9.7.3.1 General

The principles governing application of the partial factor design format to structural design are established in ISO 19900.

Design verification shall be achieved by demonstrating that design values of action effects resulting from factoring the actions do not exceed the design value of the resistance variable or model being addressed for the limit state under consideration. The partial action factors required for design verifications are presented in 9.7.3.2, and the partial resistance and/or material factors in 9.7.3.3.

9.7.3.2 Partial action factors

In Table 3, the partial action factors (γ_f) applicable to the partial factor design format are listed for each limit state and for each combination of action categories to be considered in design verification.

Where a linear analysis is adopted for a ULS assessment as described in 9.5.2, three options are available for application of the partial action factors that should normally produce the same outcome:

a) application of the partial action factors given in Table 3 to the actions prior to analysis following which the action effects are combined;

b) application of the partial action factors given in Table 3 to the actions following which the factored actions are combined and then analyzed to produce the relevant action effects;

c) analysis of each unfactored action resulting in action effects that are combined using the factors given in Table 3.

Table 3 — Partial action factors (γ_f) and combinations

Limit state	Partial action factor γ_f				
	Action category				
	Permanent (G)	Variable (Q)	Metocean and ice	Repetitive	Accidental (A)
ULS-a	1,3	1,3	0,7	—	—
ULS-b	1,0	1,0	1,3	—	—
SLS	1,0	1,0	1,0	1,0	—
Pre-ALS	1,0	1,0	—	—	1,0
Post-ALS	1,3/1,0	1,3/1,0	0,7/1,3	—	—
In the ULS-a condition, an action factor of 1,0 shall be used for the permanent action, the variable action, or both, where this gives a more unfavourable combined action effect than 1,3.					
The action factor for permanent actions in ULS-a may be reduced from 1,3 to 1,2 if the action and action effects are determined with great accuracy (for example, external hydrostatic fluid pressures acting on a rigid body).					
For the Post-ALS limit state, the partial action factors apply to intact components and the choice of factor depends on whether ULS-a or ULS-b governs verification.					

For ULS, two combinations of actions shall be considered: one to reflect gravitational action-dominated conditions; the other to reflect conditions dominated by metocean actions and ice actions. In Table 3, these two combinations are denoted ULS-a and ULS-b, respectively.

For ALS, two conditions shall be assessed. These are denoted in Table 3 as pre-ALS and post-ALS. The two accidental limit state conditions represent the structure at the time of the ALS event, and in the damaged condition, respectively. For the post-ALS limit state, in accordance with 6.3.5, intact components shall be checked to ULS-a and ULS-b combinations.

The partial action factors stated in Table 3 for the pre-ALS condition apply to values of abnormal actions and accidental events with return periods of either 1 000 years or 10 000 years (i.e. probability of occurrence is 10^{-3} or 10^{-4}).

9.7.3.3 Partial resistance and material factors

The partial resistance and material factors shall take appropriate account of the uncertainties associated with modelling resistances, the geometry of a structure and material properties. The design value of component or structure strength, R_d, shall be determined from Formula (6).

$$R_d = \frac{R_k}{\gamma_r} \tag{6}$$

where

R_k is the representative value of component or structure strength;

γ_r is the partial resistance factor.

For components with strength formulations in which the partial resistance factor applies to material strength only, the design value of material strength, r_d, shall be determined from Formula (7):

$$r_d = \frac{r_k}{\gamma_m} \tag{7}$$

where

r_k is the representative value of material strength;

γ_m is the partial material factor.

For ULS conditions in relation to steel structures, neither the partial resistance factor, γ_r, nor the partial material factor, γ_m, shall normally be taken as being less than 1,15. Where the resistance concerns bolted connections and fillet and partial penetration welds, this minimum factor should be increased to 1,30. Standards adopted for establishing structural strength (see 9.6) could require increased partial resistance factors. In such cases, these increased factors shall be used instead of the minimum factors of 1,15 and 1,30, as appropriate.

For SLS and ALS conditions, the partial resistance and/or material factors shall be 1,0.

9.7.4 Working stress design format

9.7.4.1 General

The WSD format is an approach whereby a design value of combined action effects is directly compared with the corresponding design value of strength. In this design format, the design values of both action effects and strengths coincide with their representative values.

In design verification, the acceptability of a comparison between design values of the action effects and of the strength is conditional upon the action effect being less than the design strength reduced by a safety factor greater than unity, or the design strength multiplied by a fraction less than unity.

9.7.4.2 Action combination factors

In Table 4, the action combination factors applicable to the WSD format are listed for each limit state and for each combination of action categories to be considered in design verification.

Table 4 — Action combination factors

Limit state	Action combination factor				
	Action category				
	Permanent (G)	Variable (Q)	Metocean and ice	Repetitive	Accidental (A)
ULS-a	1,0	1,0	—	—	—
ULS-b	1,0	1,0	1,0	—	—
SLS	1,0	1,0	1,0	1,0	—
Pre-ALS	1,0	1,0	—	—	1,0
Post-ALS	1,0	1,0	1,0	—	—

Design values of actions shall be combined in the most unfavourable manner, providing that the combination is physically feasible and permitted according to the design specification.

For ULS, two action combinations shall be considered: one to reflect the structure located in a calm sea with responses associated with static actions only; the other to reflect the structure subjected to extreme metocean actions and ice actions combined with relevant static actions. In Table 4, these combinations are denoted ULS-a and ULS-b, respectively.

For ALS, two conditions shall be assessed. These are denoted in Table 4 as pre-ALS and post-ALS. These ALS conditions represent the structure at the time of the accidental event, and in the damaged condition following the accidental event, respectively.

The action factors stated in Table 4 for the pre-ALS condition apply to values of abnormal actions and accidental events with return periods of either 1 000 years or 10 000 years (i.e. probability of occurrence is 10^{-3} or 10^{-4}).

9.7.4.3 Acceptable safety factors and allowable utilization factors

In design verification, the acceptability of a comparison between design values of the action effects and of the strength is conditional upon the action effect (F_d) being less than the design strength (R_d) reduced by a safety factor greater than unity (C_{SF}), or the design strength (R_d) multiplied by a fraction less than unity (η). Thus, design verification is either Formula (8) or Formula (9):

$$F_d \leq \frac{R_d}{C_{SF}} \tag{8}$$

or

$$F_d \leq \eta R_d \tag{9}$$

In this manner, the safety margin is expressed by a single safety factor ($1/\eta = C_{SF}$) applied to the design value of strength (R_d) for design verification.

Safety factors (C_{SF}) or allowable utilization factors (η) stated in RCS rules or equivalent shall be used for the ULS condition.

For both the SLS and ALS, the safety factor or allowable utilization factor shall be taken as unity.

9.7.5 Reliability-based methods

Structural reliability analysis may be used to demonstrate that a satisfactory level of reliability is achieved for a given design solution. For such an application, the governing basic variables shall be described by appropriate probability distributions, and random process theory shall be utilized to estimate the probability of occurrence of governing design situations.

The following principles shall be applied when performing a structural reliability analysis:

a) Structural reliability analysis shall not replace good engineering judgement.

b) When more than one failure state (limit state function) governs the reliability of a structural component, or when more than one component constitutes the structure being analyzed, the corresponding system reliability should be evaluated, in addition to the component reliabilities.

c) When relevant, consideration shall be given to time-dependent degradation of the resistance of the structure.

d) To the extent possible, minimum target reliabilities should be established based upon calibration against well-established cases that are known to have adequate safety.

e) Target reliabilities shall be commensurate with the consequence of failure.

f) The conduct of reliability analyses shall include sensitivity considerations with respect to important variables.

9.8 Special design issues

9.8.1 General

The special design topics covered in this subclause primarily address local strength issues. They can be dealt with variously as ULS, SLS and ALS.

Some of these topics relate to events with an annual P_e of the order of 10^{-4}, for which representative values for design variables are not easy to determine. In such cases, it can be advantageous to use risk assessment as a means of both assessing the event and mitigating the consequences of the event.

9.8.2 Slamming

In the case of ship-shaped structures, slamming effects shall be taken into account in the design of the bow (including bow flare, bow side and forward bottom), turret and stern. Slam effects can be determined in accordance with RCS rules or equivalent procedures. Slam impulses can also produce dynamic excitation (whipping) and vibration (springing) of the hull that generally amplify the global bending moments and shear forces.

For slamming on other types of floating structures particularly those with vertical surfaces, some of the same principles as for ship-shaped structures apply.

Slamming on slender components in the splash zone is discussed in 7.4.5.4.

Slamming can occur at light operational draught or during transit, generally in severe weather conditions. The design actions should include slamming as appropriate.

9.8.3 Green water

Escape routes, muster areas, temporary refuge and safety-critical equipment shall be protected from green water effects. Protection, if required, can be provided by breakwaters and similar structures. Green water effects can be determined in accordance with RCS rules or equivalent procedures, or model testing.

9.8.4 Sloshing

Sloshing analysis should be performed (see 7.6.2) in accordance with RCS rules or equivalent requirements and should include non-linear effects.

9.8.5 Wave impact on deck

Run-up resulting from wave impacts on columns and similar vertical surfaces shall be accounted when assessing wave impacts on decks.

9.8.6 Local structure and components

The following local structure and components and their integration with the main hull structure require particular attention with respect to local strength, fatigue and/or wear requirements and shall be verified to ensure satisfactory performance:

a) Structure supporting mooring system components, such as fairleads, winches, etc. This structure shall withstand, as a minimum, the action effects corresponding to a mooring line loaded to 100 % of its minimum breaking strength.

   NOTE 1 "Withstand" as used here means no permanent deformation.

   NOTE 2 "minimum breaking strength" as used here refers to the catalogue minimum breaking strength.

b) Scantlings immediately surrounding large openings, especially turret openings, moonpools, etc. At such openings, continuity of primary longitudinal structural components shall be maintained as far as practicable, and reductions in hull section modulus shall be minimized and compensated for.

c) Deck support structure for process and other equipment, including the connections to the hull frame to allow for hull deflections.

d) Riser termination and supporting structure.

e) Scantlings associated with structural discontinuities and major changes of cross-section.

f) Structure supporting attachments to yoke-moored ship-shaped structures and external turrets.

g) Breakwaters.

h) Rotating structures, e.g. external turrets, chaintable structures, bearings

i) Thickness of internal structure in locations susceptible to excessive corrosion.

j) Proportions of built-up components shall conform to established standards for buckling strength.

k) Watertight tank quadrants.

l) Details of the ends and intersections of components and associated brackets.

m) Shape and location of air, drainage and lightening holes.

n) Shape and reinforcement of slots and cut-outs for internals.

o) Elimination or closing of weld scallops associated with butt welds.

p) Toes of "softening" brackets used to reduce the effects of abrupt changes of section or structural discontinuities.

q) Boat landing, mooring and fendering systems. The combined fender/structural system should be capable of absorbing the energy of boat impact actions without overstressing the hull structure.

r) Forecastle.

s) Process and utility water intakes and outlets.

t) Watertight doors and hatches.

u) Ventilation openings.

v) Cable transits in watertight bulkheads.

w) Sea chests and caissons.

x) Bilge keels.

y) Utility and marine system water intakes and outlets.

z) Thruster penetrations and associated maintenance lifting systems.

aa) Crane pedestals (if attached directly to the hull).

Operating requirements, as well as installation, maintenance and inspection needs, shall determine the number and location of access platforms, walkways and stairways.

Fatigue damage accumulation at the fairlead, chain jack, and winch foundations shall account for cyclic loading from the mooring line and any cyclic loading from hull motions as well as from flexure of the hull in the case of ship-shaped structures and barges.

The riser support structure shall be designed for the range of possible riser angles for all design situations.

9.9 Materials

9.9.1 General

Material specifications shall be prepared for all structural materials intended for use in the construction of a floating structure. Such materials shall be suitable for their intended purpose and have adequate properties in all relevant design situations.

9.9.2 Material selection

When selecting a material, the following shall be taken into account:

a) consequences of failure;

b) degree of redundancy;

c) presence of stress concentrations;

d) accuracy of analytical stress predictability;

e) susceptibility to fatigue actions;

f) electrolytic (galvanic) corrosion generally and between different materials;

g) minimum water and/or air temperature.

When determining criteria appropriate to material grade selection, adequate consideration shall be given to all relevant phases in the life cycle of the floating structure. In this connection, there can be conditions and criteria, other than those from the in-service operational phase, that govern the design requirements in respect to the selection of material. Such criteria can, for example, be design temperature and/or stress levels during marine operations.

When assessing the properties relevant to such materials, at least the following shall be among those considered:

— chemical composition;

— strength (first yield and ultimate);

— ductility;

— toughness (resistance to unstable fracture);

— thickness-dependence;

— weldability;

— temperature-dependent properties;

— fire resistance;

— corrosion resistance;

— mechanical resistance;

— chemical resistance.

Steel properties shall be determined in accordance with:

— the requirements of RCS rules or equivalent;

— the design class (DC) approach presented in ISO 19902;

— the material category (MC) approach presented in ISO 19902.

9.9.3 Through-thickness tension

Transmission of tensile action effects through the thickness of a plate should be avoided as far as practicable, particularly in primary structural components. In cases where such actions cannot be avoided, the specification for the material shall include guaranteed through-thickness properties.

9.9.4 Aluminium substructures

Aluminium alloys may be used in the construction of structural components of floating structures. Such alloys shall be suitable for application in marine environments.

In addition to the general requirements on material selection given in 9.9.2, the following aspects shall be given particular attention in consideration of the appropriate grade of material in the design of aluminium structural arrangements:

— the influence of heat treatment in respect to the evaluation of representative structural strengths;

— possible reductions in material strength at, or adjacent to, welded connections;

— *S*-*N* data appropriate to aluminium structural details;

— heat-resistant properties.

9.9.5 Cement grout

The requirements of cement grout should be in accordance with the requirements of ISO 19902.

9.9.6 Elastomeric material

Elastomeric materials, as used in the articulating elements of flexible joints, shall be selected in accordance with the user's specification and on the design requirements of the flexible joint.

9.10 Corrosion protection of steel

9.10.1 General

The structure shall be adequately protected against corrosion. The method of protection shall be suitable for its intended position and purpose. Corrosion protection systems typically include special coatings, cathodic protection, material corrosion allowance, and corrosion monitoring, and should be designed in accordance with NACE SP0176[142] or RCS rules.

The corrosion protection philosophy shall be fully consistent with the assumptions and criteria utilized in the assessment of minimum scantlings. The corrosion protection system shall account for both internal and external hull steel wastage.

Corrosion protection systems for external surfaces most exposed to metocean actions and ice actions should be designed to withstand these actions. If there is limited possibility to adjust the draught of the floating structure to carry out external inspection, maintenance, and repair, a corrosion allowance should be included as a part of the corrosion protection system. RCS rules should be used to account for water temperature and resistivity.

Structural steel used for submerged surfaces (external surfaces, ballast tanks, drill water tanks, etc.) is prone to potentially higher corrosion, and should be protected by a combination of coatings, sacrificial anodes, and/or impressed current.

Excessive levels of corrosion protection should be avoided to minimize the possibility of disbondment of coatings and the possibility of hydrogen absorption, leading to hydrogen-assisted cracking in weld heat-affected zones (hydrogen embrittlement).

For structures with storage (e.g. a FPSO), the possible corrosive effects of H_2S, CO_2, and other gases given off by cargo oil in the tanks shall be investigated and accounted for. These effects can be enhanced by the presence of water in the tanks and by high temperatures of the stored crude oil. Similar issues shall be investigated with respect to inert gas systems. The possible effects of microbial action on horizontal surfaces should be addressed.

9.10.2 Electrical bonding and isolation

To prevent damage from cathodic protection or stray currents, mechanical interfaces with equipment external to the floating structure should be electrically bonded. Examples of such interfaces include

— mooring systems,

— chain hawsers and stoppers, and

— electrical cables.

For steel wire rope stationkeeping systems, it is recommended that the end sockets be electrically isolated to prevent the galvanized wire from acting as an anode for the adjacent components.

9.11 Fabrication and construction

9.11.1 General

General structural steel fabrication should be undertaken in accordance with RCS rules or equivalent. Fabrication of tubular structures should be undertaken in accordance with ISO 19902.

The standard utilized as the basis for fabrication, particularly with regard to local and global tolerances, shall be consistent with the requirements of the standard utilized for the design of the structure.

In-built deformations resulting from standard shipyard fabrication sequences are normally not included in the design evaluation. However, when large structural components are fabricated separately and assembled, the significance of the validity of neglecting these in-built stresses should be evaluated.

Structural welding shall be undertaken by properly qualified personnel utilizing approved weld consumables.

9.11.2 Inspection and testing during fabrication and construction

Quality control, inspection and testing shall be performed to ensure conformance with the fabrication specifications. Relevant consideration shall be given to the importance of structural connections when determining the extent of the quality control, inspection and testing to be performed.

Inspection procedures shall ensure that fabrication, including any repairs, is undertaken in conformity with drawings, specifications and procedures.

Inspection undertaken during fabrication shall, as a minimum, include inspection of the following:

— qualification and acceptance of fabrication procedures;

— qualification and acceptance of relevant personnel;

— material quality;

— dimensional control (including alignment);

— preparatory work (e.g. assembly and fit-up);

— welding;

— a non-destructive test (NDT);

— repairs;

— corrosion protection systems.

9.11.3 Fabrication details

Splices in structural pipe, beams, and joint cans of tubular structures should be in accordance with ISO 19902.

Temporary attachments to structural members should be designed in accordance with ISO 19902.

Guidance on fabrication tolerances for steel structures is given in ISO 19902 and appropriate RCS rules. Any deviation from these tolerances as a consequence of specific fabrication methods should be appropriately reflected in the design of the structure.

Special attention should be paid to interfaces between separately constructed sections.

9.11.4 Welding

Welding should follow good industry practice as described in ISO 19902 and RCS rules.

9.12 Marine operations

All marine operations shall, as far as practicable, be based upon well-proven principles, techniques, systems and equipment, and shall be undertaken by qualified, competent personnel possessing relevant experience.

Analysis of the structure in the floating condition, or during launching, upending and in other transportation/transit modes, shall be performed in accordance with this document, ISO 19901-6 or ISO 19902, as applicable.

9.13 Topsides/hull interface

In general, the design of the topsides structural arrangements shall follow the same principles as for the hull structure design. The limit states described in 6.2 shall be utilized considering site-specific environmental conditions.

Topsides structural design shall include, but not be limited to, consideration of the following:

— relative deflections in all three translation directions (e.g. hull deflections acting on topsides structure and supports);

— built-in deflections from fabrication tolerances at hull/topsides interface;

— the full operational loading range of the item being considered (e.g. full/empty combinations of tanks/pressure vessels);

— inertia components (e.g. caused by global rigid body motion);

— maximum angles of inclination (for both the intact and damaged conditions);

— solid water action effects (green water and wave slam);

— wind action effects;

— sloshing effects (partially filled tanks);

— local temperature effects (e.g. heat emissions from flaring);

— accidental action effects (e.g. helicopter crash scenarios, fire and blast, dropped, sliding and swinging objects);

— local dynamic effects (e.g. due to rigid body motions, machinery system-induced vibrations or vortex shedding);

— second-order bending effects (P-Δ effects).

For local, static structural design, the representative value of the wind velocity should be based upon a wind gust velocity with an averaging period not exceeding 3 s.

10 Fatigue analysis and design

10.1 General

This clause provides general requirements and guidance for the FLS assessment of floating structures constructed in steel. Special FLS issues for the various floating structural types are dealt with in Clauses 11 to 14. Fatigue of mooring systems and their points of attachment to floating structures are covered in ISO 19901-7. Fatigue requirements in relation to structures converted and/or re-used are addressed in Clause 15.

Fatigue analysis and design can be performed using four main methods, normally described as the following:

a) deterministic;

b) semi-probabilistic;

c) (linearized) spectral analysis;

d) (non-linear) time domain analysis.

Of the four methods, the spectral method is the most relevant for floating structures. It represents the best compromise between rigour, accuracy and computational resources. However, where non-linearities dominate, it is usually necessary to resort to time domain methods for some of the critical cases and determine fatigue damage assessments from statistical consideration of a number of realisations of these simulations. In such cases, judicious application of time domain methods can allow the development of linear empirical results that can be incorporated into a spectral method.

Fatigue analysis shall proceed as a series of spectral fatigue analyses, linearized as necessary to cover a range of floating structure draughts, operating scenarios and (possibly non-linearly determined) mean offsets. Any resonant, rigid body responses shall be appropriately accounted for in the structure's motion analysis. Certain parts of the structure subject to, for example, slamming, sloshing and equipment vibrations, can require special consideration of dynamic and/or non-linear effects (possibly involving time domain analysis). Global model tests can also help in this respect.

Fatigue testing of full- or large-scale models may be used in lieu of an analytical fatigue assessment, provided it is fully documented as being suitable for such purposes.

For fatigue strength assessment, either the procedures presented in this clause, which are based on a site-specific assessment, or established RCS methods, shall be followed. Detailed structural (finite element) models of complex joints and other complicated structures can be needed to develop local stress distributions. Structural members that transmit mooring system and riser system forces into the floating structure's hull should be carefully detailed and analyzed for fatigue damage.

The fatigue analysis shall consider significant actions contributing to fatigue damage, such as the following:

— operational design situations and associated actions;

— site-specific wave data and structure's response, including VIV and VIM;

— effects of end-of-life corrosion on the stress range;

— fatigue damage during transit;

— fatigue damage from previous service, when applicable;

— inspection and repair philosophy.

Where fatigue is assessed for prior service and an inspection history is available, previous assessments should be updated based on the findings of the inspections and consideration of whether defects have arisen (see 15.4).

Fatigue of primary hull girder in and around the turret or moon pool areas should be analyzed in areas of high cyclic bending stresses.

For a turret moored structure, additional considerations include the effects of weathervaning, to account for slow drift and occurrence of waves in off head seas.

NOTE Turrets are discussed in 18.3.

10.2 Fatigue damage factors

Minimum fatigue damage factors that should be applied to the design service life are defined in Table 5. The factors are based upon a consideration of the following:

— the consequence of failure;

— accessibility for inspection and repair;

— the ability to predict fatigue damage.

Table 5 — Fatigue damage factors

Consequence of failure	Fatigue damage factor		
	Degree of accessibility for inspection and repair		
	Not accessible	Underwater or restricted access	Dry access
Substantial	10,0	5,0	2,0
Non-substantial	5,0	2,0	1,0

In Table 5, dry access refers to fatigue sensitive locations where the possibility for close-up detailed inspection and repair in a dry and clean condition exists. If either of these conditions is not fulfilled, the fatigue damage factor shall be that appropriate for underwater access or not accessible. Consideration should be given to weather and the anticipated effects on operations in determining the accessibility of areas for inspection and repair.

When assessing the consequence of failure, consideration should be given to both structural effects and economic effects, particularly when a common type of detail subjected to similar action effects is used extensively throughout the structure (e.g. downtime, cost of repair).

Reductions in the factors presented in Table 5 may be used, provided an appropriate in-service inspection strategy is adopted.

Where crack propagation is likely from a location with a particular degree of accessibility to a location with a more onerous degree of accessibility, the latter shall dictate the choice of fatigue damage factor.

Where adjustment in draught provides satisfactory accessibility for inspection and repair, a fatigue damage factor appropriate to dry inspection may be used.

Whether the partial factor design format or WSD format is adopted, all action factors and material and/or resistance factors are equal to 1,0.

10.3 Outline of approach

For each critical detail or location, four main steps shall be performed as part of a spectral fatigue analysis:

— identification of a range of operating conditions to which the structure can be exposed throughout its design service life (e.g. tank filling, cargo oil, ballast), and a corresponding representative set of modelling configurations (i.e. idealized structural models) which, when subjected to a set of linearized spectral analyses, provides an acceptable representation of the repetitive actions applied to the structure;

— evaluation of the repetitive action effects by determination of distributions of stress ranges for each modelling configuration;

— determination of fatigue resistance;

— calculation of damage accumulation and fatigue life.

A detailed evaluation of repetitive action effects normally involves a number of steps. These are listed below and described further in 10.4 to 10.11. Some of these steps are performed in connection with some other essential aspects of the floating structure design process. Since design is generally performed as a series of parallel tasks, some of these steps can be based on suitably conservative approximations to anticipated conclusions of other design tasks.

a) Select metocean data.

b) Identify representative operating conditions that contribute to, or strongly influence, the assessment of repetitive action effects (draughts, tank filling and ballast/cargo distribution arrangements, with/without attendant vessel or mooring/off-loading arrangement, etc.) throughout the floating structure's design service life.

c) Use structural modelling of the floating structure to create representative modelling configurations.

d) Identify discrete fatigue design sea states (i.e. discretization of the wave scatter diagram plus associated wind and current).

e) Assess wind, current and slow drift to determine floating structure offsets and headings. Fatigue of the hull structure, particularly the side-shell structure, can be sensitive to heading and should be assessed as necessary.

f) Determine motion response amplitude operators (RAOs) for each of the combinations identified in e). These analyses determine frequency-dependent transfer functions of sectional forces and bending moments, or stresses.

g) Associate each fatigue design sea state with one modelling configuration to define one fatigue design situation.

h) Apply sectional action effects to determine fatigue stress ranges in hull details. This involves developing detailed models of a structure from which nominal stress transfer functions can be deduced and for which stress concentration factors (SCFs) can be determined. Simplifications used to transfer global actions to detailed structural models shall be adequate and shall not neglect important fatigue loading mechanisms.

i) For each detail, determine SCFs for each component of stress, i.e. axial, in-plane and out-of-plane.

j) Determine stress range probability distributions.

k) Calculate fatigue damage using appropriate *S*-*N* curves for each fatigue design situation.

l) Multiply the calculated fatigue damage by the probability of occurrence of step g).

m) Sum all weighted fatigue damage from step l) over all the fatigue design situations of step g).

n) Determine in-place fatigue life as the inverse of the cumulative fatigue damage ratio.

10.4 Metocean data for fatigue

Wave data shall be provided in the form of a site-specific wave scatter diagram supplemented by the long-term distributions of wave direction and, possibly, wave spreading around a mean direction. Wind and current data shall be provided on a joint distribution basis, where available, to assess structure heading, in particular for ship-shaped structures. For conceptual design, where site-specific data are not available, other sources of data may be used.

10.5 Structural modelling

Several levels of structural modelling should normally be performed. 3-D structural modelling can be required to investigate global response and to determine internal forces in the main structural components. Where such investigations are necessary, structural representation may be based on relatively crude models, with relatively large elements used to model hydrodynamic actions.

The internal forces from less detailed models are transferred to more detailed models to determine nominal stresses. Very refined modelling is necessary to derive geometric stresses or, more generally, SCFs, in all cases where RCS rules do not provide standardized solutions. The SCFs shall include all stress-raising effects associated with the geometry, except the local (microscopic) weld notch effect, which is included in the *S*-*N* curve. Different SCFs can apply under axial forces, and in-plane and out-of-plane bending moments. Shear and torsional effects may generally be neglected for slender space frame structures. For angle-stiffened plate structures, in-plane bending is precluded, but coupled torsional or tripping effects can be important.

When structural modelling at various levels of detail is used, and data are transferred from one model to another, the validity and consistency of the models and the data transfer shall be checked and documented.

Such modelling shall be performed using a suitable FE analysis package. General requirements for modelling are found in 9.4.1 with specific requirements for global and local models given in 9.4.2 and 9.4.3, respectively.

For new-build structures, the scantlings defined in 9.3 shall be used.

10.6 Hydrostatic analyses

Hydrostatic analysis shall be conducted for a sufficient number of still-water conditions (including the effect of cargo and ballast tank filling) to ensure adequate information is available on hydrostatic stiffness for input to dynamic analyses. Hydrostatic analyses shall also be conducted on different draughts, for assessment of wave pressure effects on intermittently submerged panels below and above mean water line.

The time-varying stresses arising from changes in operating scenarios (changes in draught due to cargo ballast, tank filling, etc.) should be considered.

10.7 Response amplitude operators and combinations of actions

RAOs corresponding to the following shall be added to the RAOs determined in 10.3:

— total hydrodynamic pressure arising from direct wave pressure (quasi-static component) plus dynamic components arising from diffracted and radiated waves and hull motion responses (these effects vary the draught and wave direction);

— intermittent wetting of the hull structure near the mean water line (for each draught, wave direction and hull orientation);

— dynamic (inertial) components of internal tank pressures induced by floating structure response;

— sloshing pressures;

— quasi-static and inertial components (in three directions) of the structure and topsides/equipment support reactions.

RAOs shall be expressed either in the form of real and imaginary parts or as amplitudes and phases to facilitate the handling of phase differences between wave action and response. Motion reference points shall be specified, and sufficient information shall be provided to uniquely determine the relative phasing between any dynamic response and the incoming, undisturbed wave.

10.8 Stresses and SCFs

The most important factors influencing fatigue damage are the stress range at a location, the number of applied cycles of a particular stress range magnitude and the fatigue resistance of the material.

Stresses are generally based on either the geometric (or hot-spot) stress approach described below or the classification (or "nominal stress") approach given in A.10.8. Whichever method is employed, the stress (or stress range) axis on the *S*-*N* curve shall correspond to the approach selected.

Nominal stresses shall be based on the section properties of the component under consideration. A global analysis model is normally used to determine nominal stress ranges in the vicinity of the connection.

In the geometric stress approach, a joint classification shall be assigned to the connection (or to a particular construction detail of the connection). The geometric stress shall then be determined at specific locations of the connection by multiplying the nominal stresses first by the appropriate SCF (if any) and then combining the axial, in-plane and out-of-plane stress components as given in A.10.8, accounting for any phase differences. Consideration should be given to the inclusion of the additional stress-raising effects due to the gross geometry of the joint (e.g. stress concentrations resulting from holes or local through-wall bending).

SCFs shall be derived from FE analyses (see 10.5), laboratory tests or empirical equations based on such methods. Derived SCFs shall be in a form consistent with the assumptions inherent in the relevant *S*-*N* curves. Where fatigue evaluation involves extrapolation of stresses to a considered hot-spot, documented recognized methods of stress extrapolation shall be adopted.

10.9 Stress range counting and distribution

Execution of the analyses of the structural models developed as discussed in 10.5 for each RAO and each combination of actions discussed in 10.7, results in a stress transfer function for each critical detail and/or location. Applying the wave spectra representing each FLS sea state, the stress spectra for each short-term condition can be determined for each critical detail and/or location.

Where the short-term response is narrow-banded, the stress range may be assumed to follow a Rayleigh distribution. This assumption is commonly used, even when responses are not narrow-banded, as it generally leads to conservative results. More general methods to assess the distribution of stress ranges and number of cycles are available, examples of which are given in A.10.9.

A rainflow counting process can be used to deal with the combination of low-frequency and wave-frequency stress cycles.

10.10 Fatigue resistance

Fatigue resistance shall be established using recognized, calibrated methods based on fatigue tests (e.g. *S*-*N* curves), cumulative damage ratio (Miner's Rule; see 10.11), fracture mechanics, or a combination of these. Application of these methods shall account for the effect of coatings, the presence of CP, and large plate thicknesses, as appropriate.

Suitable *S-N* curves (in air, in seawater with or without adequate CP, in tanks, etc.) may be obtained from RCS rules or equivalent, along with guidance on how these curves have been derived and should be applied.

10.11 Damage accumulation

For each loading condition, the specification of long-term metocean conditions (e.g. wave scatter diagram) together with the corresponding assessment of damage accumulation for each sea state or long-term distribution of sea states, determines the total damage associated with the portion of any single year for which this FLS situation is applicable. Total damage in one year for all such scenarios is then summed. Damage arising from other sources such as transportation/transit, previous service, etc. shall also be determined as necessary and included in the damage summation.

The total damage is the cumulative damage in-place plus the cumulative damage arising from other phases in the life cycle, i.e Formula (10).

$$D_{\text{Total}} = \left(\Sigma D_{\text{in-place phases}} + \Sigma D_{\text{other phases}}\right) C_{\text{SF}} \leq 1{,}0 \quad (10)$$

where

D_{Total}	is the total accumulated damage ratio throughout the life cycle of the platform;
$\sum D_{\text{in-place phases}}$	is the accumulated, unfactored damage ratio during the in-place operational phases;
$\sum D_{\text{other phases}}$	is the accumulated, unfactored damage ratio during operational phases, excluding in-place phases;
C_{SF}	is the appropriate safety factor from Table 5.

The safety factor in Table 5 relevant to the in-place condition should apply to all phases in the structure's life cycle. However, a different safety factor than that employed for the in-place phase(s) may be used for the other phases, particularly prior phases, see also 15.4.4.

10.12 Fracture mechanics methods

Fracture mechanics methods may be employed to quantify fatigue lives of structural details, as described in A.10.12.

10.13 Fatigue-sensitive components and connections

Selection of fatigue-critical areas can be done by means of a screening analysis of the global model analysis results and careful evaluation of critical structural details.

The following components and connections are known to be particularly sensitive to fatigue actions and shall be verified for satisfactory fatigue performance:

— foundations of equipment subjected to high cyclic actions, such as mooring winches, chain stoppers and foundations for rotating process equipment;

— components and/or structural details used to interface the mooring system with the main hull structure;

— main hull shell, bottom, decks;

— main hull longitudinal and bracket connections to transverse frames and bulkheads;

— openings in main hull;

— transverse frames;

— flare tower and attachments;

— longitudinal bulkheads;

— riser interfaces;

— topsides support structure;

— riser porches;

— caissons;

— crane pedestals;

— helideck to deck connections;

— turret structure;

— hopper corners;

— transverse frames and gussets;

— transverse bulkheads.

11 Ship-shaped structures

11.1 General

The requirements of this clause supplement, for ship-shaped structures, the general requirements and guidance provided in Clauses 9 and 10.

Structural design shall, as a minimum, conform to RCS rules or equivalent, written specifically for ship-shaped structures. National regulations also apply, where they exist (see 5.4).

RCS rules do not normally include specific structural design requirements for the construction and removal phases of an offshore floating structure. The general principles covering the design requirements for these phases are presented in Clause 9.

Ship-shaped structures often provide storage and transfer facilities for produced oil as well as support for oil processing facilities. It is important therefore to consider in the design the variations in loading accompanying different levels of crude inventory and the impact of additional systems and equipment necessary for the safe storage and transfer of crude oil.

Sufficient design situations for all anticipated pre-service and in-service conditions shall be determined and analyzed to identify the critical design cases for the hull girder longitudinal strength. This should include fully laden, light ballast, and a mix of representative operational conditions (including repairs or inspection).

Operational conditions should include, as appropriate, asymmetrical tank loading cases. Riser and mooring tensions shall be included in the design situations. The adequacy of the hull structure shall be verified for all appropriate combinations of static and dynamic actions. Consideration should be given to static and dynamic actions induced by process and utility equipment on the deck.

The total hull girder forces, consisting of the wave-induced bending moments and shear forces combined with the still water bending moments and shear forces, should be calculated in accordance with RCS rules considering both metocean actions and ice actions associated with in-place design situations and with temporary phases.

Depending on the expected metocean conditions at the installation site, the wave-induced actions at the installation site can be higher or lower than those used by RCS rules as the basis of acceptance of a tanker (for unrestricted service classification). Consequently, suitable adjustments to reflect site-specific conditions should be made.

Commonly used linear ship motion theory, which considers the hull as a rigid element, is adequate to determine the hydrodynamic actions acting on the hull girder. However, for special hull forms or for hulls susceptible to slamming, more sophisticated analysis and/or model tests that consider non-linear wave effects can be required.

When analytical formulations are deemed unlikely to predict adequately the hull girder hydrodynamic actions, model tests should be carried out to measure hull girder action effects. Measurements should be taken at critical sections of the hull, such as amidships and at one-quarter vessel length from either end.

The condition of the structure during transit from the integration yard, where the floating structure is assembled, to the offshore installation site should be carefully evaluated. The transit configuration should be analyzed for longitudinal strength considering appropriate actions along the length of the ship, using metocean parameters appropriate to the transit route and the time of the year. The sum of the still water bending moment and the wave-induced bending moment should be used to verify the adequacy of the structural strength of the ship in the transit condition.

For floating structures fitted with an internal turret, special consideration should be given to bottom slamming to prevent damage to the turret supports and bearings. In many cases, this requires adjustment of the transit draught to reduce the structure's motion responses.

For conversion and re-use of existing ship-shaped structures, see Clause 15.

Ship-shaped structures can be either permanently moored or have disconnectable mooring and/or riser systems as addressed in 18.2 and 18.4. Turret interface issues are addressed in 18.3.

Examples of special areas for ship-shaped structures are given in A.11.1.

11.2 General design criteria

11.2.1 Collision protection

Consideration shall be given to the need for suitable collision protection dependent on an assessment of the collision risk at a particular geographic location. National regulations also apply, where they exist.

Ship-shaped structures that store oil shall conform with IMO MEPC/Circ.406 requirements related to protection from the effects of collision (see A.11.2.1).

11.2.2 Deckhouse requirements

Living quarters, lifeboats and other means of evacuation shall be located in non-hazardous areas and shall be protected and separated from areas containing production facilities, oil storage, riser terminations and from the flare tower. Reference can be made to RCS rules or equivalent for definitions of hazardous and non-hazardous areas.

Positioning and arrangement of deckhouse structures shall conform to IMO requirements and RCS rules or equivalent. National regulations also apply, where they exist.

Minimum scantlings of deckhouses shall conform to the requirements of RCS rules or equivalent, accounting for location on the hull, as well as green water and wave impact.

Consideration shall be given to blast wall requirements and passive/active fire protection, depending on the distance between the deckhouse and hazardous equipment as well as the conventional cargo pump room, and on the outcome of an explosion analysis.

11.2.3 Sloshing

Operational requirements can lead to individual cargo and/or ballast tanks being partially full most of the time and, therefore, subject to possible sloshing effects. Such effects shall be considered in the design of cargo tanks, ballast tanks, and other tanks (see 9.8.4).

The cargo management operational philosophy typically used for a ship-shaped structure (e.g. FPSO) generally results in some tanks being only partly filled at almost all times. Sloshing of the fluid within a partially filled tank can be particularly critical when the natural period of the oscillations of the fluid contents is near the period of the wave-induced structure motions.

This condition, referred to as 'near resonance', occurs when the natural period of the fluid oscillation in the tank is within ±20 % of the period of some of the floating structure's rigid body motions. In such conditions, sloshing can result in fluid pressures exceeding the design pressures for the boundary members within the cargo or ballast tanks. Therefore, these potential effects should be assessed during the design.

Sloshing should be addressed for both the longitudinal and transverse directions, for a variety of filling levels. The determination of the natural period of the fluid oscillations within the tank should take into account the restriction to free flow of the fluid imposed by structures within the tank itself. Sloshing effects in conjunction with long swell waves should also be checked. RCS rules contain requirements for determining natural periods of fluid oscillations within tanks and should be referred to for guidance.

Common methods of controlling sloshing in ship-shaped structures are the inclusion of swash bulkheads, controlling tank length, and/or reinforcement of boundary structures. If reinforcement of boundary structures be adopted, the filling height that induces the greatest impact should be determined and used to design the structural boundary members accordingly. The sloshing actions can be determined from RCS rules.

11.2.4 Green water

Green water is the overtopping of sea water on or above the main deck and/or forecastle of a vessel, and is generally the result of the relative motions of a vessel with respect to the water surface in severe sea conditions. Green water on deck can be harmful to personnel and can cause severe damage to the equipment on deck as well as to the vessel's structure. The tendency of a hull to amass green water on deck should be investigated during the design stage and should be confirmed by model tests.

Green water usually occurs during severe storm conditions, particularly for wave lengths similar to that of the length of the floating structure, and can occur anywhere along the entire length of the structure. Unless the structure has been designed with adequate freeboard, the main deck and deck-mounted equipment and structures (e.g. deckhouse) shall be designed for green water actions and effects. The occurrence of green water can be assessed from model tests or from diffraction calculations. See A.7.4.5.8 for guidance.

Green water effects can be mitigated by appropriate bow shape design, including bow flare, and layout of deck-mounted equipment and structures. Deck-mounted breakwaters and other protective structures can be used to reduce effects on deck-mounted equipment and structures.

Adequate deck drainage arrangements shall be provided.

11.3 Structural strength

11.3.1 General

For ship-shaped structures, local structure and components shall be checked for the combinations of actions and limit states listed in Table 1 and Table 2 in accordance with the requirements of Clause 9. Additionally, the longitudinal bending and shear forces on the global structure shall be checked against corresponding longitudinal bending and shear strength criteria, in accordance with 11.3.3.

In the evaluation of the hull girder strength, the selection of local scantlings, and the design of the hull's main supporting members, the following recommendations and considerations apply:

a) The dynamic components produced by in-situ metocean actions can produce dynamic action effects higher or lower than those specified by RCS rules for a tanker in oceangoing service. Adjustments of the rules applicable to a tanker are sometimes needed (and allowed) depending on the conditions at the installation site. Some RCS rules apply specifically to permanently moored ship-shaped structures.

b) The impact of wet and dry weights of process equipment and the full range of mooring and riser actions should be included.

c) The effects of segregated ballast tanks included for the control of still water bending moments, shear forces, draught, and trim, should be considered.

d) The effects of local structural actions induced by the mooring system, and by production riser equipment, should be addressed.

11.3.2 Scantlings

Design scantlings are as follows:

a) When assessing *global* hull girder properties:

  — for strength design, design scantlings shall be defined as the as-built scantlings, or those intended for such purposes, with 50 % of corrosion additions/allowances deducted;

  — for fatigue design, design scantlings shall be defined as the as-built scantlings, or those intended for such purposes, with 25 % of corrosion additions/allowances deducted.

b) When assessing *local* properties (e.g. plates, stiffeners, girders):

  — for strength design, design scantlings shall be defined as the as-built scantlings, or those intended for such purposes, with the full corrosion additions/allowances deducted;

  — for fatigue design, design scantlings shall be defined as the as-built scantlings, or those intended for such purposes, with 50 % of corrosion additions/allowances deducted.

Scantlings resulting from direct design analysis utilizing site-specific metocean and ice criteria shall be checked to ensure that minimum scantling requirements are in accordance with RCS rules or equivalent. In any case, hull girder section moduli, moments of inertia and shear area (global hull girder properties) requirements shall not be less than 85 % of the corresponding requirements in RCS rules for ships in unrestricted service.

11.3.3 ULS-a and ULS-b longitudinal strength design verification

11.3.3.1 General

Longitudinal strength design verifications shall be conducted for combinations of maximum still-water and wave-induced bending moments and shear forces. Both sagging and hogging bending moment and shear forces shall be verified at a sufficient number of sections along the length of the ship-shaped structure to fully describe the bending moment and shear force distributions. The bending moments and shear forces shall be determined in accordance with Clause 9. A full range of design situations should be used, including those arising from inspections/repairs of cargo tanks, see A.5.5.1.

The still-water bending moments and shear forces and wave-induced bending moments and shear forces shall include the effects of bottom slamming, where applicable. Wave bow slams and green water effects are usually treated as local actions, although wave bow slam can induce overall action effects as described in 9.8.2.

Longitudinal strength verification shall be conducted using either the partial factor design format or the WSD format as described in 11.3.3.2 and 11.3.3.3, respectively.

11.3.3.2 Partial factor design format

The longitudinal bending strength verification shall be conducted using Formula (11):

$$\gamma_{f,s} M_s + \gamma_{f,w} M_w \leq M_u / \gamma_r \qquad (11)$$

where

M_s is the maximum representative still-water bending moment;

M_w is the maximum representative wave bending moment;

M_u is the representative ultimate bending strength of the hull girder;

$\gamma_{f,s}$ is the still-water action effect factor, to be taken from Table 3 as the factor corresponding to the permanent, G, and variable, Q, action categories for the limit state combination, ULS-a and ULS-b, under consideration;

$\gamma_{f,w}$ is the metocean and ice action effect factor, to be taken from Table 3 as the factor corresponding to the metocean and ice action category for the limit state combination, ULS-a and ULS-b, under consideration, and which, for the ULS-b combination and where the still-water bending moment represents between 20 % and 50 % of the total moment, may be reduced from 1,30 to 1,15;

γ_r is the partial resistance factor, to be taken as a minimum as 1,15 although a higher value shall be adopted if required by RCS rules or equivalent standard used to assess longitudinal bending strength.

Formula (11) assumes M_s and M_w occur at the same cross-section. If this is not the case, the moments at two or more cross-sections shall be examined to determine the most onerous combination.

When calculating M_u, the following effects on the ultimate bending strength of the cross-section shall be taken fully into account:

a) influence of co-existing stresses (such as shear and transverse stresses as well as those arising from pressure effects) on the strength of the components comprising the hull cross-section;

b) influence of buckling on component stiffness and strength, as also influenced by co-existing stresses and by the presence of typical initial geometric distortions and welding/rolling residual stresses in plate panels and stiffeners.

Shear strength verification shall be conducted using Formula (12):

$$\gamma_{f,s} Q_s + \gamma_{f,w} Q_w \leq Q_u / \gamma_r \qquad (12)$$

where

Q_s is the maximum representative still-water shear force;

Q_w is the maximum representative wave shear force;

Q_u is the representative ultimate shear strength of the hull girder;

and where $\gamma_{f,s}$, $\gamma_{f,w}$ and γ_r are as defined for Formula (11).

Formula (12) assumes that Q_s and Q_w occur at the same cross-section. If this is not the case, the shear forces at two or more cross-sections shall be examined to determine the most onerous combination.

When calculating Q_u, the effects of co-existing stresses (such as longitudinal and transverse stresses as well as those arising from pressure effects) on the ultimate shear strength of the cross-section shall be taken fully into account.

11.3.3.3 Working stress design format

Longitudinal bending strength verification shall be conducted using either Formula (13) or Formula (14):

$$M_s + M_w \leq M_u / C_{SF} \quad (13)$$

$$M_s + M_w \leq \eta M_u \quad (14)$$

where

C_{SF} is the value required by RCS rules or equivalent but not less than 1,34;

η is the value required by RCS rules or equivalent but not greater than 0,75;

and where M_s, M_w and M_u are as defined for Formula (11) and qualified according to 11.3.3.2.

If M_u (or M_u/C_{SF} or $\eta\ M_u$) is defined in terms of a limiting stress value, the cross-sectional properties used in the calculation of the moment of inertia and section modulus shall account for both the co-existing stress and the buckling effects noted in respect of M_u according to 11.3.3.2.

Shear strength verification shall be conducted using either Formula (15) or Formula (16):

$$Q_s + Q_w \leq Q_u / C_{SF} \quad (15)$$

$$Q_s + Q_w \leq \eta Q_u \quad (16)$$

where Q_s, Q_w and Q_u are as defined for Formula (12) and qualified according to 11.3.3.2, and C_{SF} and η are as defined for Formulae (13) and (14).

11.3.4 Local strength and details

In addition to the requirements of 9.8.6, special consideration shall be given to the following:

a) The strength of the structure shall be evaluated in the transit condition. For a turret-moored structure or a structure with a moonpool well, the plating of the well should be suitably stiffened to prevent damage in transit. Attention shall be given to designing structure surrounding structural discontinuities.

b) For yoke-moored and turret-moored structures, FE analyses of attachments to the hull shall be undertaken to ensure satisfactory stress distribution of concentrated mooring reactions into the hull structure.

c) The effects of green water on local hull structure, including the design of a breakwater structure used to deflect water away from equipment on the deck, shall be considered.

d) Proportions and thicknesses of structural components for reducing fatigue damage due to engine, propeller or wave-induced cyclic stresses shall be taken into account, particularly for higher strength steel components.

e) The scantlings necessary to maintain strength in way of large hatches.

f) Process equipment supports, which should be analyzed for all applicable combinations of the following actions:

— process support reactions due to equipment weight, wind actions, floating structure motions, etc.;

— all applicable combinations of hydrostatic and hydrodynamic actions on the hull frame imposed by liquids in tanks and the sea;

— differential movement between the process deck and hull due to still water and the deflections due to wave actions and thermal actions.

g) Flare boom support structure, especially in the case of overhanging (non-vertical) flare booms.

h) Crane support structures.

i) Supply boat landing areas.

j) Helideck supports.

k) Actions imposed by either side-by-side or tandem offloading.

l) Structural details in areas of high vibration, which should be designed to reduce the effect of resonance and local member fatigue.

The design of the process equipment support structure should conform to the requirements of RCS rules and of 11.3.5. Guidance for sizing beam brackets and spacing of panel stiffeners can be provided by RCS rules.

Crane support structures shall conform to the appropriate static impact factors, dynamic loading and fatigue requirements in ISO 19901-3.

Finite element analyses are sometimes required to verify the adequacy of the hull framing and associated process equipment support structure. RCS rules for the various combinations of vessel draught and tank loading typically applied to the design of tanker framing should be considered when selecting design situations. The methodology and details of the FE analyses should meet RCS rules.

When evaluating local strength, the procedures outlined in RCS rules, or equivalent, for structural details, including the effects of dynamic actions on the structure, shall be followed.

11.3.5 Topsides structural support

The effect of deformations of the hull shall be carefully considered in the design of the topsides structure.

Structural strength shall be evaluated considering all relevant design situations and action combinations. Scantlings shall be based on criteria that combine, in a rational manner, the effects of global and local responses for each structural component (see 9.13).

The location of the process facility deck and structural arrangements shall conform to RCS rules. Particular attention shall be given to hazardous zones or divisions and provision of adequate access (see 11.2.2). National regulations also apply, where they exist.

The deck support frame for process equipment, including the connections to the hull frame, should allow movement of the process skid due to hull deflection. The support structures should be designed to withstand inertial/green water actions experienced by the process equipment due to wave-induced motion responses, in addition to the effect of permanent actions in upright, heeling, and trimming conditions.

11.3.6 Load monitoring

Monitoring of operational (and relevant temporary) phases shall be undertaken. For such purposes, a loading computer for monitoring still water bending moments and shear forces shall be installed on the floating structure.

An intact stability booklet and loading manual should be prepared, documenting the stability limitations and the allowable hull girder bending moments and shear forces. These documents should provide all pertinent information regarding tank loading arrangements, and should define the appropriate loading and unloading sequences necessary to maintain hull girder longitudinal bending and shear stresses and structure hydrostatic stability within the allowable limits for all conditions including transient conditions of loading.

12 Semi-submersibles

12.1 General

This clause deals with the design of semi-submersible floating structures, including those with:

— ring (continuous) pontoons,

— twin pontoons, and

— multi-footing arrangements.

For semi-submersibles, this clause supplements the general requirements and guidance provided in Clauses 9 and 10.

Structural design shall, as a minimum, conform to RCS rules or equivalent, written specifically for semi-submersible offshore structures. National regulations also apply, where they exist (see 5.4).

RCS rules do not normally include specific structural design requirements for the construction and removal phases of an offshore floating structure. The general principles covering the design requirements for these phases are presented in Clause 9.

For conversion and re-use of existing semi-submersibles, see Clause 15.

Examples of special areas for semi-submersibles are given in A.12.1.

12.2 General design criteria

12.2.1 General

When the upper (deck) structure is required to be buoyant for a particular operating or temporary phase, or to meet stability requirements, consideration shall be given to the structural effects of the resulting actions. The effects resulting from variations in mass distributions during operating phases shall also be accounted for in the structural design.

Variations in stresses due to full/empty action combinations of pontoon tanks, including storage tanks if relevant, shall be explicitly accounted for when considering logical combinations of global and local responses in the design. In ring pontoons, the global effects of variations in pontoon tank loadings provide a significant contribution to the controlling stress components in the upper and lower flanges of the pontoon structural girder. If it is intended to dry-dock the semi-submersible, the bottom structure shall be strengthened to withstand such actions.

The stability of the structure during all free-floating pre-service phases shall be investigated. Examples of pre-service phases are the following:

— fabrication and outfitting;

— float-on and float-off from the deck of a transportation vessel;

— wet tow of the floating structure;

— hull/deck mating operation;

— ballasting down/up from the pontoon draught to a specified column draught.

12.2.2 Limitations

Where limiting design criteria apply when changing from one phase to another phase (e.g. from a transit phase to an operating phase), these shall be clearly established and documented.

12.2.3 Damage tolerance

For braces critical to the integrity of the structure and exposed to accidental damage, the strength of end connections shall be greater than the strength of the brace.

Braces located underwater shall be watertight and shall be fitted with a leak detection system to make early crack detection possible.

When configuring the upper (deck) structure, consideration shall be given to addressing the consequences of the loss of a primary structural component as the result of an accidental event (e.g. collision, fire or explosion).

The overall integrity of the semi-submersible shall be assessed for the loss, in turn, of individual braces, if any. This situation shall be considered as an ALS and all relevant factors set to unity (see 9.7.3.2, 9.7.3.3, 9.7.4.2 and 9.7.4.3).

12.3 Structural strength

12.3.1 Critical connections

Particular attention shall be given to structural continuity, fatigue resistance and detailing in locations of stress concentrations, in relation to, for example:

— critical structural connections (including brace, pontoon, column and hull connections);

— openings (including moonpools).

12.3.2 Structural detailing

In design, particular attention shall be given to structural detailing and requirements for reinforcement in areas that can be subjected to high local forces, such as:

— lower deck structure subject to wave impact (including column run-up effects);

— mooring and riser attachments;

— areas prone to accidental damage.

13 Spars

13.1 General

For spars, this clause supplements the general requirements and guidance provided in Clauses 9 and 10.

Structural design shall, as a minimum, conform to RCS rules or equivalent written specifically for spars. National regulations also apply, where they exist (see 5.4).

RCS rules do not normally include specific structural design requirements for the construction and removal phases of an offshore floating structure. The general principles covering the design requirements for these phases are presented in Clause 9.

For re-use of existing spars, see Clause 14.

Examples of special areas for spars are given in A.13.1.

13.2 General design requirements

13.2.1 Model testing

Model testing or validated software should be used to evaluate, as a minimum, the following:

— upending;

— in-place ULS conditions.

Hull upending analyses should be confirmed by validation with relevant tank model tests. The upending procedure should be analyzed to assess design global moments and maximum hydrostatic pressure heads for the initial flooding stage. This is normally undertaken utilizing quasi-static analytical procedures. Time domain dynamic analyses should be undertaken to simulate the response during the free flooding stage. Shear force and bending moments due to hydrostatic and hydrodynamic actions occurring during the upending operation shall be evaluated.

Model testing, if performed, shall be in accordance with 8.12.

The first phase of the upending of a truss spar is a free-flooding step. The upending is completed by pumping water into the lower compartments of the hard tank. This is a stable and static operation. If upending model tests are performed, special attention should be given to the proper scaling of the flooding openings and compressibility of the trapped air.

13.2.2 Static equilibrium position

When determining the static equilibrium position, account shall be taken of significant variations in the specific gravity of the seawater over the height of the hull.

Account shall be taken of set-down effects, where relevant.

13.2.3 Global action effects

Current action effects can dominate the design of certain structural components. Accordingly, the range of 100-year return period design situations to address in accordance with 6.3.2 shall include situations in which current is the dominating metocean component.

Evaluation of global response shall include consideration of the following:

— added mass and drag action effects from strake systems;

— mass and stiffness of moorings and risers;

— inertia action effects resulting from motion of the spar;

— second-order bending effects (*P*-*Δ* effects) including non-linear amplification of deflections due to rigid body rotation and second-order bending;

— diffraction effects resulting from large volume underwater elements.

13.2.4 Local action effects

Lateral and angular motions of a spar generate wave motions within the moonpool/centre-well, if any, and in ballast/liquid tanks. Such local actions resulting from these motions shall be considered with respect to both ULS and FLS.

Actions resulting from resonance effects of the water column in the moonpool/centre-well locations shall be considered.

Wave run-up effects shall be evaluated, where relevant.

External appurtenances (including strakes) shall be evaluated at ULS and FLS accounting for local drag and inertia action effects.

13.3 Structural strength

13.3.1 Critical interfaces

Particular consideration shall be given to ULS and FLS of critical interfaces, such as the following:

— hull/topsides interfaces including second-order (P-Δ) bending effects (see 9.13);

— structural brace (truss) connections;

— riser/hull interfaces;

— fairlead/bending shoe design (see 9.8.6 and ISO 19901-7);

— interfaces at abrupt changes in stiffness (e.g. skirt/tank and truss/tank transitions).

Riser/keel interface design shall consider riser entry angles, bending and axial stresses, and wear. Detailed FE analyses of riser/hull interfaces shall be undertaken when evaluating both static and fatigue strengths. A wear analysis of the riser/keel interface shall be performed, as appropriate.

Critical interfaces at relatively deep draughts, being less accessible or inaccessible, should be configured for relatively low limit state utilizations. Alternatives to using relatively low limit state utilizations for deep draught critical items include better materials, full penetration welds, more thorough fabrication inspection, and/or more refined FE models.

13.3.2 Fatigue

The fatigue analysis of riser/keel guide frames shall account for interaction between the risers and the guide frame including the effect of "sticking" of the risers against the guide frame, where relevant.

13.3.3 Structural details

In general, hull longitudinal stiffeners (those running the length of the hull) should be continuous at the intersection with horizontal structural components (e.g. decks, frames, ring stiffeners, etc.). As a minimum, in the splash zone such penetrations should have double-sided "soft" brackets.

14 Shallow-draught cylindrical structures

14.1 General

For shallow-draught cylindrical structures, this clause supplements the general requirements and guidance provided in Clauses 9 and 10. In addition, some of the requirements for ship-shaped structures given in Clause 11 apply.

Structural design shall, as a minimum, conform to RCS rules or equivalent, written specifically for shallow-draught cylindrical structures or, alternatively, ship-shaped structures. National regulations also apply, where they exist (see 5.4).

Shallow-draught cylindrical structures often provide storage and transfer facilities for produced oil as well as support for oil processing facilities. It is important therefore to consider in the design the variations in loading accompanying different levels of crude inventory and the impact of additional systems and equipment necessary for the safe storage and transfer of crude oil.

Sufficient loading conditions for all anticipated pre-service and in-service conditions shall be determined and analyzed to identify the critical design cases for the hull strength. This should include fully laden, light ballast, and a mix of representative operational conditions (including repairs or inspection).

Operational conditions should include, as appropriate, asymmetrical tank loading cases. Riser and mooring tensions shall be included in the action combinations. The adequacy of the hull structure shall be verified for all combinations of static and dynamic actions. Consideration should be given to static and dynamic actions induced by process and utility equipment on the deck.

Examples of special areas for these structures are given in A.14.1.

14.2 General design criteria

14.2.1 Collision protection

Consideration shall be given to the need for suitable collision protection dependent on an assessment of the collision risk at a particular geographic location. National regulations also apply, where they exist.

Shallow-draught cylindrical structures that store oil shall conform to IMO MEPC/Circ.406 requirements related to protection from the effects of collision. More details can be found in A.11.2.1.

14.2.2 Deckhouse requirements

Living quarters, lifeboats and other means of evacuation shall be located in non-hazardous areas and shall be protected and separated from areas containing production facilities, oil storage, riser terminations and from the flare tower. Reference can be made to RCS rules or equivalent for definitions of hazardous and non-hazardous areas.

Positioning and arrangement of deckhouse structures shall conform to IMO requirements and RCS rules or equivalent. National regulations also apply, where they exist.

Minimum scantlings of deckhouses shall conform to RCS rules or equivalent, accounting for location on the hull, as well as green water and wave impact.

Consideration shall be given to blast wall requirements and passive/active fire protection, depending on the distance between the deckhouse and hazardous equipment as well as the conventional cargo pump room, and on the outcome of an explosion analysis.

14.2.3 Global response

Viscous effects can govern the global response of the floating structure in certain conditions. Global viscous actions should be modelled accurately when evaluating these conditions and included alongside potential theory and inertia effects.

Accurate modelling of viscous effects is important to establish correct hull loading due to radiation and design motions and accelerations.

14.2.4 Local action effects

The relative fluid motions around damping boxes generates viscous effects which can dominate local loading. Such local actions should be considered with respect to both ULS and FLS.

Slamming actions, particularly on flared sections on the hull, should be considered.

14.2.5 Model testing

Model testing or validated software should be used to evaluate and quantify viscous effects on the hull, slamming actions and second order forces. Model testing, if performed, shall be in accordance with 8.12.

14.2.6 Temporary phases

14.2.6.1 General

For shallow-draught cylindrical structures, temporary phases can be critical. The following key phases should be taken into account.

14.2.6.2 Fabrication site activities

The following design situations should be addressed:

— fabrication method;

— docking condition;

— loadout;

— tank test conditions (e.g. at dock or at quay side);

— mooring at quay side;

— topsides integration.

14.2.6.3 Transit/transport conditions

The condition of the structure during transit from the hull fabrication yard to the integration yard, where the floating structure is assembled, and from the integration yard to the offshore installation site, should be carefully evaluated.

Transport is normally performed by a dry tow on a heavy-lift vessel or wet tow by tugs. In the case of dry tows, the cribbing arrangement can be critical.

During transit, special attention should be paid to items such as flare booms, crane pedestals, bilge keels, riser porches, etc., which are subjected to motion-induced loading and/or slamming. The supports of process and topside equipment should be designed to resist the forces generated by motions and accelerations.

14.2.7 In-service conditions

14.2.7.1 ULS

During normal operation at site, the structure alternates between maximum and minimum operating draughts. The cargo, utility and ballast tanks are generally filled and emptied in accordance with the operational philosophy and the MOM.

The most severe operating scenario shall be evaluated. This involves combinations of tank filling and changes of draughts to identify critical design situations. These typically are full cargo tanks at shallow draught or empty cargo tanks at deep draught. A critical load matrix shall be established.

When considering extreme and abnormal metocean and ice conditions, partially-filled tanks can also generate critical design situations in addition to those identified above.

In addition to normal operating conditions, other tank loading conditions, such as inspection, repair and tank testing, should be considered as temporary phases and taken into account in accordance with 9.2.3.

14.2.7.2 ALS

Typically the structure can be subjected to accidental actions as a result of incorrect operation, technical failure or abnormal weather conditions. The following accidental design situations are of particular concern:

— accidental heeling;

— collision;

— abnormal metocean and ice conditions;

— sea ice and glacial ice.

14.3 Structural strength

14.3.1 Global strength

The structural analysis model of hull should normally include the entire hull structure in a global model with topside or simplified topside model to ensure correct representation.

The level of detail of the global model should be sufficient to determine global stresses in the hull structure from metocean actions and ice actions, tank filling and topsides actions. Secondary structures, such as utility tanks and supports of minor equipment, need not be included in the model. Mesh size should normally be in the order of stiffener spacing. Particular attention shall be paid to correct representation of circumferential stresses and radial stresses in the hull structure.

Structural verification, i.e. yield and buckling, of the main structural systems and components can be based on the global analysis model and shall be performed in accordance with Clause 9. When local peak stresses identified by refined FE analysis in areas of pronounced geometrical change lead to excessive utilization ratios or nominal usage factors, or inadequate safety factors, the structure can be deemed fit-for-service provided plastic mechanisms do not develop in the affected or adjacent structure.

14.3.2 Local strength

The hull structure shall be verified for local yielding and buckling of plates and stiffeners in accordance with RCS rules or equivalent. The assessment shall include all relevant actions including sloshing and slamming as applicable.

In addition to the requirements of 9.8.6, particular attention should be given to the special areas listed in A14.1.

14.3.3 Capacity verification

Buckling capacity shall be verified in accordance with Clause 9.

14.3.4 Fatigue

Fatigue analysis should be performed using spectral fatigue methods in accordance with Clause 10. Particular attention should be paid to the details listed in A14.1 as their performance can differ from that found from experience with other types of floating structure.

14.4 Damage stability

The following definitions apply when assessing damage stability (see 16.5) for shallow-draught cylindrical structures:

— length (L) = breadth (B) = largest diameter between maximum and minimum operating draughts;

— “radial” replaces “transverse”;

— “tangential” replaces “longitudinal”.

15 Conversion and re-use

15.1 General

This clause addresses conversion, modification and/or re-use of existing floating structures. Issues addressed include the following:

— minimum design, construction and maintenance standards;

— pre-conversion structural survey;

— effects of prior service;

— corrosion protection and material suitability;

— inspection and maintenance.

The considerations and requirements stated of this clause are in addition to those of Clauses 9 to 14.

Examples of existing floating structures that have been converted for production include:

a) semi-submersibles, such as drilling semi-submersibles, construction and accommodation vessels, and multi-service vessels;

b) monohulls, such as drill ships, tankers and barges.

Major aspects associated with conversion/re-use include the structure’s original design and BOD (i.e. design criteria, methodology, standards, etc.), age, condition, maintenance and operational history, as well as the design, inspection and maintenance requirements for the converted structure.

The relative importance of these aspects is influenced by the structure’s intended service, strength, fatigue and redundancy requirements, and regulatory/certification requirements.

15.2 Minimum design, construction and maintenance standards

Structures that have been classed by a RCS and certified by a regulatory agency may be converted. Existing structures designed, constructed and maintained using other rules may be used for conversion provided that these rules are fully documented and can be established as equivalent to the rules of a RCS.

The converted structure shall be designed in accordance with Clauses 9 to 14, including appropriate references to current RCS rules or equivalent. In those cases where current RCS rules are inconsistent with the rules under which the existing structure was originally classed and conformity with current rules would be impractical, then an assessment should be performed to confirm that the converted structure’s design meets the intent of the current rules and regulations.

Major deviations between the requirements in effect at the time of the design and construction of the existing structure and current requirements shall be identified, and the acceptability for the deviation shall be fully evaluated on a fit-for-service basis.

15.3 Pre-conversion structural survey

The existing structure shall be subjected to a comprehensive structural survey prior to, or during, conversion. This pre-conversion survey shall establish the actual condition of the structure, including the existence of fatigue-related problems (i.e. cracking), scantling dimensions and the level of corrosion wastage. The survey results shall be used as the basis for the site-specific structural assessment of the converted structure and shall also provide the baseline condition for future in-service inspections.

The pre-conversion structural survey shall cover, to the extent practical, all structural components and details considered part of the main (or primary) structure and their intersections. As a minimum, the existing structure should be subjected to a detailed CVI in accordance with the renewal (or special) survey requirements of an RCS or equivalent, supplemented by the requirements of the appropriate requirements in Clause 19. The survey shall also include a significant level of non-destructive testing (magnetic particle inspection, eddy current testing, ultrasonic testing, alternating current field measurement, etc.) to identify fatigue-related problems and to determine the actual scantlings. Structural components and details having previous service problems (e.g. fatigue-related cracking, corrosion wastage) and been repaired or modified shall be inspected in detail (using non-destructive testing) to establish the adequacy of the prior repairs or modifications.

15.4 Effects of prior service

15.4.1 General

An existing structure generally suffers fatigue damage in-service as well as steel wastage due to corrosion (or wear); it can also experience structural damage. Criteria for steel renewal due to corrosion shall be established and agreed with the owner based on minimum scantling requirements and future anticipated corrosion rates. All damaged and/or corroded main (or primary) structure not meeting the agreed criteria shall be repaired or replaced during conversion. Other significant structural damage (e.g. dented components) shall also be repaired. Guidance for determining the extent of fatigue-related damage associated with ship-shaped structures and semi-submersibles is provided in 15.4.2 and 15.4.3, respectively.

The recommended approach to account for the effect of prior service in the site-specific fatigue analysis can depend on the age of the structure, the extent to which the structure's previous operational history is known, the type of structural repairs and modifications made to structural components and details, and the results of the pre-conversion structural survey discussed in 15.3. The minimum allowable design fatigue life, accounting for the structure's prior service, is stated in 15.4.4.

15.4.2 Ship-shaped structures

The main (or primary) structure of a ship-shaped structure comprises longitudinally stiffened bottom, side and deck plating and transverse and longitudinal bulkheads and frames. The critical areas associated with these structural components are typically located where these components intersect. Additionally, existing structural components connecting with, or adjacent to, new structural components (such as the turret structure, drilling moonpool and external turret/mooring connections) shall also be considered as critical areas.

The principal effects of prior service associated with ship-shaped structures relate to material wastage due to corrosion. Fatigue damage of existing ship-shaped structures tends to remain localized, and generally does not affect the structure's integrity, unless fatigue-related problems have not been identified and repaired. The latter could occur if the original ship-shaped structure had traded extensively in severe environments or if a design deficiency has resulted in cracking in repetitive details (e.g. side-shell connections or bottom longitudinal to bulkhead connections).

Structural strength and fatigue, inspection, maintenance and repair are particularly important for ship-shaped structures converted to floating platforms. Additionally, the converted structure can undergo major modifications, such as incorporating an internal turret or a drilling moonpool. Therefore, site-specific strength and fatigue analyses on the converted structure shall be conducted. These analyses shall also account for any reduction in scantling dimensions identified in the pre-conversion structural survey, if the affected component has not been repaired or replaced.

Differences in the specific density of the oil (assumed in the original tanker design) and produced oil stored in the converted structure, can impose weight limitations on the topsides, turrets and other items to be installed to complete the conversion. Consequently, when determining the weight of stored crude oil, the anticipated specific gravity of the produced oil shall be taken into account.

15.4.3 Semi-submersibles

The intersections of the main (or primary) components of semi-submersibles are typically highly stressed and/or prone to fatigue damage. These areas shall be subjected to site-specific strength and fatigue analyses. The analyses shall also account for any reduction in scantling dimensions identified in the pre-conversion structural survey, if the affected component has not been repaired or replaced.

15.4.4 Fatigue damage from prior service

An assessment of the fatigue damage sustained by the existing structure before conversion shall be conducted.

The accumulated fatigue damage shall be assessed via fracture mechanics/crack growth studies and/or detailed fatigue analyses of prior service, and the results of the structure's inspection histories.

Details with the highest fatigue utilizations should be inspected for fatigue cracks before service.

Remaining fatigue damage shall be determined in accordance with Formula (10) using the fatigue damage factors specified in Table 5. In some cases, as specified in A.15.4.4, the fatigue damage factor associated with prior service may be reduced from that specified in Table 5.

15.4.5 Repair of defects, dents, pitting, grooving and cracks

Structural defects, damage, cracks and any condition that can lead to structural degradation shall be corrected (e.g. crop and replace). Defects deemed acceptable shall be dealt with by a tailored monitoring/inspection programme during and after conversion.

15.5 Corrosion protection and material suitability

15.5.1 Corrosion protection

Wastage due to corrosion is a major consideration for all types of steel structures operating in the marine environment and requires special consideration for conversion. The level of corrosion wastage is dependent on the environment (i.e. sea water, fuel oil, cargo oil, tank blanketing system, etc.) that the steel has been (and in future can be) exposed to, the type of CP system used and its associated maintenance.

The existing structure's corrosion protection system can require replacement or upgrading for conversion. The specific requirements depend on the system's previous performance history and present condition, the condition of the existing structure, the refurbishing, repair and maintenance programmes to be conducted during conversion and throughout the operating life.

15.5.2 Material suitability

The steel grades used in an existing structure shall generally be considered acceptable if the vessel/floating structure was designed and constructed in accordance with RCS rules or equivalent, as stated in 15.2. However, conversion can result in the existing steel not meeting grade requirements in specific locations, such as in highly-stressed and/or fatigue-prone areas (or structural details), or for low-temperature applications. In these locations, such material shall be replaced if found not to meet specific requirements for fracture toughness, ductility, through-thickness properties, and weldability.

Consideration should be given to conducting basic materials tests on a few representative samples taken from the existing hull structure, to clearly establish the properties of the material.

15.6 Addition of new components

Attention shall be paid to the demands of the future service and to the compatibility between the existing system and new components.

When thrusters are added during conversion, structural analysis shall include vibration analysis of the foundations (see 9.5).

15.7 Inspection and maintenance

Comprehensive structural inspection and monitoring programmes shall be developed for the converted floating structure (see 5.8 and Clause 19), taking into account inspection and maintenance limitations for a permanently moored structure.

16 Stability, watertight integrity and compartmentation

16.1 General

Adequacy of stability of a floating platform shall be checked for all relevant in-service and temporary phases. The assessment of stability shall include consideration of both intact and damaged conditions. When recognized standards are utilized in the assessment of damage stability, it should be ensured that the basis for the design situations and criteria adopted in the standard is compatible with the accidental event being addressed.

For intact and damage stability, floating platforms shall satisfy all applicable IMO requirements, see A.16.1.

For stability verification, consideration shall be given to relevant detrimental effects, including those resulting from the following:

— metocean actions, such as wind, wave (including green water effects), snow and ice accretion, and current;

— applicable damage scenarios (including owner-specified requirements);

— rigid body motions;

— free-surface effects in cargo and ballast tanks;

— boundary interactions, such as mooring and riser systems.

The effects and consequences of accidental damage to the hull shall be considered. Manned control rooms shall be positioned to be above the waterline as determined for all damage conditions.

The effect of the extent of damage from penetration or flooding of one or more compartments shall be assessed in terms of stability, strength and impact on the environment, as outlined in IMO codes and RCS rules (see A.16.1). The location of the down-flooding points is critical in stability assessment. If site-specific ULS wind speeds exceed IMO requirements (see A.16.1), stability should be determined based on the site-specific data.

16.2 Inclining test

An inclining test shall be conducted when construction is as near to completion as practical to accurately determine the floating platform's weight and position of the centre of gravity. The test shall be conducted in accordance with an approved procedure.

Changes in weight conditions after the inclining test shall be carefully accounted for. Consideration shall be given to the conduct of a deadweight survey on a regular interval to ensure consistency between recorded and actual weight conditions. Where a significant discrepancy is found between the two conditions, consideration shall be given to carrying out a further inclining test.

In some cases, it is not feasible or practical to carry out an inclining test because of the floating structure's configuration. In such cases, the floating structure's lightship weight and centre of gravity should be determined by a combination of a thorough lightship survey and calculations.

In the case of conversion of a vessel (e.g. a MOU or a tanker) into a floating platform, consideration should be given to conducting an inclining test prior to conversion as a means of assessing the initial condition. An inclining test shall be conducted after a major conversion.

16.3 Compartmentation

The hull of a floating structure shall be subdivided into a number of compartments to meet strength and stability requirements and to minimize consequence of damage, pollution risks, and possible risks of loss of the platform in the event of damage.

For structures with storage, additional subdivisions can be required in the design of the hull to account for ballast water needed to control hull stresses (in all design phases) and for the storage of process-related liquids.

Additional requirements can arise from IMO regulations where oil is stored in the hull and in respect of the load line.

16.4 Watertight and weathertight appliances

Requirements for watertight and weathertight integrity shall be in accordance with IMO requirements (see A.16.4).

As a minimum, watertight closing appliances shall be installed for those external openings up to the water levels corresponding to

a) an angle of heel equal to the first intercept between the righting moment and wind heeling moment curves in any relevant intact or damaged condition, and

b) the required air gap for deck clearance.

The number of openings in watertight structural components shall be kept to a minimum. Where penetrations are necessary for access, piping, venting, cables, etc., arrangements shall be made to ensure that the watertight integrity of the structure is maintained by means of appropriate design for the pressure and other action effects likely to occur in service and following damage (including wave impact effects). Closing appliances and their controls, indicators, actuators, power sources, etc., shall be arranged so that they remain capable of functioning effectively even in the damaged condition.

Openings above the waterplane in the damaged condition can be exposed to wave action and/or changes in the waterplane due to the dynamic response of the unit. Such openings should be weathertight.

Arrangements shall be provided to ensure that progressive flooding does not occur where individual lines, ducts or piping systems serve more than one watertight compartment or are within the extent of damage resulting from a relevant accidental event.

The arrangements of watertight electrical cable penetrations should be carefully considered. Cable penetrations in hull bulkheads shall be rated for the same pressure rating as the bulkhead.

Requirements for weathertightness and watertightness of decks, deckhouses, doors, vents, etc., are generally provided by applicable flag state and national administration regulations. In the absence of mandatory requirements, the applicable IMO regulations shall be used to provide design requirements.

16.5 Damage stability

If oil is stored in the hull, the extent of damage to be assumed in damage stability calculations for a specific structure at a particular geographic location, together with the applicable international codes and conventions, should be decided by the owner, in conjunction with the regulator. Guidance on damage stability is given in IMO MARPOL.

17 Mechanical systems

17.1 General

This clause addresses those mechanical systems that normally have a strong interface with the structural design of a floating structure and/or directly affect its use in offshore petroleum production operations. This clause should be regarded as complementary to already existing design rules and standards published by RCS and national authorities, which have well-developed design guidance for mechanical systems for ships and semi-submersibles, and to some extent for spars and other unique hull forms.

Mechanical systems of a floating structure can be broken down into the following main components:

a) hull systems, including bilge, ballast, cargo handling, stripping system, non-cargo liquid storage transfer, HVAC equipment, inert gas, crude oil washing, and tank sounding and venting;

b) topsides production and utility systems;

c) import and export systems, including cargo oil and material transfer;

d) fire protection systems.

The majority of mechanical systems required for topsides production operations and their support (e.g. utilities and accommodation services) are not addressed here. However, hull deformations due to cargo loading and discharge, metocean actions and ice actions can be an important consideration in designing structural support and piping flexibility for topsides systems (see 11.3.5). Furthermore, differences in typical marine standards used for design of hull systems, and offshore standards used for design of topsides production and utility systems, should be recognized and addressed in the design of system interfaces.

17.2 Hull systems

17.2.1 General

In addition to the specific requirements for hull systems, the following general considerations relevant to watertight integrity apply:

a) Every inlet or discharge port submerged at maximum operating draught should be fitted with a valve that is remotely controlled from a manned control room. Such valves should fail-closed unless overriding safety considerations require them to remain open. Systems that require their inlet/discharge valves to fail-closed should not share a common inlet/outlet with systems that require their valves to fail-to-set, i.e. remain in their operating position on loss of control power.

b) The status of valves, i.e. closed or open, designed to fail-closed or to fail-to-set shall not be affected by the loss or restoration of control power.

c) The status of a valve should be indicated at each position from which it can be controlled.

d) Valve status indicators should be independent of the valve control system.

17.2.2 Bilge system

17.2.2.1 General

The function of bilge systems is two-fold:

a) to serve as a drainage and discharge system for any fluids that have accumulated in the hull compartments and/or bilges other than tanks specially designed to contain liquid;

b) to serve as an emergency discharge system in case of accidental flooding, for securing safety of the structure and/or safety of personnel.

In its service as a drainage system, discharge of bilges overboard shall meet IMO requirements (see A.17.2.2).

Where drainage systems associated with hydrocarbon production interface with the structure's bilge systems, special care shall be taken to prevent migration of hydrocarbons to non-hazardous hull compartments.

17.2.2.2 Arrangement

Except for ballast, cargo and consumable tanks, all watertight compartments, passageways and machinery spaces shall be serviced by a bilge or a suitable drainage system. These compartments shall be drained by at least two bilge pumps, with the backup pump(s) capable of delivering 100 % of the design bilging capacity with any single pump out of service.

For all unmanned spaces with a potential for leaks with consequential effects for intact stability and/or damage stability, bilge alarms shall be provided.

Any hull compartment containing equipment essential for the operation and safety of the floating structure shall be capable of being pumped-out when the floating structure is in the worst case inclined (damaged) condition (i.e. at its maximum incline or list angle) as determined during the damaged stability analysis.

Spaces above deck, which can normally be drained by means of a drainage system, do not require a fixed pumping system.

If the bilge piping is tied into a topsides treatment facility, back flow into the bilge system shall be prevented.

Provisions shall be made to ensure that drains from hazardous areas are completely separate from drains from non-hazardous areas.

17.2.2.3 Valves

All distribution boxes and manually operated valves associated with the bilge pumping system shall be in positions which are accessible under normal circumstances. Where such valves are located in normally unmanned spaces below the assigned load line and are not provided with high bilge water level alarms, they shall be operable from outside the space.

Bilge alarms shall be provided for all unmanned spaces with valves below the load line unless they do not affect the normal stability and/or damage stability.

All valves in machinery spaces controlling the bilge suction from the various compartments shall be of the stop-check type and, where fitted at the open ends of pipes, shall be of the non-return type.

Valves in the bilge suction pipe connected to cargo or cargo stripping pumps shall be of the stop-check type.

17.2.2.4 Pumps

Bilge pumps shall be of the self- or automatic-priming type, and shall either be capable of continuous operation in the absence of liquid flow or be automatically switched on and off by a monitoring device at the bilge suction point. Bilge pumping capacity shall be adequate to remove the maximum liquid input from non-failure operations (e.g. service water wash-down, fire water from deluge or hose reels).

For machinery spaces containing equipment essential to safety, independently powered pumps shall be considered, with one of these supplied from an emergency source of power.

Each bilge pump shall be capable of generating a flow of water through the bilge main with a velocity of not less than 2 m/s. When more than two pumps are connected to the bilge system, their aggregate capacity shall be no less effective.

17.2.2.5 Piping

The cross-sectional area of the main bilge line shall not be less than the combined areas of the two largest branch suctions.

The internal diameter of branch suctions, d (in millimetres), from each compartment shall not be less than that stipulated by Formula (17), to the nearest 5 mm (but not less than 50 mm):

$$d = 2{,}15\sqrt{A_{\mathrm{w}}} + 25 \tag{17}$$

where A_{w} is the wetted surface area of the compartment, excluding stiffening components when the compartment is half-filled with water, expressed in square metres.

17.2.2.6 Chain lockers

Chain lockers, if provided onboard, shall be capable of being drained by a permanently installed bilge or drainage system or by portable pumps. Means shall be provided for removal of mud and debris from the bilge or drainage system.

17.2.2.7 Void compartments

Void compartments adjacent to the sea or to tanks containing liquids, and void compartments through which piping conveying liquids passes, shall be drained by a permanently installed bilge or drainage system, or, alternatively, by portable pumps or temporary hoses. The use of temporary arrangements should generally be avoided.

If portable pumps are used, two shall be provided, and both pumps and arrangements for pumping shall be readily accessible.

17.2.2.8 Bilge suction from hazardous areas

Hazardous and non-hazardous areas shall be provided with separate drainage or pumping arrangements.

Hazardous spaces typically requiring a bilge pumping system should include:

— the cargo pump room,

— cofferdams adjacent to cargo tanks, and

— other watertight compartments in areas considered hazardous either due to their location or to the equipment and systems housed within.

Adequate provisions shall be made for removal of fluid accumulation in the bilges of hazardous spaces. This shall be accomplished by means of a separate bilge pump, or eductor, or bilge suction from a cargo pump or cargo stripping pump. The pump and associated piping shall not be located in spaces containing machinery or in spaces where other sources of ignition are normally present (e.g. electrical/lighting equipment, machinery capable of sparking, fans).

Fixed or portable pumps with drivers and controls provided for hazardous spaces shall be suitable for operation consistent with the nature of the fluids to be transferred.

17.2.2.9 Special considerations for semi-submersibles

Chain lockers which, if flooded, could substantially affect the semi-submersible's trim or stability shall be provided with a remote means to detect flooding and a permanently installed means of de-watering. Remote indication of flooding shall be provided at the central ballast control station.

At least one of the general service bilge pumps and all pump room bilge suction valves shall be capable of both remote and local operation.

Propulsion rooms or pump rooms in lower hulls, which are normally unattended, shall be provided with two independent high-level detection systems.

17.2.2.10 Special considerations for spars

A fixed bilge system is not normally installed in hull void spaces. To remove any liquid accumulations in hull void compartments, void spaces shall be accessible to portable pumps. At least two portable bilge pumps shall be provided along with equipment to allow deployment in any hull void compartment not fitted with a fixed bilge system. These void compartments can also be drained by use of temporary hoses connecting valved bilge outlets from the void space to a valved inlet on the bilge suction header that feeds the permanent bilge pumps.

17.2.3 Ballast system

17.2.3.1 General

The ballast system serves numerous functions, including:

— adjustment of trim, draught and centre of gravity of the floating structure to maintain optimum stability and operating capabilities, and to improve response to metocean conditions,

— taking-on and discharging of ballast to adjust for the loading and discharge of cargo oil,

— dewatering of ballast tank compartments to facilitate inspection or maintenance, and

— damage control and change of centre of gravity.

17.2.3.2 Arrangement

Consideration shall be given to the ballast system's piping and control system arrangements during the design phase with regard to interconnection and proximity to cargo systems and tanks. The piping, as well as ballast piping passing through cargo tanks or connected to ballast tanks adjacent to cargo tanks, shall not pass through spaces where sources of ignition are normally present.

Ballast tanks that are not adjacent to cargo tanks, but which are connected, via the ballast system, to tanks that are adjacent to cargo tanks, shall be treated as the same level of hazard as tanks adjacent to cargo tanks. Thus, the ballast piping and pumps shall not be located in a machinery space in which a source of ignition is normally present, unless alternative measures satisfying RCS rules or equivalent are provided. Reference should be made to the RCS rules or equivalent for guidance on ballast pump location.

The ballast systems on all types of floating structures shall be capable of pumping from, and draining, all ballast tanks when the floating structure is on an even keel or listing within the range of inclined damaged conditions.

17.2.3.3 Valves

All ballast tank isolating valves shall be arranged so they remain closed, except during ballasting operations. If remotely operated valves are installed, a means of manual control shall also be provided, and the design of the control system shall consider the effects of loss of control power and ensure that uncontrolled transfer or loading of ballast water does not occur.

Provision shall be made for a readily accessible means of isolation of the sea chest and intake system, or any discharge below the waterline level.

Where remote operation is provided by power-actuated valves for seawater inlets and discharges for operation of propulsion and power generating machinery, power supply failure of the control system shall not result in opening of closed valves.

All valves and operating controls should be clearly marked to indicate the function they serve. Means should be provided, both locally and remotely, to determine whether a valve is open or closed.

17.2.3.4 Piping

Pipes shall be arranged inboard of the zone of assumed damage penetration, unless special consideration has been taken with regard to damage stability.

Piping systems carrying non-hazardous fluids should generally be separated from piping systems that contain hazardous fluids. Cross-connection of the piping systems is permitted where means for avoiding possible contamination of the non-hazardous fluid system by the hazardous medium are provided.

17.2.3.5 Special considerations for semi-submersibles

Emphasis shall be given to redundancy and reliability of the ballast system, its control and monitoring instruments and its equipment during all modes of operation. A single-point failure on any piece of equipment, or flooding of any single watertight compartment, shall not disable the damage control capability of the ballast system.

The ballast system shall be arranged to prevent the inadvertent transfer of ballast water. The system shall also be designed so that the transfer of ballast water from one tank to any other tank through a single valve is not possible, except when such a transfer does not adversely affect the stability of the semi-submersible.

Each ballast tank shall be capable of being pumped out by at least two power-driven pumps, arranged so that tanks can be drained at all normal operating and transit conditions. The ballast pumps shall be of the self-priming type or be provided with a separate priming system.

The system shall be capable of raising the semi-submersible within three hours, or as specified by the regulator where one exists, starting from a level trim condition at deepest normal operating draught, to the severe storm draught.

The ballast system design shall prevent uncontrolled flow of fluids from one compartment into another, whether from the sea, water ballast or consumable storage. Ballast tank valves shall be designed to remain closed except when ballasting.

Remote-controlled valves shall fail-closed, and shall be provided with open and closed position indication at the ballast control station. Position indication power supply shall be independent of control power supply, unless a 24 V direct current system is used for both.

The ballast system shall be arranged so that even with any one pump inoperable, it is capable of restoring the semi-submersible to a level trim condition and draught, when subject to the design damage situations.

Ballast pumps and controls should be designed for a range of differential hydrostatic head conditions, to avoid the possibility of damage due to excessive velocity or to cavitation. Depending on the net positive suction head (NPSH) requirement for the main ballast pumps, de-watering of the ballast compartments can have a separate stripping system for lowering the water level below the level attainable by the main ballast pumps. The stripping system can also serve as partial backup to the ballast system. Provisions should be made to de-water flooded machinery spaces, with consideration given to the inclined damage angle and available NPSH to the remaining pumps. Integrating seawater supply and ballasting functions into a common system should be considered, but the reliability of the ballast system should not be impaired.

Control systems should be provided to prevent accidental opening of flood valves for all modes of operation. Isolating of systems not in use should be considered.

17.2.3.6 Special considerations for spars

The ballast system on a spar is typically made up of a series of deep well or submersible pumps for deballasting (one installed in each ballast tank) and arranged to discharge directly overboard or to a common ring main and then overboard. Ballast water is pumped into the tanks via another pump that is arranged such that it can supply ballast water to all ballast tanks. Isolation valves are provided in the ballast supply line to each tank.

System arrangements other than these can also be acceptable, provided they conform to all applicable standards.

The ballast system shall be arranged so that even with any one pump inoperable, it is capable of restoring the spar to a safe condition (i.e. satisfying strength and stability requirements) when subject to the design damage situations.

17.2.4 Tank sounding and venting system

All integral hull tanks shall be provided with sounding tubes or other suitable manual means of determining the presence and amount of liquid in the tanks. The size of sounding pipes shall not be less than 38 mm in internal diameter. Sounding pipes shall be led as straight as possible from the lowest part of the tank to an accessible location. If sounding pipes terminate below the topmost watertight deck, for oil tanks they shall be fitted with a quick-acting self-closing valve, with a test cock underneath. Sounding pipes from other tanks can terminate with a valve or screwed cap. A striking plate should be mounted in the tank to prevent damage to the plating by repeated striking of the sounding rod.

All tanks, cofferdams, void spaces, tunnels and compartments not fitted with other ventilation arrangements shall be provided with vent pipes.

The arrangements of the tank structure and vent pipe shall be such as to permit the free passage of air and gasses from all parts of the tanks to the vent pipes. The vent pipes shall be arranged to provide adequate drainage. If overflows are used in conjunction with the tank vents, their design should prohibit fluids from flowing from one watertight subdivision to another in the event of damage. In general, vent pipes should terminate on the open deck by way of return bends. All vent outlets should be fitted with a permanently attached means of closure. This means of closure should be an automatic inflow-retarding device, such as a vent check valve, dependent on the position of the vent relative to the final waterline after damage.

The selection of tank vents and overflow locations shall consider damage stability effects and the location of the final calculated immersion line in the assumed damaged floating position. Tank vents and overflows shall be located so that they cannot cause progressive flooding unless such flooding has been taken into account in the damage stability assessment. In case of tank overfill with no alternate overflow locations, the pressure head corresponding to the maximum height of the vent pipes shall not exceed the maximum allowable static pressure of the tank.

Pump capacity and pressure head shall be considered when calculating the sizes of vent pipes. In general, for all tanks that can be filled by pump pressure, the cross-sectional area of the tank vents should be at least 125 % of the effective area of the filling line. If overflows are used in conjunction with the tank vents, then this criterion should be applied to the sizing of the overflow and a reduced vent size may be considered.

Recommended minimum sizes for vent pipes are

— 50 mm internal diameter for water ballast tanks and fresh water tanks, and

— 60 mm internal diameter for oil tanks.

NOTE The above recommendations are general, and the use of high capacity and/or high head pumps can require larger sized vent pipes.

The vent outlets from fuel oil tanks and cofferdams shall be fitted with corrosion-resistant flame screens having a clear area through the mesh not less than that required for the vent pipe. These outlets should be located in a position that minimizes the possibility of ignition of gases escaping from the pipe.

17.2.5 Cargo handling system

17.2.5.1 General

If oil storage is provided in tanks within the hull, a cargo handling system should be provided to serve the following functions, as appropriate:

— receipt and storage of stabilized crude oil from the production facilities;

— de-watering of off-spec stabilized crude oil in dedicated reception tanks;

— de-oiling of produced water and/or slops;

— internal transfer between cargo tanks;

— transfer of off-spec stabilized crude oil to the production facilities;

— transfer of an isolated stabilized crude oil parcel via the offloading system to an export vessel;

— simultaneous loading and offloading;

— allowing of regular tank washing operations;

— allowing of on-site tank inspection, maintenance and repair.

17.2.5.2 Atmospheric tanks

In atmospherics tanks, the oil volume stored has a free surface. Oil discharged from the tank is generally replaced by inert gas to maintain a safe condition (see 17.2.6.2). Gas or vapour evolved from the oil, or displaced during tank filling, is generally routed to a safe vent location or captured in a closed vapour recovery system.

Atmospheric tanks are usually fitted with crude oil washing (COW) systems. COW is valuable in maintaining a low level of solid/wax build-up in the storage tanks.

17.2.5.3 Water displaced tanks

In water displaced tanks, oil is stored in tanks maintained full of liquid by displacing removed oil with seawater. This approach, which has been used extensively in concrete gravity-base fixed platforms, reduces the extremes of hydrostatic head associated with empty and full tanks, which are particularly significant with deeply submerged tank locations. It also reduces the extremes of the floating structure's draught variation associated with full and empty tank conditions and is of greater significance to hulls having small waterplane areas such as column stabilized structures or spars.

With this type of tank, care should be taken to prevent accidental discharge of oil, particularly as an emulsion layer can build up at the oil/water interface. The water displaced when the tank fills up with oil is typically discharged to sea via a buffer separation tank, generally supplemented by an oil detection and/or clean-up system prior to discharge to ensure that the content of impurities in the discharged water.

Venting arrangements should ensure that tank pressure levels remain within the design values, and that any gas evolved from the oil is safely vented.

Adequate provision should be made to address possible wax and/or solid build-up within the tanks. Removal of any such build-up is generally not possible with this system, and special consideration of piping arrangements can be needed to prevent operational problems due to contamination/blockage, etc.

17.2.5.4 Arrangement

The cargo system shall allow sufficient isolation of tanks (e.g. double block and bleed capability) to allow entry by personnel.

The submerged tank valves shall be remotely operable from deck boxes on the upper deck or from a cargo control room. The use of fail-safe valves should be considered.

Cargo tanks can be fitted with heating coils to prevent wax formation and to maintain efficient flow characteristics for pumping.

The vent outlets from cargo tanks where the flashpoint of the cargo oil is above 60 °C and vent outlets from adjacent cofferdams shall be fitted with corrosion-resistant flame screens having a clear area through the mesh not less than that required for the vent pipe. These outlets should be located in a position that minimizes the possibility of ignition of gases escaping from the pipe.

The venting of cargo tanks where the cargo oil has a flashpoint below 60 °C should be accomplished by a closed venting system designed to ensure that the tanks cannot be subjected to excessive pressure or vacuum. On floating structures where an inert gas system is installed, means shall be provided to ensure adequate tank venting when a tank is isolated from the inert gas system.

17.2.5.5 Pumps

In selecting pumps to be used in the cargo system, care should be taken to ensure that the cargo transfer pumps are designed with consideration of in-service requirements (e.g. motions and frequency of offloading operations) and to minimize the risk of sparking.

17.2.6 Inert gas system

17.2.6.1 General

If oil storage is provided in tanks within the hull, an inert gas system should be provided to serve the following functions, as appropriate:

— control of constant design pressure in the cargo tank during all loading/unloading conditions;

— prevention of the ingress of oxygen into the tank area;

— purging of tanks of hydrocarbon vapours below the explosion limit range;

— control of maximum allowable oxygen content in the cargo tank area;

— enabling of gas-freeing of isolated tanks for personnel access while still being able to maintain tank pressure during loading and offloading operations;

— automatic control of produced gas in the event of upset or failure of product stabilisation.

The inert gas generating system shall be capable of producing dry inert gas with an oxygen content of less than 5 % by volume.

In addition to integral tanks, consideration should be given to supply inert gas to storage tanks or process equipment on the deck of the floating structure.

The inert gas and ballast systems should allow for the blanketing of a ballast tank in the case of cargo leakage.

Alternatively, as a means of reducing volatile organic compound (VOC) emissions on FPSOs, hydrocarbon gas blanketing may be considered in lieu of inert gas for controlling tank pressure and oxygen ingress and maintaining a non-explosive atmosphere in cargo tanks during normal operation.

17.2.6.2 Piping system

The piping system shall be designed to serve the following functions:

— transport of inert gas flow from the inert gas generating system via a central inert gas main and branch lines to each individual cargo tank;

— prevention of back flow from the inert gas main to the inert gas generating system by a deck seal arrangement or other suitable means of isolation;

— connection to a pressure/vacuum breaker to maintain the required design pressure in the tanks during normal operation;

— in some configurations, connection to the high and low pressure/vacuum breaker valves in a central stack to prevent the building of rapid overpressure;

— transport of purge gas from the inert gas generator via a main line and branch lines to a selected tank;

— connection to a ventilation stack with flame arrestor to release excess purge gas.

17.2.7 Crude oil washing system

COW systems should follow IMO requirements (see A.17.2.7).

An inert gas system shall be employed if a COW system is utilized.

17.2.8 Production vent/flare systems

Various vent system designs should be considered early in the floating structure's design stage. Since these systems can have significant effects on weight, wind actions and centre of gravity, it is important to establish realistic relief rates and the system's sizing criteria in the initial design phase.

Flaring from a floating structure, particularly one that provides oil storage, requires the following special considerations:

— The flare structures, vent stacks and booms should be designed for dynamic loading.

— Flaring can provide an ignition source in close proximity to a large volume of crude oil and/or hydrocarbon vapour.

— Export tanker loading operations can result in venting of hydrocarbon vapours relatively close to the flare.

— For weathervaning structures, the orientation of the floating structure is dependent on the combined wind and current actions, whereas only the wind affects dispersion of gas from a vent. Gas dispersion from a vent should be analyzed for a range of possible floating structure orientations.

Safety concerns resulting from flaring near stored crude or export tanker are amplified by the limited egress opportunities for personnel. When the flare tower is also used to support the inert gas venting system for hull tanks, careful selection should be made of the venting point with respect to the possible flare ignition source.

17.2.9 Electrical systems

Electrical systems for marine systems of a floating production structure should conform to RCS rules and national/international standards.

17.3 Import and export systems

17.3.1 General

In general, a floating structure imports produced fluids from subsea wells, surface wells, and/or other nearby structures, and exports produced fluids into a fixed or mobile transportation medium, such as a pipeline or tanker. In addition, solid and liquid materials, parts and supplies can be transported to/from the structure.

The type, size, scope, and limitations of a system designed to export produced hydrocarbons from a floating production structure generally depends upon the following basic considerations or parameters:

— floating structure size, type, production and discharge rate;

— type of export and transportation system;

— water depth and site-specific metocean and ice conditions;

— hydrocarbon characteristics and operating pressure;

— scope and arrangement of other field facilities;

— space available and manoeuvring room at site;

— applicable regulations, codes and standards.

Operating philosophy generally drives the selection of the type of export system.

17.3.2 Riser functions

Risers are fluid conduits between sea floor equipment and surface facilities. Riser system integrity includes both fluid and pressure containment as well as structural and global stability.

Risers usually perform one or more of the following specific functions:

— conveyance of fluids between the wells and the surface structure (i.e. production, injection or circulated fluids);

— import, export or circulation of fluids between the surface structure and remote equipment or pipeline systems;

— guidance of drilling or workover tools and tubulars to and into the wells;

— support of auxiliary lines and umbilicals;

— other specialized functions such as well bore annulus access for monitoring of fluids injection.

Risers on floating structures cover the full range of production, injection, drilling, completion, workover and exporting operations. Floating structures riser systems have additional requirements associated with operating multiple risers of potentially different types in close proximity.

Design of the riser system itself is outside the scope of this document. See A.17.3.2 for a list of references to standards and guidelines for riser system design.

Risers for importing produced fluids and/or exporting to pipelines are usually connected to some point on the hull structure or turret (typical of ship-shaped structures), or to the deck (typical of semi-submersibles and spars). Risers impose actions on the hull structure and can require local structures with receptacles for moment-reducing and/or tensioning devices. Local structures should be designed for the maximum static and dynamic actions and action combinations as specified by the riser system designer (see 9.8.6).

17.3.3 Export systems

17.3.3.1 General

Floating structure export systems generally comprise one, or a combination, of

— pipeline export system, and/or

— tanker transfer export system.

If no storage is provided on the floating structure, the export system generally consists of one or more cargo pumps and a metering system. In the case of storage, the tanks are often manifolded to a central pump room or, alternatively, individual pumps are provided within each tank (see 17.2.5). Consideration should be given to pump and metering locations and provision of an adequate structural foundation to support such equipment.

17.3.3.2 Pipeline export

Pipeline export systems can consist of a pipeline either to a remote facility or to a nearby offloading point. In the latter case, hydrocarbons are offloaded under low pressure from the floating structure to an export tanker through a separate mooring and offloading system (normally a single point mooring) connected to the floating structure via risers and subsea pipelines. The offloading system shall be located at a suitable azimuth and at a sufficient distance away from the floating structure to allow for safe approach, departure and weathervaning of the export tanker when moored. A risk assessment shall be conducted to consider suitable mitigation measures to avoid collision between the export tanker and floating structure.

A separate offloading mooring system is used where separation between the floating structure and the export tanker is important for safety reasons or in areas where space is too limited to allow safe tandem transfer.

Unless the fluids are first transmitted to nearby booster pumping stations or compression and treatment structures, the floating structure should have high pressure gas compression, gas and water treatment and high-pressure pumping facilities, to condition the produced fluids for export.

For a turret-moored, weathervaning floating structure, a high-pressure swivel (sealed, rotatable joint or coupling) or wrap-around hose system should be specified. If the swivel or wrap-around hose is already planned for the incoming production stream, it can be equipped with multiple paths to also accommodate the outgoing export risers.

17.3.3.3 Tanker export

17.3.3.3.1 General

Hydrocarbons can be transferred from the floating structure directly into trading tankers of opportunity or into dedicated shuttle tankers and barges, for export or shuttling to onshore or offshore terminals. Transfer can also be effected through a transfer line from the floating structure to an unmanned buoy for subsequent transfer to the terminal by tanker.

Floating structure-to-tanker transfer can be accomplished using any one, or a combination, of the following transfer schemes:

— alongside transfer (side-by-side) (see 17.3.3.3.3);

— tandem transfer (see 17.3.3.3.4);

— direct transfer (see 17.3.3.3.5).

These transfer schemes can use a flexible offloading hose arrangement, an above-water hose boom, or a hard pipe swivel joint boom to transfer fluids to the offloading tanker. The flexible offloading hose can be left floating in the water or stored on a reel or any similar arrangement when not in use. The method of hose storage depends on the metocean conditions at a given location.

A dripless valve should be included as part of the system such that if quick disconnect is required no resulting pollution should occur.

Automatic valves should be set-up to close at a speed that minimizes the dynamic shock to the system. Also, it is important that good procedures and communications are developed between the offloading structure and the tanker to prevent inadvertent closing of valves.

17.3.3.3.2 Tanker stationkeeping systems

Key aspects of hydrocarbon offloading systems are the stationkeeping system to be used by the export tankers, and the offloading system to export the hydrocarbons from the floating structure to the tanker. Several options exist, to suit the various combinations of metocean and ice conditions and operating limitations (see A.17.3.3.3.2).

17.3.3.3.3 Alongside transfer

An alongside (side-by-side) transfer system consists of mooring equipment to secure the tanker alongside, fendering to prevent contact between the two hulls and a fluid transfer system using hoses or mechanical loading arms. Consideration shall be given to location of this equipment and associated local actions imposed on the hull. Limiting conditions for safe operation shall be specified in the MOM.

Excessive wave induced motions are a major cause of downtime for alongside transfer. The wave height limitation to allow safe mooring of a tanker alongside a floating structure can vary, depending upon the following factors:

— type of floating production structure;

— differences between floating production structure and export tanker sizes and hull shapes;

— relative wind, wave and current direction, speed and characteristics;

— weathervaning capability of the floating structure;

— adequacy of fenders and mooring equipment;

— transfer equipment design;

— manoeuvrability of the export tanker;

— limiting sea state for assisting tug operations.

Fenders used for alongside offloading should preferably be of a rubber, floating type filled with air or foam. Fender handling equipment should be designed for the largest size and heaviest type fender to be used. Floating structure hull strength in the fender area should be checked with respect to local buckling and yielding. Both the floating structure and its stationkeeping system should be designed to absorb the maximum mooring and impact actions caused by the export vessel, and at the same time, allow the export vessel to safely clear all mooring lines.

Consideration should be given to making both the stationkeeping and fluid transfer systems capable of rapid, remote safe disconnection in an emergency.

17.3.3.3.4 Tandem transfer

Tandem transfer consists of a mooring hawser arrangement and a floating or suspended transfer hose system. Mooring hawsers should be of suitable material and construction for the intended service and should be manufactured and tested in accordance with appropriate standards (see A.17.3.3.3.4).

The maximum peak mooring force anticipated in service shall be used to size the hawser. The maximum peak mooring force and set of metocean and ice conditions likely to cause such a force shall be clearly specified in the MOM. An appropriate means of monitoring the hawser force should be provided in the control room, along with a readout and warning of a high hawser force.

A suitable hawser termination and supporting structure shall be provided. The strength of the hawser termination and its supporting structure shall be greater than the breaking strength of the hawser.

Provision shall be made for supporting the hose termination and any associated hose storage equipment, such as a hose reel or horizontal storage tray.

The actual limiting wave height for mooring and loading operations depends upon the following:

— distance between floating structure and export vessel;

— size of export vessel and floating structure;

— crosswind and current conditions;

— floating structure stationkeeping system configuration and stationkeeping capabilities (fishtailing, surge control);

— manoeuvring space at the site;

— export tanker stationkeeping capabilities;

— stationkeeping support vessel bollard pull;

— degree of automation in the hawser and offloading connection;

— location of manifold hose connection;

— ability of operations personnel to safely access connection/disconnection areas.

17.3.3.3.5 Direct transfer

Direct transfer of hydrocarbons to DP shuttle tankers is effected by using a long loading hose without a mooring hawser between the shuttle tanker and the storage structure. The DP system on the shuttle tankers ensures stationkeeping within a pre-defined sector during transfer operations. During operation, tanker heading is normally not directly towards the storage structure.

17.3.4 Material handling

Material handling systems include provisions for supply vessels to moor against the floating structure's hull and/or DP adjacent to the structure, as well as lifting and transfer systems to transfer material to and from the structure and onboard the structure.

Due consideration shall be given to provision of mooring points and fendering arrangements for safe and efficient loading and unloading of material from supply vessels.

In arranging critical equipment, the risks posed by dropped objects shall be considered.

Material handling on a floating structure is inherently more dangerous than on land or on a fixed platform, due to the structure's accelerations/movements. This additional risk shall be considered when planning transport routes and designing lifting and transport equipment. Accelerations/movements of the platform shall be taken into consideration in all transportation of objects and in the design of transport equipment. Operational restrictions should also be considered depending on the type of platform, its motion characteristics, handling means involved and actual weather conditions.

Material handling below deck is complicated by transport routes through bulkheads and decks which are parts of the floating structure's watertight compartmentation. This shall be borne in mind when transport routes are being designed.

17.3.5 Lifting appliances

Lifting appliances can be split into two main groups:

a) offshore cranes used for material handling between the floating structure and another vessel, as well as internally on the floating structure;

b) other lifting appliances used solely for lifts internally on the floating structure.

The following considerations apply:

— lifting appliances should be designed to RCS rules or other recognized standards for offshore lifting appliances (see A.17.3.5);

— area layout shall be designed to allow the use of relevant handling equipment/facilities;

— all transport equipment shall have adequate brakes or other facilities to stop inadvertent motion;

— transport routes should lead to a lay-down area or at least to a point where pick-up by a deck crane is possible;

— lay-down areas shall have adequate fenders to stop swinging lifts causing damage.

For further information on lifting, reference can be made to ISO 19902 and ISO 19901-6.

17.4 Fire protection systems

17.4.1 General

Fire protection measures on a floating structure consist of structural fire protection, firewater systems, fixed fire-extinguishing systems and alarms.

Fire protection requirements are usually specified in national standards. Reference can also be made to ISO 13702 and RCS rules.

17.4.2 Structural fire protection systems

Systems for structural fire protection are either active (e.g. water spray) or passive (e.g. insulation or intumescent coatings). In selecting a system, the following points shall be considered:

— active systems can increase water system capacity requirements and require provisions for drainage for firewater runoff;

— passive systems provide protection but need not represent a minimum weight solution;

— requirements for access to structural components under passive coating system for inspection;

— testing requirements for active systems.

17.4.3 Firewater systems

All floating structures shall have a firewater system that supplies hose stations throughout the structure. The system shall have sufficient redundancy so that a fire in any space or open area would not render the system inoperative.

A minimum of two pumps, each capable of supplying 100 % firewater design capacity, with separate sources of power should be provided, supplying a fire main fitted with isolation valves so that, if a section fails, the failure can be isolated and the remainder of the system remains operational.

Other fire protection systems that can be supplied from the fire main include, but are not limited to

— foam systems, typically installed to protect produced hydrocarbon storage areas and helicopter decks,

— a process deluge system, and

— active structural fire protection (water spray) systems.

When sizing the firewater system, all high-consequence fire risk scenarios shall be considered and the system shall be sized to be capable of supplying all systems that would be required to operate simultaneously in any single fire risk scenario.

17.4.4 Fixed fire-extinguishing systems

Fixed fire-extinguishing systems are usually installed in machinery spaces, electrical equipment rooms and control stations. These systems include gaseous systems, sprinkler systems, water mist systems, foam systems and dry chemical systems, and can be manually actuated or automatically actuated by a fire detection system.

RCS rules and applicable national/international standards should be consulted for fixed fire-extinguishing systems for protection of the marine component of a floating structure.

Fixed fire-extinguishing systems for the industrial component of a floating structure (process facilities) shall be provided to address hazards associated with the process facilities in enclosed spaces containing process equipment, process-related machinery, hydrocarbon storage areas, electrical equipment rooms and other areas or spaces constituting a fire hazard.

17.4.5 Alarms

Flag and national administrations often have specific requirements for general alarm systems. In the absence of specific requirements in RCS rules or equivalent, IMO requirements should be conformed to (see A.17.4.5).

18 Stationkeeping systems

18.1 General

A floating structure shall be provided with suitable means of keeping its position at the specific site of intended operation. These means typically consist of a stationkeeping system connecting the floating structure physically to the seabed, or a DP system whereby the floating structure is kept in position by means of thrusters, or a combination of both.

The design of stationkeeping systems shall be in accordance with ISO 19901-7.

The type of stationkeeping equipment involved depends upon the type of floating structure and the chosen system solution.

18.2 Mooring equipment

18.2.1 Winches

Most floating structures use mooring winches of the same type. Alternatives for mooring winching equipment are covered in ISO 19901-7. One winch per mooring line should be used if the mooring system is to be continuously adjustable. An alternative is to have a group of mooring lines served by one common winch. This alternative should only be used if continuous adjustability is not required.

The winch pulling power should be specified when designing the mooring system, based on the worst allowable installation and/or adjustment weather conditions.

Mooring systems with fairleads should be capable of moving the chain/wire system sufficiently to make critical inspection of the moorings at the fairleads. Sufficient capability in terms of chain lockers or alternative means to secure the chain should be provided for this possibility.

The chain-bearing surfaces (e.g. winch chain wheel or chain jack latches) should be formed to suit the chain to be used.

18.2.2 Fairleads and chain stoppers

Chain stoppers on each mooring line shall lock the mooring line to the mooring attachment point once the required installation tension is reached.

Various types of fairleads or bending shoes should be considered and employed for routing of the mooring lines from the winches to the point where they leave the floating structure. Intermediate fairleads should be direction-fixed and the last fairlead before the line leaves the structure should be rotatable in at least one plane.

The chain-bearing surfaces (e.g. guide roller in wheel-type fairleads or chain-stopper latches) should be formed to suit the chain to be used.

Chain stoppers and fairleads and their supporting structures should be designed for a force equivalent to the minimum breaking strength of the mooring line (see also ISO 19901-7).

18.2.3 Monitoring and control equipment

Monitoring of mooring line tension or line angle shall be performed to detect line failure, for example, by instrumentation.

Local winch and chain-stopper control shall be specified, and can involve remote control and monitoring of winch, chain stopper and line parameters.

18.3 Turret

18.3.1 General

A turret mooring system allows a ship-shaped structure to rotate or weathervane around a geostationary turret that is physically moored to the seabed with a multi-line spread mooring system. A suitable bearing system shall be provided at the interface between the floating structure and the turret. A means for locking the turret to the hull and controlling the relative rotation should be considered, if relevant.

Turret moored structures can fall into two groups: freely weathervaning or those with heading control.

Some freely weathervaning structures have a locked turret, which either unlocks by active intervention or starts rotating when a pre-set yaw moment is attained.

Structures with heading control try to keep the bow into the waves to minimize the roll motion. An important aspect of these structures is the need for redundancy in the thruster system.

18.3.2 Turret structure

The turret structures supporting the mooring lines shall be designed for the maximum combined actions to which they can be subjected during service. The various situations to which mooring systems can be subjected are described in ISO 19901-7.

Fatigue damage due to repetitive actions shall be assessed.

Wave slamming effects shall be considered, where appropriate.

Suitable inspection methods shall be provided to allow inspection and maintenance of the turret structure during its design service life.

18.3.3 Bearing system

18.3.3.1 General

The function of the bearing system is to transfer the forces between the turret and the hull. The working conditions of the bearing system depend on the type of system, but unless the turret is of the disconnectable type, the system shall be designed for actions resulting from the ULS and ALS design situations, exposure to salt water and to ambient temperatures. If roller bearings are used, the bearing shall be adequately protected from seawater ingress by a suitable sealing arrangement and suitable lubrication arrangements. Contamination of the grease with dust should be expected.

18.3.3.2 Forces on the bearing system

The forces on a turret bearing system include, but are not limited to, the following action effects:

— mooring line and riser actions;

— buoyancy of the turret (varying with draught);

— inertia of the turret due to floating structure accelerations;

— weight of the turret (inclination due to roll and pitch to be considered);

— global deformation of the structure;

— friction-induced bearing and swivel torques;

— hog/sag structure deflections resulting in moonpool ovalization;

— effects due to entrapped water and added mass;

— effects induced by assembly tolerances and fabrication tolerances.

The bearing should be designed for the maximum combination of such actions as expected in service.

Local support structure shall be designed for maximum action effects and allowable deflections as specified by the bearing manufacturer.

Fatigue damage to bearings and local support structure due to repetitive actions shall be assessed.

Bearings shall be designed according to an internationally recognized standard (see A.18.3.3).

18.3.3.3 Alternative bearing designs

A number of different bearing types are used. The most common are

a) roller bearings based on rollers in sealed grease-filled units,

b) roller systems based on rails and large-diameter steel “bogie” wheels,

c) sliding bearings based on low-friction pads on spring supports sliding against a machined stainless steel surface.

On some turret systems, all the force is transmitted by one bearing while, on others, there are two, an upper and a lower bearing, with the lower bearing typically transmitting horizontal forces only. In some cases, the lower bearing, typically a rubber fender, is installed as a back-up for the mooring forces experienced in extreme conditions.

Where self-lubricating sliding bearings are used, expected wear rates and maximum total wear over the design service life shall be assessed using appropriate test data.

18.3.3.4 Inspection, maintenance and repair

The bearing system is vital for the safety and functionality of a turret-moored floating structure. Therefore, the bearing function shall be maintained during the life of the structure. Where possible, access for inspection and maintenance shall be built into the systems. Alternatively, a monitoring system shall be specified. In harsh metocean and ice conditions, the bearing system should be designed with redundancy to secure the function of the turret (force transfer and structure rotation) in any weather conditions. The system should be designed to facilitate inspection, maintenance and repair activities at location, with a minimum of downtime.

18.3.4 Turning and locking systems

Some turrets have a turning system for controlling the rotational position of the turret relative to the floating structure. For naturally weathervaning structures with roller bearing systems, the turning system is usually omitted. Generally, systems based on sliding bearings have a turret-turning system to avoid twisting the mooring lines and risers as the structure rotates to minimize the weather exposure. The system can be based on hydraulic cylinders and grippers, a rack and pinion system, etc.

The system performance is characterized by a turning force and a rotating velocity. The necessary force is determined as the maximum calculated turning resistance plus a safety factor. The necessity for a redundant system should be evaluated.

The necessary turning velocity depends on the maximum required rotational speed of the structure. This is a function of the expected heading change rate of the metocean actions or ice actions. Normally, a full rotation (360°) in one hour should be sufficient, but this shall be determined for each structure based on a site-specific analysis.

18.4 Disconnectable structures

18.4.1 General

Disconnectable structures (see 5.3.8) are a particular class of floating structures. In normal operations, their behaviour is similar to that of permanently moored structures. However, upon occurrence of a threshold event, a disconnectable floating structure is capable of rapid disconnection from its ancillary components (risers, moorings, etc.).

The rapid disconnection allows the floating structure to move to a location where the metocean or ice conditions are less severe than those existing or forecast at the original location, protecting the structure and/or other components (moorings, risers, etc.) from the extreme actions that would be experienced, if the platform remained connected.

18.4.2 Categorization

A structure shall not be categorized as disconnectable unless

a) a reliable forecast or identification of the threshold event is technically and operationally feasible,

b) disconnection is part of the operating philosophy, and the process is clearly defined in the platform's MOM, and

c) sufficient time and resources exist to safely disconnect the platform after the occurrence or detection of a threshold event.

18.4.3 Threshold events

Threshold events are the following:

a) the approach of a hazard (e.g. a tropical cyclonic storm, iceberg) whose intensity or magnitude exceeds predefined limits, and which might result in unacceptable consequences on one or more platform components (moorings, risers, structure, etc.);

b) the measured value of one or more response parameters (motions, accelerations, tensions, etc.) for the platform or for a key component (e.g. production riser) exceeds a predefined limit.

Basing the disconnection decision on a specific type of threshold event depends heavily on the operating philosophy adopted. In practice, type a) threshold events, with the exception of sudden hurricanes, can be systematically tracked with sufficient advanced warning.

Disconnection based on type b) threshold events can originate, for instance, from the desire to avoid exposing risers to winter storms, which are not easily detected and tracked. Another example would be failure of the stationkeeping system to maintain the excursions of the structure within prescribed limits.

In more general terms, the criteria for disconnection should represent a reasonable balance between setting the event limiting value too low (less onerous design situation but frequent disconnections) or too high (more onerous design situation but less frequent disconnections).

18.4.4 Operational mode

There are two distinct modes of operation:

— connected mode (see 18.4.5);

— disconnected mode (see 18.4.6).

Disconnection can involve complete disconnection of the structure from the riser system and from the mooring system, where applicable, creating two independent systems. The dependability of the disconnection process is critical to ensure that the floating structure does not experience actions exceeding pre-set limits. A safe and reliable operating procedure based on a risk assessment should be documented in the MOM. This procedure should be periodically tested and witnessed to ensure continuous safety and reliability of the system.

18.4.5 Connected mode

18.4.5.1 General

In the connected mode, the actions used in the design of the structure and other platform components should be derived from metocean and/or ice parameters at least as severe as those that characterize the threshold event. Threshold event data should include directionality information.

The operating procedure should ensure disconnection so that the threshold actions are not exceeded.

Production operations should be timely suspended ahead of the disconnection sequence to minimize environmental risk.

The details of the production suspension process should be included in the disconnection procedure.

18.4.5.2 Design criteria

For type a) threshold events, a watch circle should be defined that allows sufficient time to react to approaching hazards. The actions to be taken to disconnect (planned or emergency) should be based on the amount of time available to react to changing conditions. Recurring risk analyses during operation should be performed to ensure possible scenarios regarding the impact of an event are considered. In this case, the structure and other platform systems (risers, moorings, etc.) shall be designed for the restricted ULS (R-ULS) design situation associated with the structure remaining connected. This design situation relates to conditions either just below those associated with the threshold event or those for an event which does not provide the opportunity for disconnection (e.g. sudden hurricane).

For type b) threshold events, a feedback system monitoring responses of vulnerable components can be used, in conjunction with other operating parameters, as the trigger for the disconnection sequence. The procedures shall be clearly defined in the MOM. In this case, the design situation is determined by the conditions that result in the maximum allowable utilization. Once this maximum is reached, disconnection is effected.

For ship-shaped structures, riser and/or stationkeeping systems are typically the limiting components in the connected mode. The threshold conditions can include different combinations of wave, wind, and current values and associated headings.

The BOD should fully describe the limits of operation. A rosette of the combined riser and stationkeeping limitations should be developed to define the threshold event(s) that forms the basis of the floating structure design in the connected mode.

18.4.6 Disconnected mode

Once the floating structure is disconnected, the requirements for the behaviour of the structure and its structural integrity and stability depend on the type of platform under consideration.

The systems and components secured to the well site (risers, stationkeeping system, buoys, etc.) shall satisfy the ULS and ALS (abnormal) design situations for the site.

In the disconnected mode, a structure (with or without oil storage) with self-propulsion (e.g. a FPSO based on a converted tanker) shall conform to the requirements prescribed in the relevant documents listed in 5.4.2.

Structures without propulsion (with or without storage) shall conform, as a minimum, to requirements for an oceangoing tow in accordance with the requirements of ISO 19901-6.

For floating platforms that provide storage, the effects of sloshing due to the cargo and other liquids present at disconnection should be accounted for.

19 In-service inspection, monitoring and maintenance

19.1 General

This clause defines the requirements for structural integrity management of floating structures.

The extent of structure covered by these requirements includes the following:

a) the main structure, which can conveniently be divided into three zones — atmospheric, splash and submerged — bearing in mind that draught changes can occur for many floating structures;

b) all structural attachments, such as turrets, helidecks, flares, cranes and process decks, and their interfaces with the main structure;

c) structural interfaces between main structure and riser system;

d) non-structural attachments, i.e. any structural component that interfaces with the main structure and/or structural attachments whose deterioration can be detrimental to the integrity of the structure to which it is attached, including appurtenances and their connections (e.g. anodes or hydrophones);

e) CP systems.

Other major components of a floating platform (mooring systems, lifting equipment, riser systems, etc.) should also be subject to a similar regime of structural integrity management as that proposed here for the hull structure.

19.2 Structural integrity management system philosophies

19.2.1 General

Structural integrity shall be managed through a structural integrity management (SIM) system. The purpose of the SIM system is to provide a formal process for ensuring the integrity of the structure throughout its intended design service life on a fit-for-service basis.

The owner shall be the responsible for the effective implementation of a SIM system throughout the lifetime of the structure. Typically, the designer initiates the specification and development of the SIM system. This identifies how the structure is expected to respond and any limitations inherent in the design, whether in the form of loading limitations or metocean restrictions that apply to weather-sensitive operations. The fabricator provides the as-built details including final weights, CoG coordinates, material properties, welding records, etc. The operator augments this information with the results of inspection, monitoring and maintenance programmes, upgrades and modifications, etc., to be used as the basis for deciding on future requirements for these programmes.

The owner shall ensure that suitable arrangements are in place for monitoring and maintaining the integrity of a floating structure throughout its life cycle. Such arrangements include the following:

— planned maintenance and inspection of the structure;

— periodic assessment taking account of conditions in relation to original design expectations;

— assessment of damage or suspected damage;

— arrangements for repair work in the event of damage or deterioration.

Periodic assessments should reflect current good practice and incorporate advances in knowledge and changes in risk level, as appropriate. The frequency, scope and methods of inspection should be sufficient to provide assurance, in conjunction with associated assessments, that the integrity of the structure is being maintained.

Implementation of a SIM system can benefit significantly from the effective design for access for inspection, maintenance and repair both internally and externally.

Approaches to dealing with structural integrity management vary depending upon field life, type of floating structure and sophistication of local infrastructure. In turn, these factors can influence the philosophical approach to the specification of a SIM system, which can vary from one involving emphasis on the use of monitoring equipment to one with a preference for the extensive use of inspections. Irrespective of the philosophy, the resulting SIM system shall aim to maintain the integrity of the structure throughout its design service life.

The SIM process, as illustrated in Figure 1, consists of four primary elements which are implemented as a continuous cyclic process:

a) database development and data acquisition;

b) evaluation;

c) planning;

d) implementation.

The activities within each stage are not necessarily mutually exclusive and overlap of activities between the various stages occurs.

The process is based on an evaluation of the original design of the structure, inspection findings throughout the life of a structure, damage found through inspection, overloading, and changes in loading and/or use.

The results from the evaluation are used to develop and implement an effective long-term topsides and underwater inspection strategy. The SIM process is further detailed in ISO 19901-9[1)].

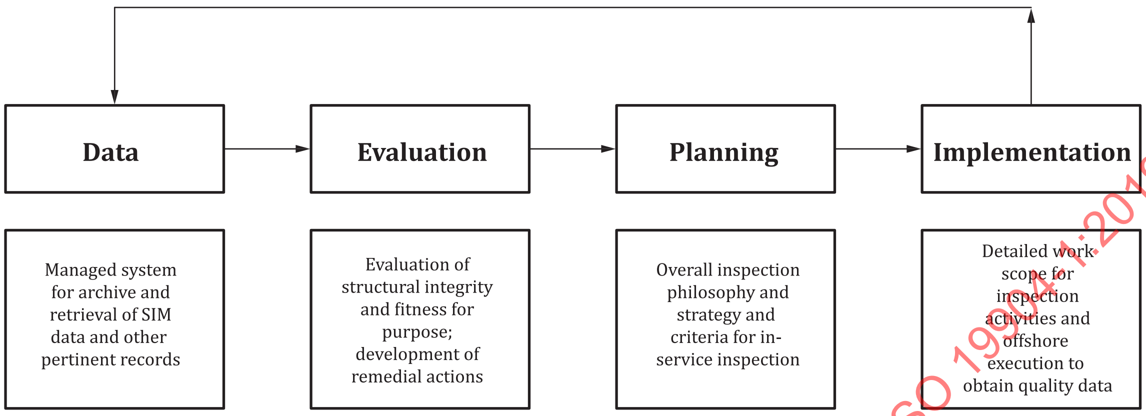


Figure 1 — SIM process

National and regional regulations can require a SIM system to be documented in a form suitable for verification or for review by a regulator.

19.2.2 Database development and data acquisition

The database shall consist of appropriate information relating to the life cycle of the floating structure, such as the following:

a) appropriate details of ownership, delegated authority, chains of command both onshore and onboard, operational procedures, emergency procedures, standby vessel arrangements, and other information consistent with IMO requirements;

b) details of the location (latitude, longitude, water depth), metocean details (wind, wave, current, tide, temperature, etc.), ice details, interpolated/extrapolated metocean and ice parameters for design;

c) design information, including the BOD and premise, the standards to which it was designed and other details (calculations and drawings, corrosion allowances, etc.), ideally in electronic format; areas, elements, components and other aspects of the design that were of concern to the designers or needed special attention during design should be well documented for ready appreciation and easy access by those developing and implementing the SIM system;

d) results of any risk assessment, FE analysis, etc., in which integrity- and safety-critical elements have been identified;

e) fabrication records including drawings, material certificates (including cross-referencing to location of the material within the structure), construction tolerances and coformity records, weld inspection records (ultrasonic, x-ray, etc.), anomalies, defects, rectifications, repairs, baseline survey;

f) in-service data from inspection and monitoring programmes including environmental data, addition (or removal) of equipment and facilities, and results of updated modelling and analysis;

g) for structures converted from other service, conversion records including structure surveys, structural inspection data, thickness measurements, condition of coatings and CP systems, weld inspection data, retrieval of design and fabrication information, service history, quality assurance (QA) records, materials datasheets, etc.

1) Under preparation. Stage at the time of publication: ISO/FDIS 19901-9:2019.

Particular attention shall be paid to special areas, such as turrets, helideck supports, fatigue sensitive zones, and areas where stress raisers or hard termination points exist. To ensure effective transfer of knowledge relating to special areas, the project team and the operation team shall clearly identify these locations, why they are critical (e.g. strength, fatigue, limited experience), whether or not they are inspectable, and what the assumptions are for ensuring fitness-for-service (e.g. increased strength or fatigue safety factors, load monitoring, inspection activities). Those special areas, where inspection or monitoring is assumed to be the primary method for ensuring fitness-for-service, shall be designated a structural critical inspection point (SCIP) and shall be included within the inspection plan. Interfaces between major structural components and assemblies usually fall into the category of SCIPs (e.g. erection butt welds, topsides supports).

The database shall be stored in a readily retrievable format. A master copy shall be kept ashore by the owner. A copy shall be kept onboard, either complete, or as in accordance with the owner's policy with a minimum of the key structural integrity information required by governing regulatory agencies.

19.2.3 Evaluation

Evaluation shall involve risk assessment, detailed analysis (including FE and cumulative damage analyses), and other forms of assessment as necessary — either of the overall structure or parts thereof where damage has arisen or occurred, or of special areas as appropriate. It shall be floating-structure-specific and site-specific and be based on a fit-for-service philosophy.

The evaluation shall be performed annually, as a minimum, and following accidents, repairs, modifications and reviews of inspection data, as necessary. The review of inspection data shall ensure the data gathered, e.g. by general visual inspection, have been reported, assessed, and incorporated in the database. The results of the evaluation shall subsequently be reviewed by the owner. A review shall also be performed following changes in ownership or regulations.

Risk-based inspection approaches can usually be of considerable benefit in the evaluation process and in the scheduling of inspections. Such approaches enable probabilities and risks to be explicitly evaluated and related back to target values.

Where a safety case regime is in effect through applicable national regulations, such safety cases can form part of the evaluation.

Evaluation shall consider continuing conformity with standards or RCS rules, as appropriate. National regulations also apply, where they exist. If any of these regulations change during the structure's life cycle, consideration shall be given to any appropriate corrective action.

In the case of a major conversion, typically involving a change of functionality or replacement or addition of new topsides modules, or even a complete mission change of the whole structure, the design of the structure is subject to the national regulations in effect at the time of the conversion.

19.2.4 Planning

Planning shall identify the processes, procedures and techniques required to be implemented as a result of evaluation to ensure that the objectives of the fit-for-service assessment are realized. Failure mechanisms, deterioration rates and the consequences of failure shall be considered, to determine the methods, frequency and scope of inspections, and possible repair and change-out procedures.

A "walk-through survey" can often assist in the pre-planning stage. This helps identify departures from the as-built drawings which shall be updated accordingly, locations for attachment points, etc.

It is important to identify and examine all damage situations for each floating structure system and subsystem.

Some detailed aspects to be considered in the planning stage are discussed in 19.3.

19.2.5 Implementation

Implementation refers to the detailed execution of the processes, procedures and techniques identified during planning and normally includes programmes concerned with inspections, maintenance and monitoring, as well as identifying the need to effect repairs and/or change-outs.

Some detailed aspects to be considered in the implementation stage are discussed in 19.4.

Data gathered during this stage, as well as information issued during the planning stage, should be incorporated into an update of the database. Update of the database should be undertaken at least once per year, unless justification is presented to extend this period.

The properties of crude oil can have an important influence on the structural performance of a floating production structure, particularly if modest-to-large quantities of crude oil are stored onboard. Since the properties of crude evolve as the field is depleted, the effects of these changes should be monitored and assessed throughout the life of the field.

19.3 Planning considerations

19.3.1 General

Structures and structural connections, the failure of which would incur serious consequences in respect of safety, environmental or economic loss, shall be subject to particular attention in the planning of inspection, monitoring and maintenance.

Appropriate requirements for underwater inspection shall be incorporated into the inspection and maintenance programme, as necessary. Methods of inspecting and maintaining the corrosion protection systems should be identified.

The inspection programme shall specify and describe all inspection activities to be undertaken during the design service life of the structure.

Particular attention shall be given to special areas, any known fabrication anomalies and defects, areas of suspected damage or deterioration, and repaired areas. The inspection schedule shall take into account locations highlighted by service experience and the design assessment. The scope of structural inspections shall include inspection of welds and parent material in critical areas.

19.3.2 Inspection categories

19.3.2.1 General

Inspections usually seek to identify symptoms and tell-tale signs that are evident on the surface and that originate from defects. In most cases, signs of damage are obvious before the integrity of the structure is impaired; however, it should not be assumed that this is always the case.

There are two categories of inspections:

a) scheduled inspections (see 19.3.2.2);

b) unscheduled inspections (see 19.3.2.3).

19.3.2.2 Scheduled inspections

Scheduled inspections are undertaken as a direct consequence of developing and implementing the SIM system.

A baseline inspection shall be carried out and recorded before the structure leaves the fabrication yard or before the structure is put into service. This shall establish the as-built condition of the structure. In practice, much of the inspection can be performed when the structure is in its final stages of building, conversion or outfitting. Inspection conducted on-site can be limited to quantifying the effects of installation.

Scheduled inspections shall be performed on a regular basis to monitor the condition of the structure and are normally performed during the implementation stage of the SIM system. Scheduled inspections basically aim to record departures of the structure from its condition at the time of the baseline survey. They can also record data that strictly form part of the baseline survey but which were missed or not collected at the time. Furthermore, they can record information relating to structural deterioration, accidents or significant occurrences of design situations that were not previously recorded, e.g. marine growth, coating deterioration, CP polarization and obvious damage.

Following the execution of modifications and/or repairs, they, together with any directly or indirectly affected elements or components of the structure, shall be inspected to record the details of such modifications and/or repairs and the effects on the structure. Such inspections shall record details and information consistent with the requirements of the baseline inspection.

19.3.2.3 Unscheduled inspections

Unscheduled inspections occur as a result of an unexpected event (e.g. an accident), exposure to a near-design-level event (e.g. a hurricane) or a change in ownership or platform location.

All accidents shall be assessed to identify appropriate inspection requirements. The extent of structure inspected shall be consistent with the severity of the accident. This shall, as a minimum, include the structure local to the contact or impact position as well as those more remote sections of the entire structure liable to be directly or indirectly affected. This requires recognition of the consequences of the local and overall dynamic response of structures to transient actions. Analysis can be necessary to identify the location and extent of such consequences.

In special circumstances, emergency repairs are necessary shortly after an accident has occurred and before any inspection has been conducted. In these cases, the emergency repairs can mask some consequences of the accident or induce further damage. Such consequences shall, if relevant, be documented, in addition to those arising from the accident itself.

Damage can arise as a result of a floating structure experiencing actions at, or near, the level of those considered in the design, such as the passage of large waves and/or wind gusts. In the case of such events, an inspection shall be conducted to identify the location and extent of any possible damage and/or other form of deterioration. Where damage is detected, an assessment shall be conducted to confirm the adequacy of the original design models and update these as required.

A change of ownership is likely to precipitate a revised approach to the way in which a SIM system database is evaluated, planned and implemented. The new owner shall verify the existing condition and establish an appropriate philosophy for inspection, maintenance and repair.

A change in the location of a structure can lead to the conduct of a revised baseline inspection or part thereof. In such a case, the database shall be updated to reflect, primarily, changes to the details of the location, the metocean and ice data, and the metocean and ice parameters for design. This then usually leads to a rerun of the evaluation stage of the SIM system to account for the effects of the transit from the previous site. Both of these can result in alterations to the conclusions of the planning phase of the SIM system.

19.4 Implementation issues

19.4.1 Personnel qualifications

All evaluations and the development and maintenance of the inspection strategy shall be performed by an appropriately qualified team of personnel who are

— familiar with relevant information about the specific structures under consideration,

— knowledgeable about corrosion and erosion processes and prevention,

— professionally competent in structural engineering, and

— experienced in offshore inspection tools and techniques.

These personnel should also be involved in any other phases of the structural integrity management cycle for the floating structure, for example, in subsequent risk assessments, where practical.

Only suitably qualified personnel, such as supervisors, inspectors, divers, ROV operators and data recorders, shall be assigned to perform inspections.

These persons shall be

a) qualified to relevant standards, and

b) trained, qualified and experienced in inspection and safe working procedures.

19.4.2 Equipment certification

Any equipment or measuring instruments used as part of a structural inspection and monitoring system shall be provided with current, valid calibration certificates, or a ready means of confirming that they remain within acceptable calibration standards.

19.4.3 Inspection programmes

The following types of inspections can be used when planning and implementing inspection programmes, some of which could be performed underwater:

— GVI general visual inspection;

— CVI close-up visual inspection;

— TM thickness measurements;

— WI weld inspection;

— FMD flooded member detection;

— CP cathodic protection system inspection.

Each of the inspection types is described in A.19.4.3 together with some of the techniques and types of equipment that can be employed to perform them. The list of techniques and types of equipment is not exhaustive and the owner may exploit other alternatives. The reliability, accuracy, precision and tolerance of the system, including the operating personnel, shall be established.

When developing the requirements for an inspection programme, an inspection at a general level should initially be specified (e.g. GVI compared with CVI, CVI compared with TM or WI). Should evidence be discovered during a general inspection that a more detailed type of inspection is needed, then the more detailed type of inspection shall be performed. For example, if coating breakdown is detected during a GVI, then a CVI and/or TM inspection should be performed immediately, to quantify whether the breakdown has allowed the onset of corrosion and, if so, to what extent.

If an anomaly is discovered during an inspection,

— its extent and seriousness shall be quantified by a more detailed type of inspection, or

— its possible progressive spreading or intensifying shall be assessed by analysis within the SIM system fit-for-service framework.

19.4.4 Preparations for inspections

19.4.4.1 Access

Precautions shall be taken to ensure safety during inspections. Tanks and spaces shall be made safe for entry and work. Any equipment that is needed to effect an emergency recovery shall be readily available and checked to ensure it is in full working order before any tank is entered.

All tanks and spaces subject to internal inspections shall be thoroughly ventilated to ensure they are gas-free prior to personnel entry. During inspections, they shall be monitored for pockets or emissions of hazardous gases. Casings, ceilings or linings, and loose insulation where fitted, are to be removed as necessary for examination of plating and framing. Staging, rope attachment points (for abseiling) or other safe forms of support are to be provided to enable access to all parts of tanks and spaces subject to CVI, TM and WI.

Some floating platforms can adopt a particular draught or trim to make specific areas of their hull or critical structural details accessible for inspection, maintenance and repair.

Inspection of areas that are predominantly above water or in the splash zone can be undertaken during quiet sea conditions by providing moveable staging from which an inspector can apply the appropriate type of inspection or measurement.

Some areas of the hull, specific structural details and appurtenances and associated coatings remain submerged or in the splash zone throughout the design service life and can only be inspected, maintained or repaired by a ROV or diver, or by building a temporary cofferdam around them.

For safety reasons, the use of a ROV should be preferred to a diver intervention.

Operational planning and preparation should be carried out to ensure that all activities associated with the intended inspection, maintenance or repair can be performed within weather windows or restricted time-slots consistent with other platform systems.

19.4.4.2 Cleaning

In preparation for inspections, spaces and surfaces should be sufficiently clean (removal of accumulated loose corrosion, scale, water, dirt, oil residues, etc.) to reveal corrosion, deformation, fractures, damage, or other structural deterioration so that the extent of these can be correctly measured and recorded. Cement and other bonded surface treatments shall be checked for adherence and removed if not sound or where the condition of the plating beneath is in doubt.

Some inspection techniques require coating removal (e.g. MPI) necessitating reinstatement following such inspection. Consequently, it can be advantageous to adopt techniques that do not require coating removal or thorough cleaning (e.g. eddy current, ACFM).

Anti-fouling coatings are generally applied to the external surface of the hull to prevent build-up of marine growth. In some areas, coatings can be only partially successful, leading to the build-up of hard and soft marine growth, and it can be necessary to remove both types of marine growth before a CVI or other similar inspection can be performed. Care should be taken to avoid damaging coatings where they remain effective.

Most types of inspections performed on floating structures can be implemented without removing or damaging the coatings.

ROVs are generally capable of removing marine growth. Where divers are deployed as an alternative to, or in conjunction with, ROVs, care shall be exercised to ensure that water intake systems are not in use or activated when a diver is in the vicinity.

19.4.5 Inspection results and actions

The records of all inspections shall be entered into the database (see 19.2.2). If deterioration or damage is detected, an evaluation shall be performed to quantify the effect on the floating structure's integrity. If the deterioration or damage occurs in a special area, this should be reflected in the level of evaluation performed. If such evaluation determines it to contain substantial corrosion, such an area should be subject to increased CVI and TM as determined by the SIM system.

19.4.6 Maintenance programmes

Maintenance programmes shall be developed by the owner based on the expected life of the mechanical system or component under consideration. The supplier/manufacturer can be of considerable help in preparing an appropriate maintenance programme. In preparing maintenance programmes, however, account shall be taken of conditions under which the floating structure is operating that can lead to premature breakdown of the system or equipment, and contingency plans shall be developed accordingly.

19.4.7 Monitoring programmes

Monitoring programmes can be used to help check the condition of a floating structure over a period of time and in the carrying out of day-to-day operations. They can be fully continuous, as in the use of tension measuring devices for mooring lines, or discrete, as in most of the techniques discussed in A.19.4.3.

Techniques have been, and are constantly being, developed that can monitor various forms of damage and deterioration, and which alert the owner when advanced to a stage where action is required to prevent further progress. The results of such techniques should be assessed on a regular basis in conjunction with the database, to assist in the identification of significant deterioration.

19.5 Minimum requirements

19.5.1 General

For cases where a risk-based approach has not been pursued to determine locations and intervals of inspections, this subclause specifies the minimum scope and periodicity of inspections to be performed. These minimum requirements are intended to supplement those of any applicable standards, RCS rules or equivalent, where in use.

For ship-shaped structures and semi-submersibles, the requirements of this subclause are based on well-documented experiences.

For spars, the equivalent experience base is less developed. In this case, the designer shall ensure that these minimum requirements remain adequate as the technology matures.

For innovative designs, engineering judgement and a degree of caution are necessary. Guidelines should be provided to encourage operating personnel to make occurrence reports so that these can be properly evaluated.

The following minimum requirements have been developed for floating structures with design service lives in excess of 10 years and which can move location and change owner.

19.5.2 Minimum inspection requirements for main structure

19.5.2.1 General

The general requirements as stated in 19.4.3 shall apply.

Working within an overall asset integrity management framework, alternative inspection programmes may be used, provided they can be shown to satisfy levels of safety equivalent to, or greater than, those implied by the minimum requirements given in this subclause.

In general, when a detailed type of inspection is required to be performed due to evidence discovered during a less detailed inspection, the more detailed type of inspection should be performed with at least the same frequency as that of the more general inspection type. It can, however, be necessary to perform more frequent inspections using the more detailed type of inspection to ensure that the integrity of the structure is not compromised.

Table 6 specifies minimum requirements for the type of inspection and the frequency with which each shall be performed for the main components of floating structures. Each of the inspection types is discussed further in 19.5.2.2 to 19.5.2.6.

Table 6 — Inspection requirements for main components (including CP systems)

Component	Location	GVI		CVI		TM		WI	
		I years	*E* %	*I* years	*E* %	*I* years	*E* %	*I* years	*E* %
Exterior structure[a]	Atmospheric	1	100	—	—	—	—	—	—
	Splash zone above water line	1	100	—	—	—	—	—	—
	Splash zone below water line and submerged	2,5	100	—	—	—	—	—	—
	Special areas	—	—	2,5	100	—	—	2,5[b]	50[b]
Interior structure[a]	Ballast tanks [c]	1	20	5	—	15[d]	—	—	—
	Slop tanks	2,5	50	—	—	5	—	—	—
	Oil storage cargo tanks	2,5	50	2,5	50[e]	5	—		—
	Storage tanks exterior (fuel oil, potable water, lubrication oil)	5	100	—	—	—	—	—	—
	Storage tanks interior (fuel oil, potable water, lubrication oil)	15	100	—	—	—	—	—	—
	Void spaces	5	100	—	—	5[f]	—	—	—
	Machinery spaces	1	100	—	—	1[f]	—	—	—
	Special areas	—	—	1	100	—	—	2,5[b]	50[b]
CP system	External	—	—	2,5	—	2,5[g]	—	—	—
	Internal	—	—	5	—	—	—	—	—
Any	Showing substantial corrosion					1[h]	100		

Key

I: inspection interval (in years)

E: extent (percentage) of inspection

NOTE The extent applies to the total number of components, e.g. tanks.

[a] Including girders, stiffeners, plating, attachments, appurtenances, openings, penetrations, vents and pipes.

[b] The procedures according to 19.2.3 may be used to demonstrate longer intervals and/or lesser extents are acceptable subject to the requirement of 19.5.2.5.

[c] Ballast tanks are assumed to have a suitable hard coating, see A.19.5.2.1.

[d] More frequent intervals can be required where the coating breakdown is found.

[e] One transverse section and adjacent frames (different ones at successive inspections) plus one transverse bulkhead together with adjacent transverse section and frame (opposite tank ends at successive inspections).

[f] At discretion of owner.

[g] Measure cathodic potential readings and check for fouling/damage.

[h] More frequently if recommended by the owner.

In general, scheduled inspections should be performed within three months of the due date unless a written justification is submitted and accepted by all interested parties. Alternatively, a continuous inspection programme is acceptable.

The intervals and extent of weld inspections required for special areas shall be critically evaluated and established such that the probability that a critical structural defect can develop within the interval between inspections is consistent with that to realize a reliability level equivalent to that implicit in this document.

19.5.2.2 General visual inspection (GVI)

One of the main objectives of the GVI is to establish the condition of coatings. It is normally possible as a result of a GVI to assess this without resorting to a CVI. The coating condition shall be graded as follows.

Good: a condition with only minor spot rusting.

Fair: a condition with local breakdown of the edges of stiffeners and weld connections and/or light rusting over 20 % or more of areas under consideration, but less than as defined for poor condition.

Poor: a condition with general breakdown of coating over 20 %, or hard scale at 10 % or more of the areas under consideration.

If the coating is good, CVI and TM are not normally required. If the coating is fair, consideration should be given to performing a CVI annually and TM every 5 years. If the coating is poor, a CVI shall be performed annually, in addition to TM, if required by the owner.

A GVI can be effective in establishing the condition of coatings without resorting to a CVI. The coating condition shall be graded annually.

19.5.2.3 Close-up visual inspection (CVI)

Special areas (internal) or areas where the coating condition is poor shall be subject to CVI annually unless more frequent inspections are recommended by the designer or as a result of a special structural assessment.

19.5.2.4 Thickness measurements (TM)

TM shall be performed on all areas suspected of suffering substantial corrosion. They should also be performed at the owner's discretion where the coating condition is poor and, in any case, at 5 year intervals where the coating condition is fair.

19.5.2.5 Weld inspections (WI)

The intervals and extent of weld inspections required for special areas shall be critically evaluated and established such that the probability that a critical structural defect can develop within the interval between inspections is minimized.

19.5.2.6 Cathodic protection (CP) system inspection

Sacrificial anodes should be examined for depletion and replaced if not in a satisfactory condition, taking due account of inspection intervals. CP potential measurements can be used to demonstrate the satisfactory performance of sacrificial anodes.

Impressed current system anodes and cathodes shall be checked for damage, fouling by marine growth and carbonate deposits.

Any repairs or replacements to the CP system shall be recorded in the database.

19.5.3 Minimum inspection requirements for structural and non-structural attachments

Table 7 specifies minimum requirements for the type of inspection and the frequency with which they are to be performed for the various structural and non-structural attachments.

Structural attachments not listed in Table 7 should be matched to the attachment in the table whose conditions of exposure, loading and maintenance most closely resemble those of the attachment in question.

Table 7 — Inspection requirements for structural and non-structural attachments

Attachment	Component	Location	Frequency of inspection years			
			GVI	CVI	TM	WI
Structural	Cranes	Foundation	—	1	—	5
		Pedestal[a]	—	—	—	—
	Flare/vent	Foundation	—	1	—	5
		Structure	1	—	—	5
	Deckhouse	Foundation	1	—	—	—
	Helideck	Foundation	—	1	—	5
		Structure	1	—	—	—
	Turret	Foundation	—	1	—	1
		Structure	—	1	5	5
	Hose-reel connection	Foundation	—	1	—	5
		Structure	—	1	—	—
	Riser support	Foundation	—	1	—	5
		Structure	—	2,5	—	—
	Process deck support	Foundation	—	1	—	—
		Structure	—	2,5	—	—
	Chain stoppers/ table	Structure	—	2,5	—	—
	Hawser reel	Foundation	—	1	—	5
		Structure	—	2,5	—	—
	Drilling derrick support	Foundation	—	1	—	5
		Structure	—	1	—	—
	Tandem mooring	Foundation	—	1	—	5
		Structure	—	1	—	—
	Breakwater	Foundation	—	1	—	5
		Structure	1	—	—	—
Non-structural		External	—	2,5	2,5	—
		Internal	—	5	—	—

[a] See A.19.5.3.

19.5.4 Inspection results and actions

The effects of deterioration shall be assessed on a case-by-case basis. Such evaluation shall be performed in accordance with the requirements of 19.2.3.

19.5.5 Tank testing and watertightness

Tanks shall be tested with a head of liquid to the top of access hatches for cargo tanks, or the top of air pipes for ballast tanks. As a minimum, such tests shall be performed at five year intervals, or more frequently if the need is established by the SIM system. When selecting tank test pressures, consideration should be given to the possible effects of equipment or operation malfunction.

Testing may be waived by agreement of the owner if coatings remain intact and no significant thickness reductions are found during inspection, unless structural modification to the tank has been performed. With such agreement, lack of leakage during operational filling of adjacent tanks can be taken to demonstrate watertight integrity.

Consideration should be given to the loaded condition of adjacent tanks when the test head is to be imposed. It is important to establish that the corresponding conditions were considered and checked by the designer. Caution is required, owing to the risk of damage arising during these tests.

For other floating structures that do not store large quantities of product, the watertight integrity of tanks, bulkheads, hull and other compartments shall be verified by visual inspection. Areas of severe corrosion shall be tested for watertightness, non-destructive tested or thickness gauged.

20 Assessment of existing floating structures

20.1 General

The various initiators that can lead to a requirement for an existing structure to be assessed are listed in 5.9.

Following the occurrence of an assessment initiator, the prime objective of an assessment is to ensure that a floating structure can continue to operate safely. The assessment generally deals with global performance of the structure. If the structure does not pass the assessment, mitigation shall be effected. Assessment procedures are described in 20.2 and mitigation options are described in 20.3.

20.2 Assessment procedures

20.2.1 Scope of assessment

This subclause provides minimum requirements which apply generally to the assessment of existing floating structures.

For a disconnectable floating structure (e.g. a ship-shaped structure), post-disconnection, the requirements of this subclause apply only to those parts of the platform exposed to the post-disconnected conditions, e.g. risers, mooring buoys, spider buoys, or buoyant riser towers.

Floating structures should be assessed individually as well as on an area-wide basis to determine if they are high consequence structures, i.e. those which, in case of structural failure or major damage, can affect other parties either directly by the structure's failure or indirectly by disruption of the structure's operability (e.g. in the case of a hub platform). In the case of high consequence structures, consideration should be given to exceeding the minimum acceptance criteria defined in 20.2.4.

20.2.2 Assessment conditions

The metocean and ice conditions to be used in an assessment shall be derived from a site-specific study performed at the time of the assessment in accordance with the requirements of ISO 19901-1 and 9.2.2 of this document. If the original design metocean and ice conditions are known to still be applicable, they may be used in place of those derived from a contemporary site-specific study.

In some regions of the world, design metocean and ice conditions can change relatively significantly over a short period of time (e.g. sudden hurricanes in the Gulf of Mexico). These shall be accounted for particularly if they impact on the platform evacuation or disconnection strategy.

20.2.3 Assessment procedure

The structure to be considered is that of the as-is configuration. This shall account for all changes to the structure since its original installation (e.g. additions or removal of payload, risers, etc.) and the results of the most recent inspection(s) including hull, mooring system and other components to update corrosion allowances and other assumptions used in the original design and accounting for damage to key components as necessary.

Actions due to loss of air gap (e.g. wave in deck) and to green water, as appropriate, shall be included.

Using the metocean and ice conditions of 20.2.2, verification of the structure shall be performed. This verification evaluates the consequences of changes in configuration and/or in metocean and ice conditions which can increase or decrease the actions on, or operating envelopes of, critical structural components.

Acceptance criteria are provided in 20.2.4.

20.2.4 Acceptance criteria

If the assessment satisfies the requirements of 9.7, no further action is necessary.

If the assessment does not satisfy the requirements of 9.7, mitigation measures (see 20.3) should be adopted.

As an alternative to mitigation, a fitness-for-service approach may be implemented in which case the following minimum requirements shall be met.

a) The floating stability of the structure (allowable KG) is maintained in accordance with the approved certification criteria for all operating conditions in both the intact and damaged conditions. In particular, downflood points (e.g. access hatches and other points) should be checked for potential water ingress.

b) For conventionally-moored structures, the mooring system does not exceed its relevant limit state for the maximum tension case in the intact condition, or failure of one line does not lead to sequential failure of one line after the other, otherwise known as system unzipping. Transient analysis may be limited to the duration over which peak actions are maintained. All mooring interface hardware remains within geometric operating limits.

c) Primary structural components required for structural integrity satisfy the requirements of 9.7. Some of these are the deck to hull connection, truss to hard tank connections of a spar, and pontoon to column connections on a semi-submersible.

d) Pipelines and risers do not fail and all their interface hardware remains within geometric operating limits.

e) No failure occurs at critical connections of major production and drilling modules to the structure.

Other key aspects include

— positioning of down-stop and up-stop of riser support systems (down-stop and up-stop are mechanical/ structural components intended to limit the riser downstroke and upstroke), and

— high-stress low-cycle fatigue of critical structural elements, or mooring components;

Redistribution of stresses in secondary structure may be exploited provided buckling does not result nor any allowable strain limits are exceeded.

20.3 Mitigation

Following an assessment that does not satisfy the verification requirements of 9.7, mitigation typically involves reducing actions on the structure, such as removing unused risers, or increasing the structure's strength. Mitigation can also include active programmes to minimize the consequence of damage or failure, such as plugging and abandoning unused wells or removing inactive process equipment. Cost-benefit analysis is typically used to assess mitigation options. The chosen option shall be demonstrated to meet the assessment requirements.

Preventive mitigation can help extend the life of a structure or improve its chances of survival in a design event.

Action reduction includes the following:

— relocating or removing piping and other systems located below the lowest deck;

— relocating or removing equipment on the lowest decks subject to wave or ice actions;

— removal of unused boat landings, walkways, stairs, barge bumpers, etc.;

— removal of unused wells and risers;

— removal of process equipment, tankage or piping no longer employed to reduce surface areas exposed to wind and waves as well as permanent actions;

— raising the deck(s) to prevent wave or ice actions on the deck;

— laying down or removing a drilling rig ahead of a design metocean or ice event;

— operational plans to reduce hydrocarbon or other liquid inventories prior to a design metocean or ice event.

Strengthening should be based on specific engineering assessment of the structure and can include the following:

— improved tie-down of topsides structure and equipment;

— strengthening members or adding auxiliary bracing members;

— strengthening of joints.

Activities that can minimize the consequences of damage or failure include the following:

— relocating or removing piping and other systems located below the lowest deck;

— relocating or removing equipment on the lowest decks subject to wave or ice actions;

— strengthening or shielding of piping, equipment and other systems located on the lowest decks from potential damage due to wave or ice actions;

— plugging and abandoning unused wells;

— reducing hydrocarbon and/or chemical inventories on the facility;

— providing alternative means of production if a platform is damaged or destroyed, such as pre-planning for alternative export lines, emergency jumper lines to undamaged platforms, etc.

A continuous mitigation process should be considered even for structures where assessment is not required. For floating structures, a significant portion of downtime following an extreme or abnormal metocean or ice event results from damage to structures and systems that do not affect the structure's global strength. Examples include damage to topsides safety equipment and systems, especially on lower decks subject to wave or ice actions, and toppled deck equipment due to a combination of inadequate securing and high winds. Following evacuation in advance of an extreme metocean or ice event, such damage can give rise to safety hazards when the structure is re-boarded as well as result in significant repair, downtime, and economic consequences.

21 Other hulls

21.1 General

This clause covers the design of types of floating structures not specifically covered by Clauses 11 to 14. The stationkeeping systems for such floating structures are covered by Clause 18 and ISO 19901-7.

In the absence of readily available established design practices and standards for the design of an unconventional floating structure, an appropriate methodology shall be developed to address all significant features of the structure's behaviour, in accordance with sound engineering practices. The owner shall discuss the proposed design methodology with the regulator (where one exists) and/or a RCS, and obtain approval at the project's initiation.

Different existing practices or standards can be applicable to different parts of such a floating structure. Existing standards shall be selected giving due consideration to their compatibility with each other and to their consistency with standards of safety and reliability accepted by the offshore industry. Formal reliability analysis methods can be used to establish the design criteria and/or the standard for the proposed design.

For concepts with unusual configurations, metocean actions, ice actions, and action effect calculations should be verified by model tests.

21.2 Structural steel design

Structural details peculiar to a specific floating structure design should be given careful attention to establish that all appropriate actions are represented. Selection of a design code or standard for such components should be reviewed to ensure it is applicable for the intended design.

21.3 Stability and watertight integrity

In general, the stability requirements in Clause 16 apply. In addition, special consideration should be given to resolve any unconventional stability issues specific to a new configuration.

The requirements for righting/heeling moment curve area ratios should be considered judiciously for application to unconventional floating structures.

Annex A
(informative)

Additional information and guidance

A.1 Scope

Figures A.1, A.2, A.3 and A.4 show typical examples of the types of floating structures covered by this document.

RCS rules and equivalent national documents are frequently referenced throughout this document. Reference to specific RCS rules or equivalent documents, along with more general documents, are included in this annex. References [4], [18], [21], [41], [53], [62], [63], [69], [70], [71], [78] and [138] form a good basis for the overall planning, design and operation of floating offshore structures.

NOTE Citation of these references does not constitute an endorsement of all the methods and recommendations contained therein. It is therefore advisable to verify with RCS the latest versions of applicable rules. The references listed could be completely or partly superseded by newer or other rules.

Requirements for floating structures intended primarily to perform drilling and/or well intervention operations (often referred to as MODUs), even when used for extended well test operations, are covered by the IMO MODU Code[114] and RCS rules, for example References [17], [53], [110] and [138]. Requirements for floating structures used for offshore construction operations, for temporary or permanent offshore living quarters, or for transport of equipment or products, can be found in RCS rules.

For concrete structures, see ISO 19903[136].

For floating structures intended to operate in arctic environments, this document should be supplemented by ISO 19906 or other suitable standards.

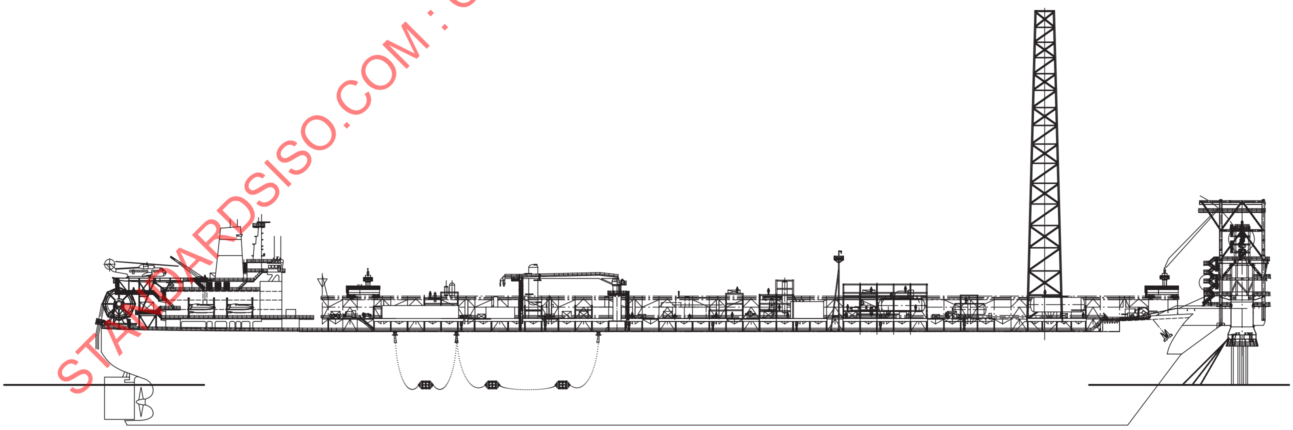


Figure A.1 — Ship-shaped floating structure

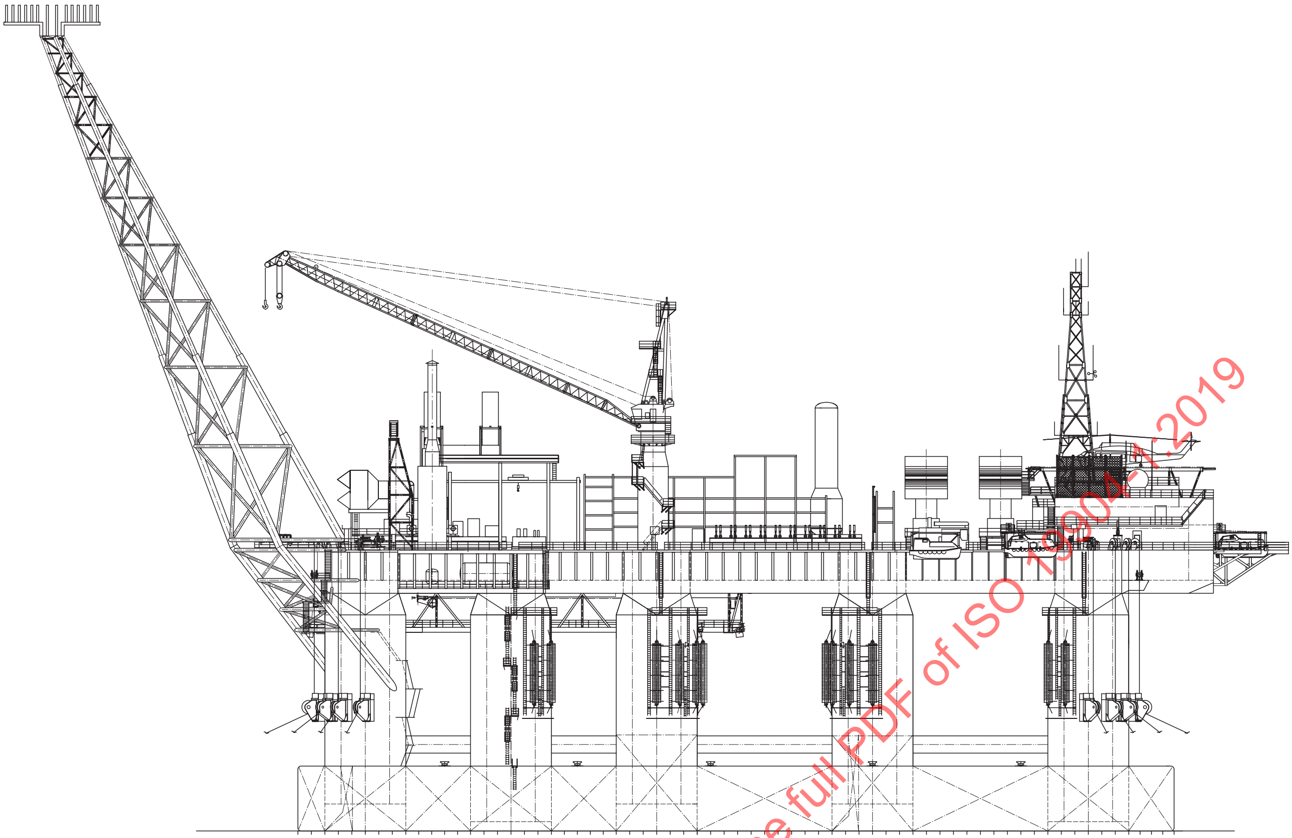
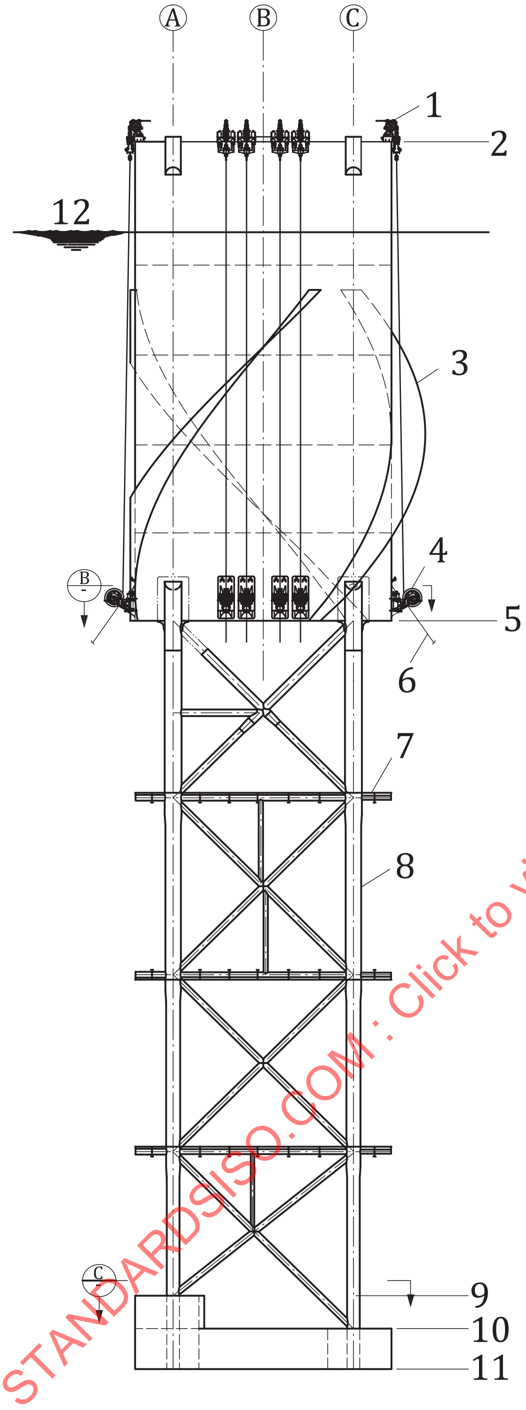
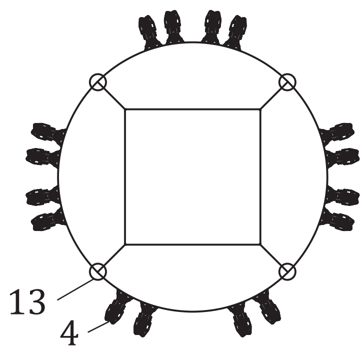


Figure A.2 — Semi-submersible floating structure

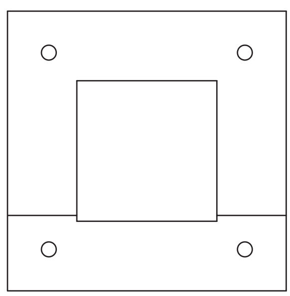
All elevations are in mm



a) Outboard profile



b) Section B

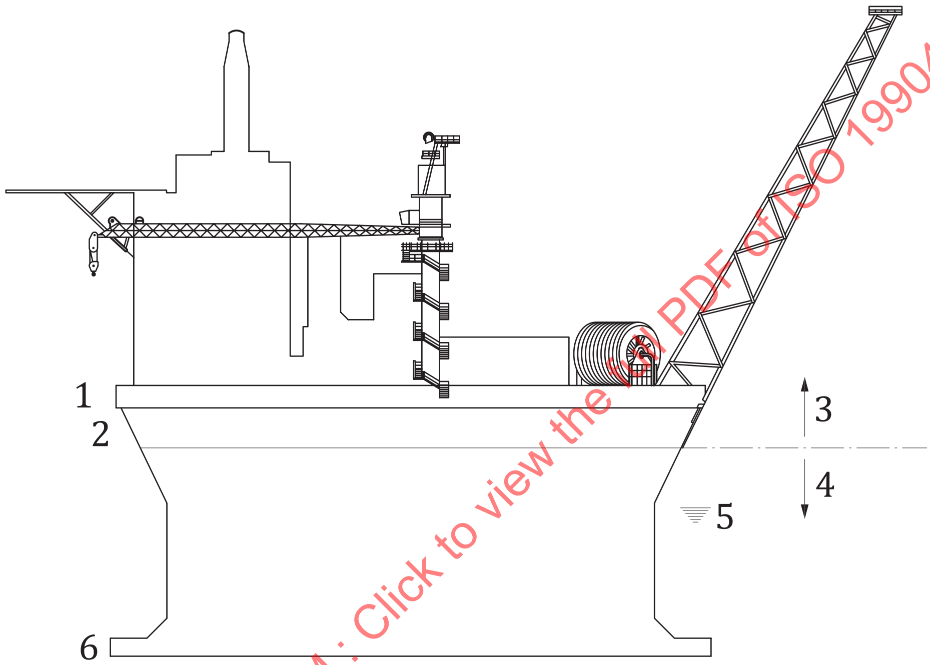


c) Section C

Key

1	chain jack (typ.)	8	tubular (typ.)
2	spar deck 8 - EL. 227360	9	deck 2A – EL. 13600
3	strake (typ.)	10	deck 2- EL. 7500
4	fairlead (typ.)	11	deck 1- EL. 0
5	deck 3 – EL. 138620	12	MWL EL. 210596
6	mooring chain (typ.)	13	truss leg (typ.)
7	heave plate (typ.)		

Figure A.3 — Spar floating structure



Key

1	process deck	4	hull
2	main deck	5	water level
3	topsides	6	damping skirt

Figure A.4 — Shallow-draught cylindrical structure

A.2 Normative references

No guidance is offered.

A.3 Terms and definitions

No guidance is offered.

A.4 Symbols and abbreviated terms

No guidance is offered.

A.5 Overall considerations

A.5.1 General

In general, the functional requirements for floating offshore structures are identical to those for other offshore structures. For tension leg platform (TLP) requirements, reference can be made to API RP 2T[23].

Floating structures are generally used as an alternative to fixed structures for applications where the water depth would make bottom-founded structures impractical or uneconomical, or when ease of removal and redeployment of the structure are economically attractive.

In those cases where produced oil is exported by pipeline, limited oil storage is provided on the floating structure. The storage is generally accommodated in the process system as additional residence time, or in additional surge vessels. If, on the other hand, oil export through a pipeline is not planned or available, a considerable volume of oil storage is generally required to allow export by shuttle tankers or barges. In such cases, the storage capacity is usually provided aboard the floating structure. Alternatively, storage capacity can be provided on the export tankers or barges. In this case, inability of the export vessel to accept the produced crude would result in a forced production shutdown unless a backup redundant shuttle/storage vessel is provided.

A.5.2 Safety requirements

The intent of robust design is to verify adequate margins in maintaining stationkeeping, structural integrity, floating stability and avoiding loss of fluid containment. Key considerations are the following:

a) degradation of floating stability through compartment flooding or other causes;

b) positioning of down-stop and up-stop of riser support systems;

c) capacity and ductility of key riser components;

d) mooring line safety factors, and the capacity of key mooring components as well as the capacity and ductility of their support structures;

e) adequacy of key structural components, such as: deck to hull connection, truss to hard tank connections on a spar, or pontoon to column connections on a semi-submersible.

In general, floating structures should be designed so that the arrangement and separation of various spaces, particularly living quarters, relative to oil storage tanks, are in accordance with IMO SOLAS regulations[115]. The placement of machinery spaces above oil storage tanks may be accepted, on condition that an equivalent level of separation and protection is provided.

RCS rules or equivalent define areas or compartments of floating structures as “hazardous areas” according to their proximity to equipment, pipes or tanks containing certain flammable liquids and depending on whether or not these fluids are at temperatures approaching or exceeding their flashpoints. Reference [66] describes safety principles and arrangements.

Guidance on the conduct of formal risk assessments can be found in References [13], [64], [105] and [147].

On oil tankers, the main hazardous area extends over the cargo tank area up to a height of between 2,4 m and 3,0 m above the main deck. Hazardous areas also exist around tank vent outlets and any other areas connected with the loading or discharge of cargo. On ship-shaped structure platforms the process equipment is accommodated on a deck structure constructed at a height of at least 3,0 m above the cargo/upper deck.

A.5.3 Planning requirements

A.5.3.1 General

Structural integrity and serviceability throughout the structure's life cycle are not simply functions of the design calculations but are also dependent on the quality control exercised in construction, the supervision on-site and the way the structure is used and maintained.

A.5.3.2 Exposure level

No guidance is offered.

A.5.3.3 Basis of design

No guidance is offered.

A.5.3.4 Design practices

No guidance is offered.

A.5.3.5 Inspection and maintenance philosophy

No guidance is offered.

A.5.3.6 Documentation

No guidance is offered.

A.5.3.7 Extreme weather preparedness

Examples of extreme weather preparedness are given below:

a) Plan evacuation of platforms that are at greater risk of failure and those that are furthest from shore first. Begin evacuation of non-essential personnel early.

b) Give special consideration to evacuation planning for platforms located where rapidly developing extreme weather conditions (e.g. sudden hurricanes) occur at short notice, including evacuation of nearby structures expected to safely survive conditions in excess of the event. Pay special consideration to the logistics and safety of the evacuation operation and to securing the platform against spill potential.

c) Begin preparing structure operations for safe shut-in as early as possible, including system pump down, securing equipment and control panels, reducing liquid inventories, etc.

d) Secure loose objects and equipment that can become airborne projectiles. Store movable equipment in safe and dry areas.

e) Develop advance plans for post-adverse weather access to the structure in cases where normal access and safety systems, such as boat landings, walkways, power, etc., are not necessarily available or functional due to damage.

f) Establish guidelines for safe re-boarding of a damaged structure, with minimum acceptance criteria for platform access and egress.

A.5.3.8 Disconnectable floating platforms

No guidance is offered.

A.5.4 Additional standards and specifications

No guidance is offered.

A.5.5 General requirements

A.5.5.1 General

The design of a floating structure has many points of similarity with that of a seagoing ship. Accordingly, many concepts and rules can be extrapolated from those used in the shipping and marine industries. On the other hand, some notable differences exist and should be adequately accounted for, including the following.

a) **Site-specific environment**

For floating structures, strength standards set by RCSs are based on criteria relating to a world-wide trading pattern.

b) **Dynamic actions characteristics**

The actions on the hull of a floating structure are substantially different from those associated with seagoing trading ships, see Reference [14].

c) **Effect of mooring system**

Static and dynamic mooring and riser forces can be substantial, and their effects on the hull girder longitudinal bending moments and shear forces should be accounted for in the design calculations.

d) **Long-term service at a fixed location**

Seagoing ships generally spend a proportion of their time in sheltered water conditions. Permanently moored structures normally remain on station all the time and disconnectable structures only move off station in certain conditions and generally remain in the local area. In addition, the expectation of the field life can be in excess of 20 years.

e) **Seas approaching from a predominant direction**

For seagoing ships, in severe weather steps are generally taken to minimize the effects of such conditions, such as altering course or alternative routing. Moored permanent structures generally cannot take such evasive actions, and even those with weathervaning capability can experience a greater proportion of waves approaching from bow sector directions.

f) **Zero ship speed**

Although moored structures generally have zero forward speed, the use of zero forward speed in calculations where forward speed is a parameter is not necessarily conservative when estimating the effect of such calculations on a moored structure.

g) **Range of operating loading conditions**

Seagoing tankers have a limited range of operational conditions and are typically fully laden or in-ballast. Many types of moored platforms, in consideration of their oil storage capability, should be checked for a number of design situations. These can include a full range, from ballast through intermediate conditions to fully loaded, returning to ballast via offloading.

h) **Tank inspection requirements**

Seagoing ships are generally taken to dry dock for periodic survey and repair. Permanently moored structures are usually inspected on station. Thus a full range of design situations should be verified, covering each tank (or combinations of tanks) empty in turn, in combination with site-specific metocean and ice actions.

i) **Change in return period from normal RCS rules**

Typical RCS rules for ships are based on providing adequate safety margins against events with a 20-year return period. This document provides instead that the design should be based on a typical return period of 100 years.

A.5.5.2 Structural design philosophy

Satisfactory protection against accidental damage can be obtained by a combination of the following measures:

a) reduction of the probability of damage to an acceptable level;

b) reduction of the consequences of damage to an acceptable level.

The use of ductile materials leads to a structure that does not collapse suddenly, because ductility allows a structure to redistribute internal forces and thus absorb more energy prior to failure. Measures for obtaining structural ductility include

— making the strength of connections greater than the strength of the members,

— providing redundancy in the structure, so that alternate load redistribution paths can be developed,

— avoiding dependence on energy absorption in slender struts and slender unstiffened and stiffened plates and shells with limited degrees of post-buckling reserve strength,

— avoiding pronounced weak sections and abrupt changes in strength or stiffness, and

— using materials that are ductile in the operating temperature range.

A.5.5.3 Design criteria

No guidance is offered.

A.5.5.4 Hydrostatic stability and compartmentation

No guidance is offered.

A.5.5.5 Weight control

Details on the implementation of mass distribution verification are given in ISO 19901-5[135].

A.5.5.6 Global response

No guidance is offered.

A.5.5.7 Stationkeeping

Specific requirements and guidance on stationkeeping systems can be found in ISO 19901-7

A.5.5.8 Materials

Guidance on materials can be found in RCS rules, for example Reference [67].

A.5.5.9 Topsides layout – safety considerations

Guidance on topsides arrangements and layout can be found in RCS rules as well as in ISO 19901-3.

A.5.6 Independent verification

General requirements in respect of quality control are stated in ISO 19900.

A.5.7 Analytical tools

When the global analytical model does not take account (or full account) of local action effects, or the global analytical model does not contain sufficient detail to analyze a certain response to the required accuracy, local detailed analytical models should be established to evaluate local structural response. Such a case normally applies to hull tank arrangements in structures with a relatively deep draught, where detailed FE analysis should be performed to evaluate responses from all relevant combinations of internal and external pressure actions. Combined responses from various action combinations are then normally developed by linear superposition of the individual action effects.

It is normally not practical to consider all relevant actions (both global and local) in a single model, for the following reasons, among others:

— Single model solutions do not normally contain sufficient structural detailing, e.g. for ULS structural assessment, response down to the level of the stress in plate fields between stiffeners is normally required.

EXAMPLE Internal structure not modelled in sufficient detail to establish internal structural response to the degree of accuracy required, or insufficient element type, shape or fineness (e.g. mesh size).

— Single model solutions do not normally account for the full range of internal and external pressure combinations.

EXAMPLE Internal tank pressure up to the maximum design pressure, maximum external pressures, full extent of internal and external pressure combinations.

— Variations in tank actions across the section of the structure.

EXAMPLE Where the structural section is subdivided into a number of watertight compartments across its section.

— Design situations that need not be covered by global analysis.

EXAMPLE Damage, inclined conditions.

— Single model solutions do not normally account for the full range of “global” tank loading conditions.

EXAMPLE Tank loading distributions along the length of the floating structure, asymmetric tank actions.

— Single model solutions need not fully account for all action effects.

EXAMPLE Viscous effects (drag actions) on slender members, riser interface actions and thruster actions.

Generally, single model solutions containing sufficient detail to include consideration of all relevant actions and design situations result in extremely large models with a very large number of load cases. Therefore, it is often more practical and efficient to analyze different action effects utilizing a number of appropriate models and superimposing the responses from one model with the responses from another to assess the total utilization of the structure.

In order to satisfy formulae of equilibrium for floating systems, it is not normally practical to apply action factors. In such cases, it is instead generally appropriate to factor the response rather than the action. However, when applying this approach to non-linear systems, considerable care should be exercised.

A.5.8 In-service inspection and maintenance

See A.19.4.3 for further information on inspection programmes.

A.5.9 Assessment, re-use and life extension

No guidance is offered.

A.6 Basic design requirements

A.6.1 General

The general principles on which requirements for the structural design of offshore platforms are based are documented in ISO 19900.

A.6.2 Limit states

Examples of limit states are documented in ISO 19900.

A.6.3 Design situations

A.6.3.1 General

Design situations should be determined in accordance with ISO 19900 and with the requirements of ISO 19901-1.

Aspects to be considered in determining design situations include the following:

— service requirements for the intended function of the floating structure;

— design service life for each function;

— method and duration of construction activities;

— expected method of removal of the structure and, where applicable, any intended relocation;

— hazards (accidental and abnormal events) to which the structure can be exposed during its design service life;

— potential consequences of partial or complete structural failure;

— nature and severity of environmental conditions (meteorological, oceanographic and active geological processes) to be expected during its construction and design service life.

A.6.3.2 ULS situations

When actions act simultaneously, representative values may be determined based upon consideration of the joint probability of the events. Design values of representative metocean actions and ice actions should always be established with the intention to result in the MPM (or minimum) action effect for the limit state under consideration. Different design situations can give rise to the most onerous action effects for different components in the structure.

A.6.3.3 SLS situations

No guidance is offered.

A.6.3.4 FLS situations

No guidance is offered.

A.6.3.5 ALS situations

No guidance is offered.

A.6.3.6 Temporary phases

For temporary phase conditions, the reduction of the return period applicable for establishing the metocean actions or ice actions may normally be taken as follows.

a) For operations with a duration no greater than 3 days, design conditions should be established such that the temporary operation is not initiated unless reliable weather forecasts provide adequate assurance that the limiting metocean or ice design conditions will not be exceeded.

b) For operations with a duration greater than 3 days but where it is possible to abort the temporary phase operation within a period not exceeding 24 h, design conditions should be established such that the temporary operation is not initiated unless reliable weather forecasts provide adequate assurance that the limiting metocean design criteria or ice design criteria will not be exceeded. In such cases, the operation should be discontinued if the weather forecasts indicate metocean or ice conditions in excess of those established as design conditions.

c) For operations with a duration greater than 3 days, but where the operation does not involve risk of life, injury to personnel, or significant environmental consequences, a minimum of a one year return period should be used as the metocean or ice design condition. This condition may take account of seasonal effects but should normally not be taken as being less than a two-month seasonal span.

The structure, supported during construction by keel and bottom blocks on the dock floor, is generally launched by controlled flooding of the dock. During the undocking operation, critical aspects regarding the actions on blocks and the structure are difficult to predict. Accordingly, analyses are generally limited to the evaluation of the stability of the structure, which can be critical due to the light displacement.

Guidance on marine operations is given in ISO 19901-6.

A.7 Actions and action effects

A.7.1 General

ISO 19900 contains general principles governing the definitions of actions, action effects and action combinations that can influence the safety of a floating structure or its parts throughout the structure's life cycle.

A.7.2 Permanent actions (*G*)

Permanent actions generally include, but are not limited to the following:

— self weight of structures;

— weight of topsides permanent fixtures and functional equipment;

— weight of permanent ballast and equipment;

— deformations imposed during construction;

— deformations due to differential support settlement during fabrication;

— actions resulting from distortions due to welding;

— actions resulting from external hydrostatic pressure;

— pre-tension in mooring lines, if of a permanent nature.

Control and monitoring of the mass and centre of gravity of offshore structures is discussed in ISO 19901-5[135].

A.7.3 Variable actions (Q)

Variable actions generally include, but are not limited to the following:

- actions due to personnel occupancy and associated logistics (helicopter landings, etc.);
- actions due to performance of the structure's operations (crane hook and drilling hook actions, etc.);
- actions associated with drilling operations;
- self weight of temporary structures and equipment;
- actions associated with stored materials, equipment, gas, fluids and fluid pressure;
- actions associated with loadout, transportation, offloading, installation operations, etc.;
- actions from fendering and mooring;
- actions from variable cargo, ballast and equipment;
- deformations due to global bending of the hull;
- all moving actions such as for movable drilling derricks;
- deformations due to changes in temperature (including sea and air temperatures).

In the absence of specific requirements, the local design action intensities stated in Table A.1 (adapted from NORSOK N-003[144]) may be used in the structural design of the deck of a floating platform. Local action effects resulting from these action intensities should be combined with the corresponding global action effects for the structural components in question.

Table A.1 — Minimum local action intensities for decks

Area	Local design[a]		Factor to be applied to distributed action for:	
	Distributed action kN/m^2	Point action kN	Primary design[b]	Global design[c]
Storage area	*q*	1,5*q*	1,0	1,0
Laydown area	*q*	1,5*q*	*f*	*f*
Lifeboat platform	9,0	9,0	1,0	d
Area between equipment	5,0	5,0	*f*	d
Walkway, staircase and platform	4,0	4,0	*f*	d
Walkway and stairway for inspection and repair only	3,0	3,0	*f*	d
Roof accessible for inspection and repair only	1,0	2,0	1,0	d

q is to be evaluated for each case as follows:

— storage areas for cement or wet or dry mud should be 13 kN/m^2 or $\rho g H$, whichever is the larger,

where

ρ is the mass density (in kg/m^3),

g is the acceleration due to gravity (m/s^2), and

H is the storage height (m);

— laydown areas are not normally designed for less than 15 kN/m^2.

f is equal to either 1,0 or $(0{,}5 + 3/A^{0{,}5})$, whichever is the smaller, where A is the action area, expressed in square metres.

Wheel actions are to be added to distributed actions where relevant (wheel actions can normally be considered acting on an area of 300 mm × 300 mm).

Point actions are to be applied on an area 100 mm × 100 mm, and at the most severe position, but not added to wheel actions or distributed actions.

For actions on floors in accommodation and office sections, see ISO 2103[119].

Handrails should be designed for 1,5 kN/m, acting horizontally.

a Design of deck plates and stiffeners.

b Design of deck beams and beam columns.

c Design of deck main structure (and substructure). Global action cases should be established based upon “worst case”, representative variable action combinations, conforming to the limiting global criteria to the structure. For buoyant structures, these criteria are established by requirements to the floating position in still water, and intact and damage stability requirements, as documented in the MOM, considering variable actions on the deck and in tanks.

d May be ignored.

A.7.4 Environmental actions (E_e)

A.7.4.1 General

Environmental actions include, but are not limited to, actions caused by the following:

— wind;

— waves;

— currents;

— marine growth, snow and accumulated ice acting in conjunction with other metocean actions, and their effects on variable actions;

— ice sheets or floes;

— temperatures (including effects on material properties);

— earthquakes.

If special circumstances require consideration of seismic actions, reference should be made to ISO 19901-2[134].

An in-depth presentation of actions on general structural types is given in EN 1991[93].

A.7.4.2 Environmental site-specific data

Metocean statistics and characteristics are described in ISO 19901-1.

Global circulation currents are driven by large-scale global effects. Loop currents are associated with major ocean current circulation patterns, e.g. Gulf of Mexico loop current. Eddy currents are circulatory features shed from loop or other major circulation currents. Eddy currents can persist for several months or more. Internal waves are propagating waves that can occur at the interface between layers of fluids having different densities.

Marine growth is a common designation for surface growth on offshore structures, caused by plants, animals and bacteria. The marine growth characteristics are governed by the biological and oceanographic conditions at the actual site.

The specific gravity of marine growth is in the range of 1,0 to 1,4, depending on the type of organism.

A.7.4.3 Wind actions

For ship-shaped structures that are similar in profile to very large crude carriers (VLCCs), wind coefficients can be taken from Reference [151].

Consideration should also be given to wind-sensitive topsides structures, such as flare towers; see also ISO 19901-3.

A.7.4.4 Current actions

For ship-shaped structures that are similar in profile to VLCCs, current coefficients can be taken from OCIMF Prediction of Wind and Current Loads on VLCCs[151].

A.7.4.5 Wave actions

A.7.4.5.1 General

Wave actions can normally be determined using either a deterministic or a stochastic description of the waves. For application to floating structures, first and higher-order perturbation theories are generally used to describe the wave kinematics and resulting wave actions.

Examples of local hydrodynamic instabilities are the following:

— vortex shedding on slender components;

— galloping effects on non-circular slender elements.

A.7.4.5.2 Actions on large-volume bodies

No guidance is offered.

A.7.4.5.3 Actions on slender components

Additional guidance on the choice of the appropriate values for the drag and inertia coefficients is provided in ISO 19902, RCS rules and similar guidelines.

This document is not sufficiently detailed to host a discussion on the selection of appropriate hydrodynamic coefficients for floating (and fixed) structures in practical design. The coefficients specified in the normative text are considered minimum acceptable values to ensure an adequate level of safety.

Depending on the wave theory used, an equivalent force coefficient may be employed.

The inertia coefficient for floating structures (and for dynamically-sensitive structures) is different than that for static fixed structures. For floating structures, a higher drag coefficient can be unconservative because it increases the damping level and thus decreases the dynamic response.

Accordingly, valid reasons exist to use different coefficients for the analysis of a static fixed structure and the analysis of a floating (or a dynamically-sensitive) structure. This is further described in NORSOK N-003[144].

A.7.4.5.4 Slamming on slender components

Time duration and lengthwise extent of slamming actions need consideration. These are short duration events localized near the waterline and depend, among other things, on the rate of immersion of the component. Formula (5) is for instantaneous immersion of the entire component.

See References [61] and [154] for more information.

A.7.4.5.5 Higher-order non-linear wave actions

When a linear, regular, first order wave is interacting with itself and a floating structure, actions of different nature arise. In addition to first order linear exciting wave actions, mean non-linear second order forces (drift forces) and non-linear forces varying in time with twice the first order wave frequency act on the structure. Effects due to analytical formulations higher than second order are usually neglected.

Irregular, random waves are modelled as the sum of a large number of elementary waves of given frequencies and amplitudes (a wave spectrum). Superimposing the contributions of the elementary waves, the resulting second order exciting actions contain three components. These are the mean actions (drift), actions varying in time with a frequency equal to the frequency difference (slow drift), and actions varying in time with a frequency equal to the frequency sum (high-frequency actions).

The slow drift actions can be important for the design of stationkeeping systems for floating structures and for offshore loading systems. If current is present, the effect of the current on the mean drift actions and slow drift actions should be taken into account. These effects can alter the mean and varying actions and give rise to associated slow drift damping.

For large-volume structures with a small water-plane area, the slow drift actions can result in large vertical motions.

The sum frequency actions can have an important effect on the total wave action effects on certain types of floating structures. This phenomenon is often referred to as “springing” and is primarily associated with TLPs.

The higher-order action effects should be determined by a consistent higher-order theory with due reference to model tests.

A.7.4.5.6 Wave enhancement effects

No guidance is offered.

A.7.4.5.7 Shallow water effects

No guidance is offered.

A.7.4.5.8 Slamming and green water actions

Operational experience with trading and other ships has shown that slamming can result in structural damage, particularly on the ship's bottom forward.

The longitudinal extent of slamming depends on hull form and hull scantlings.

Slamming can result in high pressure on local structures and can cause damage in areas remote from the impact area, such as masts, crane posts, helideck supports, deckhouses, piping and equipment.

It is recommended that measurements be taken during the model testing programme to determine frequency, severity and extent of wave impact actions on the hull, so as to devise a suitable strategy for structural design.

Slamming can result in dynamic global bending moments and shear forces in the hull. First order (wave frequency) hull motions and slamming responses are both highest in waves of length approximately equal to the ship length. Slamming on both a flared bow and a flat forefoot can result in large moments. The flat forefoot is particularly susceptible to slamming at small draughts.

Recommended current state-of-the-art publications are References [46], [47], [48], [61], [102], [103], [154], [156] and [157].

A.7.4.6 Vortex-induced vibrations and motions

A.7.4.6.1 Simplified assessment of vortex-induced vibrations and fatigue

A simplified assessment of VIV-induced fatigue of a slender component may be performed using models linking the response amplitude to hydrodynamic parameters, such as reduced velocity, Keulegan-Carpenter number and current to wave flow ratio.

The following procedure may be applied:

a) Assume undisturbed current velocities by neglecting the influence of the waves.

b) Assume a representative velocity profile.

c) Identify the planes of vibration for the relevant mode shapes of the component.

d) Determine the natural frequencies and mode shapes for the component's bending in the cross-flow direction based on analytical models or by FE analysis.

e) Define a band of local vortex shedding frequencies f_S along and around the component using Formula (A.4) — typically Sr = 0,14 to 0,25.

f) For each modal frequency, identify the portions of the component that fall within the limits of the local shedding frequency.

g) Identify the most likely mode shapes to be excited by VIV and select the one with the highest curvature (typically, this is the mode with the highest frequency among the "probable modes"). Care should be taken to ensure that fatigue damage associated with other mode shapes is accounted for.

h) Assume a vibration amplitude of the component for the anticipated mode equal to Formula (A.1):

$$a_v = 1{,}3 \times d \quad \text{(A.1)}$$

where

a_v is the vibration amplitude;

d is the member outside diameter.

i) Compute the corresponding stress range [see Formula (A.2)]:

$$S = C_{SCF} E \kappa d \tag{A.2}$$

where

S is the stress range;

C_{SCF} is the stress concentration factor (if applicable);

E is the material (Young's) modulus;

κ is the curvature;

d is the member outside diameter.

j) Estimate the fatigue damage by application of the relevant S-N curve as Formula (A.3):

$$D = C_1 f_n T_1 S^m / C \tag{A.3}$$

where

C_1 is the average number of seconds per annum = 3,155 76 × 10^7 s.

D is the fatigue damage ratio;

f_n is the frequency of the relevant mode, expressed in hertz;

T_1 is the design service life of the member, expressed in years;

and where m and C are constants defining the S-N curve.

k) Then perform a weighted summation of computed damage over the long-term current distribution for velocities and direction.

A.7.4.6.2 Multi-modal response analysis based on empirical models

If significant VIV-induced fatigue damage is likely, more thorough calculations should be conducted. The next level of refinement typically involves methods for multi-modal response analysis based on empirical or semi-empirical values of the hydrodynamic coefficients. One way of achieving this is by application of a generalization of the procedure given in A.7.4.6.1. There are also two other main approaches for calculating the response, see A.7.4.6.3 and A.7.4.6.4.

A.7.4.6.3 Modal response in the frequency domain

This approach can incorporate general current profiles. Typically, a FE formulation is adopted. A correlation function for the loading process at two points along the component, as a function of their relative distance, is introduced. The parameters used in the model for the calculation of action and action effects generally require calibration with model field data.

A.7.4.6.4 Response in the time domain

For this approach a substantial database of cross-section tests is required giving hydrodynamic coefficients, frequencies and phase angles for various combinations of incident velocity and cross-section vibration. If a time domain simulation can be shown to give a statistically stationary response, a response spectrum can be constructed.

A.7.4.6.5 Methods based on solution of the Navier-Stokes equations

The analysis based on solution of the full Navier-Stokes equations consists of a set of 2D fluid-flow analyses for sufficiently many cross-sections along the component, including modelling of the dynamic boundary conditions. The direct solution of the complete flow formula is currently restricted to low Reynolds numbers (no turbulence in the near wake). Validation of the numerical results by sensitivity studies with respect to key parameters should accordingly be performed. Comparison with results obtained from full-scale or model experiments is also essential for calibration and fine-tuning of the numerical algorithms.

A.7.4.6.6 Methods for reduction of VIV

Particular emphasis should be given to those cases where the vortex shedding frequency is a multiple of one or more resonant frequencies.

The vortex shedding frequency is typically calculated from Formula (A.4):

$$f_s = Sr \frac{v}{d} \tag{A.4}$$

where

f_s is the vortex shedding frequency;

Sr is the Strouhal number;

v is the flow velocity normal to the slender member axis;

d is the member diameter.

Vortex shedding is related to the drag coefficient of the member considered. High drag coefficients usually accompany strong, regular vortex shedding or vice versa. Thus, the Strouhal number is a function of the Reynolds number for smooth, rounded members.

Moreover, for rounded, hydrodynamically smooth members, the vortex-shedding phenomenon is strongly dependent on the Reynolds number (Re) for the flow, as follows:

$1\times10^2 \le Re < 0{,}6\times10^6$	periodic shedding
$0{,}6\times10^6 \le Re < 3\times10^6$	wideband random shedding
$3\times10^6 \le Re < 6\times10^6$	narrowband random shedding
$Re \ge 6\times10^6$	quasi-periodic shedding

For rough members, the vortex shedding should be considered strongly periodic in the entire Reynolds number range.

For determination of the velocity ranges where vortex-shedding-induced oscillations can occur, a non-dimensional reduced velocity, v_r, is used [see Formula (A.5)]:

$$v_r = \frac{v}{f_m d} \tag{A.5}$$

where f_m is the natural frequency of the pipe.

Another parameter controlling the motions is the non-dimensional stability parameter for VIV, K_S, defined as in Formula (A.6):

$$K_S = \frac{2m_e\delta}{\rho_w d^2} \tag{A.6}$$

where

ρ_w is the mass density of seawater;

m_e is the effective mass per unit length;

δ is the generalized logarithmic decrement of damping defined by either Formula (A.7) or Formula (A.8):

$$\delta = \delta_s + \delta_h \tag{A.7}$$

or

$$\delta = 2\pi\xi \tag{A.8}$$

where

δ_s is the logarithmic decrement of structural damping;

δ_h is the logarithmic decrement of hydrodynamic damping;

ξ is the fraction of critical damping.

As a guideline, VIV in current and waves can occur when the parameter ranges in Table A.2 are fulfilled.

Table A.2 — VIV occurrence regions

Member located in	Cross-flow excitations		In-line excitations	
	v_r	K_S	v_r	K_S
Wind	$4,7 < v_r < 8,0$	$K_S \leq 25$	$1,7 < v_r < 3,2$	—
Current	$3,5 < v_r < 16,0$	—	$1,0 < v_r < 4,5$	$K_S \leq 1,8$
Waves (dominant) and current	$3,0 < v_r < 16,0$	—	$1,0 < v_r < 4,5$	$K_S \leq 1,8$

If the screening shows that VIV is likely to occur, the actions and effects arising from this phenomenon can be assessed using one of the following approaches, in order of increasing complexity:

a) simplified assessment of vortex-induced vibrations and fatigue (A.7.4.6.1);

b) multi-modal response analysis (A.7.4.6.2 to A.7.4.6.4);

c) computational fluid dynamics solving the Navier-Stokes formulae (A.7.4.6.5);

d) laboratory tests.

All four methods may be used for slender components (risers, umbilicals, tubular members, etc.), but only c) and d) apply to large-volume structures.

If the calculated VIV-response suggests potential problems, there are two main approaches for reducing the VIV effects:

— modification of the component properties, i.e. tension, diameter, structural damping;

— introduction of vortex suppression devices.

Several different methods exist for reducing the amplitude of VIV. It is usually possible to avoid the resonant cross-flow region when the highest reduced velocity is below 3,0, i.e. below the resonant region. To be well above the resonant area is much more complicated. There is always a higher natural mode with a frequency that corresponds to the vortex shedding frequency.

A second possibility is to add vortex suppression devices to the cylinders. These can be divided into the following three categories, according to the way they influence the vortex shedding:

— surface protrusions (wires, helical strakes, etc.) triggering separation;

— perforated shrouds, axial slats, etc. (breaking the flow into many small vortices);

— near wake stabilisers, preventing the building of the vortex street.

A.7.4.7 Direct ice action

See ISO 19906.

A.7.4.8 Temperature effects

No guidance is offered.

A.7.4.9 Tidal effects

No guidance is offered.

A.7.4.10 Geotechnical hazards

See ISO 19901-2[134].

A.7.5 Accidental actions (*A*)

A.7.5.1 General

Accidental actions typically result from, for example:

— collision/impact with or from a vessel, helicopter or other objects;

— dropped objects;

— fire and blast;

— change of intended pressure difference;

— leaks;

— unintended change in ballast distribution;

— unintended flooding of a hull compartment;

— failure of mooring lines(s);

— loss of DP system causing loss of heading;

— loss of propulsion or tug during transit to site leading to exposure to beam sea.

A.7.5.2 Collision

The energy absorbed by the floating structure during a collision impact is less than or equal to the total impact kinetic energy, depending on the relative stiffness of the impacted parts of the floating structure and the impacting vessel and also on the mode of collision and vessel operation. These factors may be taken into account when considering the energy absorbed by the floating structure.

For the North Sea and the Gulf of Mexico, typical standby vessel sizes and corresponding impact velocities are listed in Table A.3.

Table A.3 — Typical standby vessel sizes and impact velocities

Location	Typical vessel mass tonnes	Typical impact speed m/s
Northern North Sea	5 000	2,0
Southern North Sea	2 500	2,0
Gulf of Mexico	1 000	0,5

Typical added mass coefficients are 1,4 for broadside collisions and 1,1 for bow/stern collisions.

Reference should be made to IMO MARPOL and RCS stability rules or equivalent for typical collision zones.

A.7.5.3 Dropped object

No guidance is offered.

A.7.5.4 Fire and blast

When assessing blast overpressure actions and duration, consideration should be given to all relevant parameters, including the following:

— the stoichiometric composition of the explosive mixture;

— the position and volume of equipment, piping, etc., in the area;

— the venting arrangements, configuration of confining bulkheads, etc.;

— position of ignition within the area under consideration;

— dimensions of the area where the blast is expected to occur, etc.

The range of overpressures encountered in respect of hydrocarbon explosions in offshore oil and gas structures is normally about 0,5 bar although overpressures can occasionally reach values as high as 5 bar to 6 bar[2)].

A.7.6 Other actions

A.7.6.1 Stationkeeping actions

Action effects caused by the stationkeeping system are presented in ISO 19901-7.

A.7.6.2 Sloshing actions

Major factors involved in sloshing are the following:

— tank dimensions;

— filling level of tank;

— metacentric height;

2) 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2

— natural periods of structure motions and of cargo and/or ballast motions, usually in roll and pitch modes;

— floating structure draught.

A.7.7 Repetitive actions

No guidance is offered.

A.7.8 Action combinations

For many types of floating structure, it is not always obvious which metocean design situation controls the design. Identifying the most onerous maximum (or minimum) action effects and basing the design on them is a process often referred to as “response-based design”.

When actions act simultaneously, representative values may be determined based upon consideration of the joint probability of the events. In the absence of site-specific joint probabilities, combinations of environmental action events that can be considered for the ULS condition are listed in Table A.4.

Table A.4 — Recommended annual probability of exceedance, P_e, of selected action effects for combinations in the ULS condition

Combination	Action effect resulting from					
	wind	waves	current	ice/snow	earthquake	sea level
1	10^{-2}	10^{-2}	10^{-1}	—	—	10^{-2}
2	10^{-1}	10^{-1}	10^{-2}	—	—	10^{-2}
3	10^{-1}	10^{-1}	10^{-1}	10^{-2}	—	mean
4	—	—	—	—	2×10^{-2} [a]	mean

[a] Correspond to the minimum return period; see ISO 19901-2[134].

A.8 Global analysis

A.8.1 General

Floating structures are dynamically excited by wind, waves and current. Wave and current actions on the hull of a floating structure are covered by large-body hydrodynamic theory. In addition to ordinary wave frequency actions, these structures are also subject to slow-drift excitation from waves and wind. Some structural forms (e.g. spars) are also sensitive to vortex-induced motions due to current and waves – see References [163] and [164].

Floating structures are kept on location by stationkeeping systems, which generally consist of moorings, sometimes combined with thrusters, or dynamic positioning systems. The restoring force characteristics of a mooring system are given by the number of mooring lines, line layout pattern, pretension level, and restoring force characteristics of each line. Traditional catenary mooring lines are composed of wire and chain segments (often in combination with clump weights and buoys) to achieve the required restoring and line characteristics. Taut mooring lines are often used for deep water applications.

Depending on the structure’s functions, risers of various types and sizes connect the structure to the seabed, to pipelines, or to other field components. Riser tensions and pretensions act on the structure.

Mooring lines and risers are slender marine structures and have similar static and dynamic behaviour. It is therefore possible to apply the same methodology for global analysis of mooring lines and risers.

A more detailed description of the procedures to be used for the global analysis can be found in ISO 19901-7.

A.8.2 Static and mean response analyses

A.8.2.1 General

The most significant metocean actions for floating structures are normally those induced by wave actions. The characteristics of waves can either be described by deterministic design wave methods or by stochastic methods using wave spectra. Deterministic methods are used when sea states are represented by regular waves defined by wave height and wave period. Stochastic methods are used if the irregular nature of the sea is a significant design parameter. The sea states are then represented by wave spectra, which are characterized by significant wave height and peak spectral period or mean zero-crossing period.

Stochastic methods for response analysis of large body structures are in principle recognized as the best methods for simulating the irregular nature of wave actions. Computer tools for such analyses are available and global response is normally evaluated by stochastic methods.

Stochastic results are not well-suited for structural design, as simultaneity of the internal force/moment and stress distribution is lost. A regular wave analysis allows for evaluation of force/moment and stress distribution diagrams, while retaining phase information.

The preferred method for determining global responses is to undertake a long-term response analysis, calculated based on the site-specific wave scatter diagram. The short-term response can then be calculated with a long-term probability of exceedance during a specified time. An alternative to using the full scatter diagram is to develop a 100-year contour line on the scatter diagram and to calculate the global action effects for a range of short-term sea states on this contour line to find the maximum value. If contours are used, the uncertainty associated with the wave period should be accounted for.

The structural response of a floating structure is sensitive to wave period (length), e.g. maximum hull girder responses for ship-shaped structure structures often occur in sea states with waves of a length equal to the length of the floating structure.

A.8.2.2 Static equilibrium in still-water condition

No guidance is offered.

A.8.2.3 Mean response analysis

The response of the floating structure to mean metocean actions may be used for frequency domain analysis, or as the initial condition for time domain analysis. Additionally, the mean structure response is generally required for dynamic analyses of risers and moorings.

A.8.3 Global dynamic behaviour

Dynamic response may be computed in the frequency or time domain.

The linear response to steady state actions may be determined in the frequency domain.

Transient response is most easily determined in the time domain, or by using recognized charts or formulae for dynamic amplification.

A.8.4 Frequency domain analysis

The most significant limitation of frequency domain techniques is that all non-linearities in the formulae of motion are ignored or replaced by linear approximations. Typical non-linearities are introduced by viscous damping, drag-induced actions, time-varying geometry, horizontal restoring forces and variable water surface elevation. In most cases, these non-linearities can be satisfactorily linearized. This can be accomplished by linearizing a term about some operating point, or through another suitable technique (equivalent energy dissipation, etc.).

In cases where both time and frequency domain techniques can be considered, the frequency domain often has the advantage of fewer and simpler computations. In the case of large floating structures, where wave scattering and radiation is important, the inviscid hydrodynamic properties are most conveniently calculated in the frequency domain.

A.8.5 Time domain analysis

Time domain solution methods are often used for final, detailed design stages and for checks on frequency domain solutions. Furthermore, time domain methods are usually used for ULS and ALS analyses, but are not normally used for FLS analysis.

Guidance on the determination of extreme values from the results of a time domain analysis can be found in ISO 19901-7.

A.8.6 Uncoupled analysis

The second step is the time-consuming part of the uncoupled analysis and is normally carried out for critically loaded mooring lines and risers, one by one.

A.8.7 Coupled analysis

The main drawback to the coupled approach is that the computational effort needed is significantly higher than for the uncoupled analysis.

A.8.8 Resonant excitation and response

Examples of resonant responses generally not directly excited by linear wave actions are the following:

— the roll resonance of a barge/ship or of a spar with a low transverse metacentric height (GM);

— the heave resonance of spars or semi-submersibles;

— the surge, sway and yaw resonance of a moored floating platform;

— internal centre-well resonance;

— ballast or cargo tank sloshing modes.

Among mechanisms known to create resonant excitations, a general class exists called Mathieu instabilities. These occur in situations where the system stiffness varies with time. Mathieu instabilities are known to occur as a consequence of variable hydrostatic stiffness of a semi-submersible or spar.

A.8.9 Platform offset

No guidance is offered.

A.8.10 Air gap and wave crest assessment

No guidance is offered.

A.8.11 Platform motions and accelerations

No guidance is offered.

A.8.12 Model tests

The numerical predictions and model experiment results are complementary. Through careful interpretation, each of these results can be used to partially circumvent limitations of the other. One of the greatest values of model tests is that the results are obtained without requiring any a priori assumptions about the nature of the responses. This is almost never true of numerical models. On the other hand, limitations in model test facilities and scale effects normally require substantial interpretation of the results to translate them into full-scale ones.

The primary objectives of model tests fall into three broad categories:

a) to determine the response of a particular structural configuration;

b) to validate methods for analytical or numerical prediction of system responses;

c) to confirm that no extraordinary or unexpected behaviour of the tested configuration occurs.

Further information can be found in Reference [106].

A.8.13 Structural analysis

Full-scale measurements from similar structures may be used to support design assumptions and improve design estimates. In-service measurements may be used to confirm or improve design assumptions, and can provide a basis for revising earlier estimates of payload/operating limits and design service life.

A.9 Structural modelling, analysis and design

A.9.1 General

No guidance is offered.

A.9.2 Representative values of actions

A.9.2.1 General

No guidance is offered.

A.9.2.2 Representative values of actions for operating phases

No guidance is offered.

A.9.2.3 Representative values of actions for temporary phases

During the fabrication sequence, the actions acting on the structure generally depend on the following:

— the procedures and methods of erection and assembly followed by the yard;

— the facilities for handling and lifting the fabricated parts;

— the facilities used for the final outfitting (e.g. dock, slipway or quay).

Construction typically consists of prefabrication of small components and assembly of elementary blocks. After completion, the blocks are transported to the dock/slipway area for erection. The overall size and weight of the blocks are restricted by the production and hoisting capacity of the yard. The effect of lift-induced actions should be analyzed to ensure stress levels and deformations are acceptable.

On the dock/slipway the blocks are positioned and welded to adjacent structures. Particular consideration should be given to support arrangements and proper alignment between blocks. Internal forces can be minimized by proper erection and welding sequences.

The installation of the structure consists mainly of the installation of its stationkeeping system (the foundation at the sea floor and the mooring system) and the hooking up of the floating structure to this system.

In most cases the removal operation is the reverse sequence of the activities carried out for installation and, consequently, similar considerations apply.

A.9.2.4 Actions at interfaces

No guidance is offered.

A.9.3 Design scantlings

For ship-shaped structures, scantling considerations are specified in Reference [108].

A.9.4 Modelling

A.9.4.1 General

The extent of detail in a structural model is a balance between accuracy of results and limited resources. Model extent, FE type, element size, and level of detail should be consistent with the intended purpose of the structural model.

Appropriate element size is dependent on model function and stress gradient. In a global analysis, where the function of the model is to simulate global structural response and identify governing load cases, element sizes in the order of structural panel size (spacing between the main girders), or girder depth are generally appropriate. The element size should be sufficient to ensure connectivity of structural elements included in the model. For a local model, element size should be significantly reduced. To evaluate structural response near stress concentrations (regions of high stress gradient), the element size should generally be of the order of the plate thickness.

Mesh quality can significantly affect predicted stress response. Selection of element type, size and shape should be appropriate to the analysis being undertaken. Sharp transitions in element size can distort the stress flow through a structural component, hence element size transitions should be placed away from the area of interest. Mesh quality should be reviewed to verify that distorted (and/or elongated) elements are not in areas of high stress concentration.

Boundary conditions should be defined so as not to significantly affect the results of the analysis in a detrimental manner, e.g. artificially constrain, support or stiffen the structural model. Model boundaries should be located sufficiently far from the area of interest that they do not significantly alter the results.

Specialized elements (e.g. contact elements) and/or techniques (e.g. constraint equations) should be used with extreme caution due to the complexities introduced into the models.

Sub-modelling and sub-structuring techniques may be utilized. These techniques can require additional verification due to the complexities introduced into the modelling process.

FE analyses should be carried out with verified computer codes. Well-documented element types with a proven track record in offshore structural modelling should be used for analysis models. Modern elements can be used if sufficient validation is performed with comparisons to more mature technology.

A.9.4.2 Global models

Linear spring elements may be used to model mooring system stiffness provided the spring constants are calculated based on actual mooring system parameters. Ill-conditioning errors can occur where large rigid body displacements are required to obtain mooring force equilibrium. The possibility of such errors arising should be investigated. Where variations in mooring stiffness model parameters significantly affect responses, the acceptability of adopting linear spring elements should be evaluated.

For shell element or combined shell element/beam element global models, element size is normally similar to structural panel size. Where this is not possible, a less refined global model may be used to determine global response, which should then be mapped to a more detailed model (with limited extent) for structural evaluation. Primary stiffening (stiffeners and girders) may be modelled by beam elements.

A.9.4.3 Local models

For components subjected to well-defined local actions, manual calculations may be adequate provided they are based on well-established empirical formulae or basic engineering principles. The actions used in these calculations should be based upon global responses and local actions acting on the component.

A.9.4.4 Response evaluation

When real and imaginary stress data are combined to determine the maximum response within a wave cycle, attention should be given to the fact that derived stress components (e.g. equivalent and principal stresses) are non-linear combinations of the basic stress components and therefore non-harmonic in nature. Establishing maximum values for these derived stresses over a cycle of a complex action requires searching for the maximum value by stepping through the cycle. Stress data should be determined at each 5° to 10° of wave phase when searching for maximum response.

Typically, artificially high stress gradients can occur in the following cases:

— near constrained boundaries, except at natural constraints such as symmetry;

— near sharp transitions in finite-element size;

— at locations where shell and solid elements are joined using boundary elements or constraint formulae;

— at locations of artificially concentrated application of actions or forces.

Artificially low stress gradients typically occur in the cases where the element size is too large.

A.9.4.5 Model verification

Different action criteria and modelling techniques can be appropriate for different limit states. Different types of analysis can also be required for a given limit state, e.g. the analysis used for air gap as opposed to that used for ultimate strength for ULS.

A.9.5 Structural analysis

A.9.5.1 General principles

No guidance is offered.

A.9.5.2 Linear analysis

No guidance is offered.

A.9.5.3 Non-linear analysis

Generally, it is necessary to undertake parametric studies to evaluate different action histories to cover all modes of failure in structural components.

The ULS check is normally performed by carrying out a linear elastic response analysis of the structure to determine stresses or stress resultants (moments, forces) in the individual components, and checking that the ultimate capacity is adequate, component by component, using structural resistance formulations that can incorporate non-linear effects occurring at component collapse.

Component strength is normally determined by experimental methods, generalized by parametric or by non-linear structural analyses. If multiple stress/force components affect the component strength, the strength may be expressed by interaction equations.

A.9.6 Structural strength

References [2], [3], [24], [25], [78], [79], [80], [81], [86], [89] and [94] give guidance on ultimate and buckling strength design for a range of components and systems.

A.9.7 Design verification

A.9.7.1 General

The term *partial factor design format* is used in this document rather than the other definitions for this methodology *limit state design* (or *load and resistance factor design*).

Partial factor design and WSD approaches have been treated as parallel requirements in this document. The motivation for this parallel approach is the everyday use of both approaches by the offshore industry in different countries.

The current view is that WSD is simply a partial factor design where, for linear response, the whole safety factor is applied to the material. (For non-linear responses, such as buckling, further adjustments to the design formulae are made so that the WSD method remains compatible with the ULS.) Therefore, partial factor design can be considered as being valid when either WSD or partial factor methods are utilized.

A comparison of the methods can be made via parallel standards for offshore structures, including floating structures, for example DNV OS-C101[68] (partial factor) and DNV OS-C201[72] (working stress).

A.9.7.2 SLS deflection limits

Guidance for deflection limits for both primary and secondary load-carrying components is presented in Table A.5.

Table A.5 — Limit deflection criteria in the SLS

Structural member	Span/Deflection
Primary load-carrying components	>340
Secondary load-carrying components	>250

A.9.7.3 Partial factor design format

Background to the derivation of reliability levels for offshore structures can be found in Reference [100].

A.9.7.4 Working stress design format

No guidance is offered.

A.9.7.5 Reliability-based methods

In principle, the purpose of structural design is, amongst other objectives, to ensure an adequate reliability. General principles related to reliability-based structural design are documented in ISO 2394[120], while structural reliability of marine structures is addressed in Reference [88].

A.9.8 Special design issues

Sloshing is specifically addressed in BV Guidance Note NI 171[57].

Further information concerning green water and wave slam actions and effects can be found in References [46], [47], [48], [61], [102], [103], [154], [156] and [157].

A.9.9 Materials

A.9.9.1 General

BV Rule NR 216[49], DNV OS-B101[67] and DNV OS-C101[68] provide some guidance on materials applicable to offshore floating structures.

A.9.9.2 Material selection

Selection of a higher toughness grade at the design stage makes the structure more tolerant of fatigue cracks and more capable of redistributing forces away from overstressed areas.

A.9.9.3 Through-thickness tension

No guidance is offered.

A.9.9.4 Aluminium substructures

The mechanical characteristics of aluminium alloys should be determined in accordance with ISO 6361-1[121].

Eurocode 9[98] can be utilized for the general design of aluminium structures. The design of aluminium ships is addressed in BV Rule NR 561[52].

A.9.9.5 Cement grout

No guidance is offered.

A.9.9.6 Elastomeric material

For more information on elastomeric materials, see API RP 2T[23].

A.9.10 Corrosion protection of steel

Specific areas to be considered in the design of the corrosion protection system for the structure include the following:

a) External surfaces:

- underwater hull;
- waterline area;
- above waterline;
- deck areas;
- topsides.

b) Internal surfaces:

- void spaces (open and closed);
- machinery and equipment spaces;
- storage spaces;
- ballast tanks (active, passive, and reserve [dry]);

— cargo and slop tanks (tankers, barges);

— fuel tanks;

— fresh water tanks;

— drill water tanks;

— other tanks (e.g., brine).

Two types of systems (or approaches) are typically used to provide corrosion protection for the structure: coating (paint) systems and CP (sacrificial anodes, impressed current) systems. These systems are typically used in combination to provide a complete corrosion protection system for the structure. CP systems are far more effective when used with coatings because they then need only to protect against coating breakdown, see References [77] and [141]. CP systems are normally an aid for maintaining the condition of a coated structure and not a substitute for the coating.

The corrosion protection system requirements for a specific surface or tank depend on the type and required duration of service. For example, the system requirements can vary for an "active" ballast tank (i.e. tanks having continuous changing of sea water), "passive" ballast tanks (i.e. tanks maintaining a constant amount of sea water), cargo oil tanks, and drill water tanks. Additionally, the type of coating system selected (e.g. epoxy-base, "float-coat" type) depends upon the structure's inspection programme, in terms of personnel access and cleaning requirements.

When evaluating the requirements for a corrosion protection system, the following aspects should be among those considered:

— required design service life of the corrosion protection system;

— consequences of corrosion damage;

— accessibility for inspection, maintenance and repair;

— exposure to corrosion-aggressive environments;

— exposure to erosive environments or mechanical damage;

— the complexity of the local geometry;

— galvanic effects between different materials.

References [54], [60], [90], [95], [96] and [142] give some indication of requirements for corrosion protection.

Allowing for a diminution for structural hull thickness is discussed in Reference [91].

A.9.11 Fabrication and construction

Further information on general construction and repair principles can be found in Reference[111].

Weight control should be effected in accordance with the requirements of ISO 19901-5[135] for which, with respect to weight control classification, a floating structure should be treated as being of Class A.

In the areas surrounding critical connections, continuity of strength is normally maintained through joints with axial stiffening members and shear web plates being made continuous. Particular attention should be given to weld detailing and geometric form at the point of the intersections of the continuous plate's components with the intersecting structure. Guidelines on fabrication and testing of offshore structures are given in DNV OS-C401[74].

Welds at critical connections should have smooth profiles without undercut.

Penetrations through load-bearing structural members should be carefully detailed and, where necessary, reinforcement should be fitted. Evaluation of the structural strength adjacent to openings should include consideration in respect to both static and fatigue resistances. Penetrations through structural components critical to structural integrity should be minimized, and areas where penetrations are prohibited should be clearly shown on fabrication drawings.

A.9.12 Marine operations

A.9.12.1 General

Installation of a floating structure typically includes the following activities:

a) site survey;

b) installation of subsea infrastructure and subsea components, as applicable;

c) installation of floating structure;

d) installation of mooring system:

   — spread mooring, or

   — spider buoy deployment,

   — CALM system deployment, or

   — turret system deployment;

e) installation of riser systems;

f) installation and hook-up of well production, utility, process, and export systems;

g) installation of topsides facilities;

h) commissioning and start-up.

A.9.12.2 Site survey

Prior to the initiation of installation operations, a survey of the proposed installation site should be carried out, including a sea floor survey to ensure that no recent changes to the installation area (such as debris and cuttings, seabed movements) have occurred that could prevent installation of the sea floor components.

A.9.12.3 Installation plan

A plan outlining the methods and procedures should be prepared for each activity associated with the installation of the floating structure. This can be in the form of a written description, specifications, drawings, and/or engineering reports.

Restrictions or limitations to any of the installation operations due to metocean and ice conditions, hydrostatic stability, motions, structural strength, lifting capabilities, etc., should be clearly identified. The plan should define weather conditions, equipment status and logistic support under which installation operations should be

— initiated,

— suspended,

— terminated, and

— reversed for each major phase of the procedure.

Comprehensive contingency plans covering all phases of the installation should be included in the installation plans and procedures. Contingency plans should be developed to ensure that each phase of the installation operations could be reversed if a malfunction occurs.

A.9.12.4 Installation of mooring system

The mooring system should be installed as outlined in the installation plan specific to that operation. The plan should specify each mooring line length and the sea floor coordinates of anchors or piles.

A CALM system would require the installation of the mooring legs of the buoy first and subsequent connection of the buoy to the floating structure by hawser or yoke.

A turret mooring system can be internal or external to the structure, and can be either fixed or disconnectable. For a fixed turret system, the installation scenario would be similar to that of a spread mooring system used for a CALM. A disconnectable turret mooring system would require a multi-step installation.

A.9.12.5 Installation of riser systems

Procedures for running risers should be developed considering the following factors:

— water depth;

— type of riser system (e.g. integrated or non-integrated surface, or subsurface completion);

— type of connections and latching devices;

— whether buoyancy is included (either internal or external air cans or foam);

— whether guidelines are to be used or not.

A.9.12.6 Well production, utility, process, and export systems

Well production, utility, process and export systems should be installed and hooked-up in accordance with the applicable requirements. The process flow diagrams, process and instrumentation diagrams (P&IDs), piping drawings, schematics, arrangements drawings, and associated specifications should be strictly followed during the installation and hook-up of these systems.

A.9.12.7 Commissioning and start-up

Start-up and commissioning of the floating production platform should be carried out following the procedure outlined in the specific plan for this operation. Procedures should be developed to address all aspects of commissioning, start-up, and associated safety and execution activities.

A.9.13 Topsides/hull interface

General requirements and guidance applicable to topsides structural arrangements are given in ISO 19901-3. National regulations and requirements also apply, where they exist.

A.10 Fatigue analysis and design

A.10.1 General

Fatigue-related documents of general applicability in the design and assessment of floating structures include References [6], [15], [41], [59], [82] and [104].

A.10.2 Fatigue damage factors

An early source for the fatigue design factors was NORSOK N-004[145], where almost identical categories and similar factors were recommended but instead of the value 5,0 that appears in Table 5, the value 3,0 was adopted. ISO 19902 adopts similar categories (with the exception of "dry access") and identical safety factors. The reason for using 5,0 instead of 3,0 is to adopt the same logarithmic scale for safety factors as adopted for cycle numbers.

A.10.3 Outline of approach

No guidance is offered.

A.10.4 Metocean data for fatigue

No guidance is offered.

A.10.5 Structural modelling

No guidance is offered.

A.10.6 Hydrostatic analyses

No guidance is offered.

A.10.7 Response amplitude operators and combinations of actions

No guidance is offered.

A.10.8 Stresses and SCFs

— **Nominal and geometric stresses**:

In fatigue, a distinction is made between the classification (or nominal stress) method, in which SCFs are implicitly included in the design curve, and the geometric (or hot-spot) stress method where SCFs are explicitly accounted for and only weld notch effects are included in the corresponding S-N curve.

In components modelled by beam elements, nominal stresses are stresses that are parallel to the longitudinal axis of the component, i.e. axial stress, in-plane bending stress and out-of-plane bending stress. Shear and torsional stresses may be neglected. The structural geometric stress method is well established for tubular structures, and stress components should be combined in accordance with the requirements of ISO 19902.

For large, plated structures, geometric stress design methods are evolving. Shell or solid elements on the order of $T \times T$ (where T is the plate thickness) can be used at the points of stress concentration. The geometric stresses can be defined by surface stress extrapolation, or by extracting and extrapolating shell bending and membrane stresses to the toe of the weld. The corresponding S-N curves are similar to, or slightly below, those for tubular structures.

In the classification method, the nominal stress should be determined in a manner consistent with the stress determination used to establish the *S-N* curve for the detail (typically an area of 0,3 m × 0,3 m) and should have a clearly defined principal stress direction which is aligned with the way the detail was tested.

— **Stress concentration factors**

SCFs are necessary to account for local changes in geometry, such as at welds, changes in thickness or diameter, or offset of member centrelines.

In the geometric stress approach, parametric formulae and other published sources are available for the geometric SCFs of many common geometries (e.g. butt welds in pipes). Sources for SCFs for less common geometries are scarcer. Thus, FE modelling, physical models or other methods can be necessary to define these SCFs explicitly. Notch SCFs are included in the appropriate *S*-*N* curve category, so only the geometric SCFs should be considered.

It is critical that as-fabricated components conform to the limiting assumptions of the analytical model. Not only is it important to ensure that the defect size distribution of the fabricated component is less than the defect size analyzed, but also that the weld profile conforms to that modelled. This is especially important for areas such as the root of single-sided butt welds where the weld profile can be difficult to achieve and to inspect.

In fracture mechanics fatigue analyses, SCFs and their gradients are used to include notch effects in the stress intensity factor solution. The results of the fatigue crack growth rate and maximum tolerable flaw size calculations can be influenced by the values of the geometric and notch SCFs. Both global and notch geometry effects are included in the cyclic as well as the maximum stresses (see A.10.12). An effort should be made to capture the decay of the notch SCF as the crack progresses in from the surface.

A.10.9 Stress range counting and distribution

Frequency domain analysis is normally well suited for determining cyclic stress ranges for fatigue analyses. Stress histogram data generated from frequency domain analyses should include a sufficient number of stress blocks and wave approach directions to accurately represent lifetime stresses.

A simplified approach to stress range counting is to combine the distributions of stress ranges over a set of short-term sea states that correspond to the long-term occurrence of a particular fatigue design sea state, thereby determining a distribution of stress ranges for this longer period. In this case, it has been found that a two-parameter Weibull distribution is useful for an empirical representation of stress ranges.

Various improvements have been published to enhance cycle-counting formulae. Alternatively, realisations of stress time histories can be generated and rainflow-counting routines used to identify and count distributions of stress ranges. For a review and discussion of these methods, see Reference [40] or [41].

A.10.10 Fatigue resistance

The *S*-*N* approach assumes the availability of lower bound representative *S*-*N* curves for the components being analyzed. These curves are intended to be representative of material environment, cyclic stress range and frequency, mean stress and level of CP, as appropriate.

Residual stresses in or around welds can be assumed to have magnitudes equal to the yield stress in tension. Stress variations in or around welds can hence be assumed to always range downwards from the yield stress in tension. For fatigue-dominated conditions, applied stresses are typically less than half the yield stress; therefore, the associated stress ratio (maximum stress divided by minimum stress) is greater than zero. Consequently, for welded connections, stress range is the sole stress parameter that governs fatigue, while mean stress and stress ratio are unimportant parameters.

Weld improvement allowance may be considered, if necessary, during construction and/or at later assessments, although it is not good practice to allow for such effects at the design stage.

A.10.11 Damage accumulation

In some cases, the *S*-*N* curve is replaced by a discrete series of stress range steps (or bins) and the damage is accumulated on the basis of the accumulation of damage for each bin. In such cases, a minimum of twenty bins should be used to discretize a continuous *S*-*N* curve.

Closed-form expressions are available for integration of accumulated damage for Rayleigh and Weibull distributions of stress ranges applied in conjunction with piecewise linear *S*-*N* curves. These are usually expressed in terms of gamma functions and incomplete gamma functions. It is important to check the definitions of these functions, since different definitions and normalization conventions are applied.

Fatigue damage from multiple simultaneous sources (e.g. wave frequency actions, slowly varying second order wave actions, wind actions and vortex-induced vibrations) should be calculated by adding the stresses, followed by raising the combined stress range to the power *m* (from the *S*-*N* curve). Calculating fatigue damage independently from separate sources can be seriously unconservative.

Normally, potential accidental damage (e.g. a dented panel following boat impact) may be ignored in fatigue assessments because such damage lasts a relatively insignificant period relative to the design service life. However, where a preferred orientation or listed attitude of a damaged floating structure is liable to generate large fatigue actions on critical structural components, the likely rate of such fatigue damage should be checked.

A.10.12 Fracture mechanics methods

Fatigue damage estimates may be undertaken by the use of fracture mechanics methods[42][43][44]. The fatigue damage is a function of the range of stress intensity, initial and final flaw sizes, and material crack growth constants from the Paris formula. The Paris law variable ΔK is the stress intensity factor range and is defined as a single term parameter that incorporates the effect of changing crack length as well as stress magnitude range. The parameter ΔK may be calculated from available solutions for an assumed crack model at each increment of crack growth, given the crack geometry and the applied cyclic stresses.

In fracture mechanics assessment of a defect, a failure criterion should be defined to set the amount of crack propagation allowed in a component prior to failure. The maximum total stress relevant for a design situation, including the maximum stress and any relevant residual stresses, should be used in the assessment.

The crack model assumed for the stress intensity factor solution should reflect the as-fabricated geometry, including local stress concentrations and plausible initial flaw locations, types and sizes. Realistic account of the life expended in crack initiation should be included as this can represent a substantial portion of the design service life, for non-welded details in particular. The cyclic stress range that is used in the calculation of the stress intensity factor range is the stress range modified by an appropriate SCF. The stress intensity factor should include the effects of local geometry and all applied membrane and bending stresses.

A.10.13 Fatigue-sensitive components and connections

Experience from tankers operating in the UK North Sea shows that longitudinal cracks can occur in the fillet weld between longitudinals/stringers and the side shell. The cracks were found to be associated with s/T ratios larger than 50 (where s is the spacing between longitudinals/stringers and T is the plate thickness). The cracks are typically caused by three mechanisms: local plate bending due to lateral pressure, twisting caused by unsymmetrical longitudinals/stringers, and deflection of the primary members of the hull girder (stringer deflection). Consequently, low s/T ratios should be chosen during design, and fatigue assessment should be performed in sizing the proposed scantlings.

A.11 Ship-shaped structures

A.11.1 General

General guidance on ship-shaped floating structures is given in RCS rules, for example References [53], [63] and [138], while a rational approach to the basic ship-shaped structure configuration selection is presented in Reference [162].

Examples of special areas for ship-shaped structures are the following:

— tank bottoms for corrosion;

NOTE Corrosive environments can exist under accumulations of sludge in the bottoms of cargo tanks, and given the access and planning difficulties described in this clause, an owner can decide to invest more time and effort during the design and fabrication phases to ensure that some areas are more fully protected against corrosion and fatigue.

— salt water ballast tanks and tops of cargo tanks, for corrosion;

— stiffener/bulkhead and stiffener/bulkhead/side-shell connections, both in the outer shell (due to wave action), and in cargo tanks (which can experience prolonged, severe sloshing actions), for fatigue;

— turret mountings and bearings, for hull flexure effects;

— mooring attachment details, for fatigue, corrosion and wear;

— cargo handling systems and equipment, for corrosion;

— structural supports and deck equipment, for green water impact actions;

— riser terminations and restraints (usually in the turret area), for fire hazard.

In addition, the following areas should be examined for adequate fatigue life in the midship area, turret area, and in the fore-most and aft-most cargo tank areas:

a) representative attachments and penetrations to main deck and bottom plating;

b) bottom, inner bottom, side shell, inner side, longitudinal bulkhead and deck longitudinal end connections to transverse frames and transverse bulkheads;

c) end connections/bracket terminations (bracket toe and flange toe) of transverse frames;

d) end connections (corner details)/bracket terminations of longitudinal stringers;

e) block erection butt welds in deck and bottom plating;

f) topsides and crane supports to deck (and relevant welds below deck);

g) turret hull girder support structure;

h) representative scallops and mouse holes of structural connections adjacent to deck and bottom plating and at side shell;

i) at the details of scallops in transverse girders (at penetrations for the longitudinals);

j) upper and lower knuckles of transverse frames;

k) hopper knuckle, horizontal stringer to bulkhead connections, cross ties and bilge keels.

Ship-shaped structures based on converted tankers, which can have void or water ballast tanks in the side, concentrated around midships, can experience relatively large hull girder bending moments in the case where two adjacent tanks are damaged. Such bending moments can exceed the minimum RCS rules for the intact structure by a significant percentage. Consequently, in addition to a check on the structure's stability (see Clause 16), the residual strength of the hull girder should be verified in the damaged condition.

A.11.2 General design criteria

A.11.2.1 Collision protection

IMO MEPC/Circ.406 is a comprehensive document describing minimum requirements and the application of double sides or other means of limiting pollution in case of a collision, for both new-build FPSOs/FSUs and conversions. IMO MEPC/Circ.406 provides guidance on how to apply requirements written for tankers to FPSOs and FSUs.

For new-build tankers, IMO MARPOL requires a double hull. For new-build FPSOs, IMO MEPC/Circ.406 reduces this to double sides.

IMO MARPOL allows the operation of existing single-hull tankers for a number of years, depending on their age and design. The principle is that in the course of time single-hull tankers disappear (they are “phased-out”). IMO MARPOL Regulation 13G describes this process in detail. IMO MEPC/Circ.406 allows the conversion of existing single hull tankers into FPSO/FSU, independent of their age, provided that a number of other requirements stated in IMO MARPOL are met. IMO MARPOL Regulation 13G is, according to IMO MEPC/Circ.406, not applicable to FPSOs or FSUs.

In this document, the determination of a suitable collision protection is based on the assessment of the collision risk. Where collision risk is reduced by the use of ballast tanks and void tanks in the side, these tanks should be effectively spread over the floating structure length to mitigate the impact of damaged and flooded tanks on damaged stability and residual hull girder strength.

IMO MARPOL requirements for tankers are generally enforced by, or on behalf of, a flag state. Ship-shaped structure floating structures used for storing oil are generally regulated by the coastal state (referred to as the "national authority" in this document). IMO MEPC/Circ.406 gives guidance and recommendations to the coastal states on how to apply IMO MARPOL, Annex 1, to FPSOs and FSUs. This document requires conformity with the guidelines contained in IMO MEPC/Circ.406 as a minimum, whether the floating offshore structure is flagged or not, and whether required by the national authorities or not.

National authorities can overrule flag states and impose stricter double hull requirements on the floating offshore structures under their jurisdiction.

A.11.2.2 Deckhouse requirements

No guidance is offered.

A.11.2.3 Sloshing

References for sloshing are given in A.9.8.

A.11.2.4 Green water

References for green water action and related design issues are presented in A.7.4.5.8.

A.11.3 Structural strength

A.11.3.1 General

No guidance is offered.

A.11.3.2 Scantlings

Scantling requirements in the various RCS rules generally give similar outcomes. However, when dealing with ship-shaped structures in benign waters, the permitted reductions on scantlings compared with the unrestricted service condition requirements vary significantly. As very little technical material was available to substantiate the use of any particular level of reduction, the most conservative of the RCS permitted reductions has been adopted in this document.

A.11.3.3 ULS–a and ULS–b longitudinal strength design verification

A.11.3.3.1 General

Wave-induced bending moments and shear forces should normally be determined as indicated, i.e. by reference to Clause 9. For conceptual or preliminary design, RCS rules formulations provide appropriate preliminary values, except in the case of wave-induced vertical shear forces when the following formulae provide more suitable positive and negative envelope values [see Formulae (A.9) and (A.10)]:

$$Q_{\text{wv-pos}} = 0{,}45 f_{\text{qwv-pos}} C_{\text{wv}} LB\left(C_{\text{b}} + 0{,}7\right) \tag{A.9}$$

$$Q_{\text{wv-neg}} = -0{,}45 f_{\text{qwv-neg}} C_{\text{wv}} LB\left(C_{\text{b}} + 0{,}7\right) \tag{A.10}$$

where

$Q_{\text{wv-pos}}$ is the positive wave-induced vertical shear force, expressed in kilonewtons;

$Q_{\text{wv-neg}}$ is the negative wave-induced vertical shear force, expressed in kilonewtons;

$f_{\text{qwv-pos}}$ is the distribution factor for positive wave-induced vertical shear force along the floating structure length, to be taken as:

= 0,0	at the aft perpendicular (AP)
$= 1{,}59 \dfrac{C_{\text{b}}}{C_{\text{b}} + 0{,}7}$	for 0,2L to 0,3L from AP
= 0,7	for 0,4L to 0,6L from AP
= 1,0	for 0,7L to 0,85L from AP
= 0,0	at the forward perpendicular (FP)

and where, for values of L between those specified, the distribution factor is determined by interpolation;

$f_{\text{qwv-neg}}$ is the distribution factor for negative wave-induced vertical shear force along the floating structure length, to be taken as:

= 0,0	at the AP
= 0,92	for 0,2L to 0,3L from AP
= 0,7	for 0,4L to 0,6L from AP
$= 1{,}73 \dfrac{C_{\text{b}}}{C_{\text{b}} + 0{,}7}$	for 0,7L to 0,85L from AP
= 0,0	at the FP

and where, for values of L between those specified, the distribution factor is determined by interpolation;

C_{wv} is the wave coefficient, to be taken as:

$= 10{,}75 - \left(\dfrac{300 - L}{100}\right)^{1{,}5}$	for $150 \leq L \leq 300$
= 10,75	for $300 < L \leq 350$

$$= 10{,}75 - \left(\frac{L-350}{150}\right)^{1{,}5} \quad \text{for } 350 < L \leq 500;$$

L is the length between perpendiculars, expressed in metres;

B is the moulded breadth, expressed in metres;

C_b is the block coefficient.

A.11.3.3.2 Partial factor design format

The partial factors prescribed for use in Formula (11) are based on those given in Reference [146]. The reason for selecting this set of factors was that, at the time of development of the first edition of this document, few other sets of requirements for ship-shaped offshore structures provided appropriate ULS factors.

The magnitudes of the partial factors are such that when the moment is at one of the extremes, i.e. pure still water moment or pure wave-induced moment, the product of the partial load and resistance factors approaches 1,50. When the moment is an equal combination of still water moment and wave-induced moment, the combined partial factors produce an overall safety factor of 1,24.

In contrast, under sagging conditions the overall safety factor for tanker structures, designed in accordance with the hull girder ultimate strength requirements of Reference [108], varies from 1,10 for still water-dominated conditions to 1,43 for wave-dominated conditions, and under hogging conditions from 1,21 for still water-dominated conditions to 1,45 for wave-dominated conditions.

Under wave-dominated conditions, the smaller overall safety factor required for tankers is not unexpected given the shorter design return period to which it relates, 20 years, compared with the 100 years for structures designed in accordance with this document. This difference in return period does not, however, explain the larger factor adopted in this document for still water-dominated conditions compared with that required of tankers.

A review[101] of 2014 FPSO requirements[16][69] found that partial factors for their sizing had generally reduced compared with those adopted for use in Formula (11). However, there was no industry consensus of how the factors in Formula (11) could be accordingly adjusted.

A.11.3.3.3 Working stress design format

For structures designed to WSD, RCS rules typically specify a utilization factor less than unity as a means of restricting the applied stress caused by the moment (or shear) to a proportion of yield stress. The proportion usually depends on whether the stress is a single stress value or a combined stress value calculated via the Maxwell-Huber-Hencky-von Mises criterion (usually referred to as the von Mises stress). For example, Reference [108] limits the von Mises stress in a mild steel ship deck or bottom to 80 % of yield, a proportion that reduces as yield strength increases. Such first yield checks underestimate the ULS bending strengths of ships with stocky cross-sections because of the additional capacity available from plastic moment behaviour.

In contrast to the tanker requirements which relate to first yield, the WSD check Formulae (13) and (14) refer to ultimate bending strength of the hull girder. Thus, for comparison between the overall safety factors for tankers and those for floating offshore structure, the difference between first hull girder yielding and hull girder ultimate bending strength should be taken into account together with an allowance for the difference in design return periods. Expressed in utilization factor terms, a value of 0,75 is appropriate which, when converted into a safety factor, and rounded toward the average value adopted in the partial factor design approach, leads to a C_{SF} value of 1,34.

A.11.3.4 Local strength and details

No guidance is offered.