
**Petroleum and natural gas
industries — Concrete offshore
structures**

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

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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 replaces the first edition (ISO 19903:2006). The main changes compared to the previous edition are:

- update of the document to reflect the updated editions of the International Standards on offshore structures prepared by TC 67;
- clarifications on the use of reference standards for design;
- extension of scope to design of floating concrete offshore structures, including removing “fixed” from the title of this document;
- clarifications on the selection of soil parameters for soil-structure interaction in [7.3.3](#);
- Additional information on the dynamic aspects pertaining to floating concrete structures in [7.4.2.1](#).

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, ISO 19904-1, 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 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 nature or combination of the 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 such 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 67 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 based on experience gained from the design, execution and use of a number of fixed concrete platforms, in particular from more than 40 years of experience with such structures in the North Sea. The background documents used for developing this document are from the following types:

- national regulations and other requirements from the authorities;
- regional standards;
- national standards;
- operator's company specifications;
- scientific papers and reports;
- reports from inspection of structures in use.

This document applies the concept of a reference standard for design. The text that previously referred to NS 3473.E, the former Norwegian standard for concrete design that was widely used for the design of fixed offshore concrete platforms, has been amended in this document, since, as part of the Eurocode programme, NS 3473.E has been withdrawn and is no longer maintained.

This document now draws on the experience gained with fixed and floating concrete offshore structures. This experience shows that concrete offshore structures perform well and are durable in the marine environment. These structures are all unique, one-of-a-kind structures, purpose-made for a particular location and a particular set of operating requirements. This document reflects, in particular, the experience and the conditions in the North Sea and the east coast of Canada, and the design rules and practices used there, but is intended for worldwide application.

In order to provide a standard that will be useful to the industry, a comprehensive treatment of some topics is provided where there is currently no other relevant reference. For such well-known topics as the design formulae for concrete structural members, this document is intended to be used in conjunction with a suitable reference standard for basic concrete design (see [8.1.1](#)). The designer can use suitable national or regional design standards that provide the required level of safety.

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Petroleum and natural gas industries — Concrete offshore structures

1 Scope

This document specifies requirements and provides recommendations applicable to fixed, floating and grounded concrete offshore structures for the petroleum and natural gas industries and for structures supporting nationally-important power generation, transmission or distribution facility. This document specifically addresses

- the design, construction, transportation and installation of new structures, including requirements for in-service inspection and possible removal of structures,
- the assessment of structures in service, and
- the assessment of structures for reuse at other locations.

This document is intended to cover the engineering processes needed for the major engineering disciplines to establish a facility for offshore operation.

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 4463-1, *Measurement methods for building — Setting-out and measurement — Part 1: Planning and organization, measuring procedures, acceptance criteria*

ISO 16204, *Durability — Service life design of concrete structures*

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 19901-2, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 2: Seismic design procedures and criteria*

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

ISO 19901-4, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 4: Geotechnical and foundation design considerations*

ISO 19901-5, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 5: Weight control during engineering and construction*

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

ISO 19901-8, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 8: Marine soil investigations*

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

ISO 19904-1, *Petroleum and natural gas industries — Floating offshore structures — Part 1: Monohulls, semi-submersibles and spars*

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

ISO 22966, *Execution of concrete structures*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19900 and the following apply.

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 abnormal design situation

design situation in which conditions exceed conventionally specified design conditions and which is used to mitigate against very remote events

Note 1 to entry: Abnormal design situations are used to provide robustness against events with a probability of typically 10^{-4} per annum or lower by avoiding, for example, gross overloading.

3.2 abnormal level earthquake ALE

intense earthquake of abnormal severity under the action of which the *structure* (3.51) should not suffer complete loss of integrity

Note 1 to entry: The ALE event is comparable to the abnormal event in the design of structures which are described in ISO 19901-2 and ISO 19902. When exposed to the ALE, a manned structure is supposed to maintain structural and/or floatation integrity for a sufficient period of time to enable evacuation to take place.

3.3 accidental design situation

design situation involving exceptional conditions of the *structure* (3.51) or its exposure

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

3.4 action

external load applied to the *structure* (3.51) (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. An imposed acceleration can be caused by an earthquake

[SOURCE: ISO 19900:2019, 3.3]

3.5 action effect

result of *actions* (3.4) on structural components or on the structure

EXAMPLE Internal force, moment, stress or strain; deflection rotation

[SOURCE: ISO 19900:2019, 3.4]

3.6 addition

finely divided material used in *concrete* (3.12) in order to improve certain properties or to achieve special properties

Note 1 to entry: This document deals with two types of inorganic additions:

- nearly inert additions (type I);
- pozzolanic or latent hydraulic additions (type II).

3.7 admixture

material added during the mixing process of *concrete* (3.12) in small quantities related to the mass of cement to modify the properties of fresh or hardened concrete

3.8 aggregate

granular mineral material suitable for use in *concrete* (3.12)

Note 1 to entry: Aggregate can be natural, artificial or recycled from material previously used in construction.

3.9 air cushion

air pumped into underbase compartments of the *structure* (3.51)

Note 1 to entry: The air cushion is normally applied in order to reduce the draft and increase the freeboard of the structure and/or to alter the structural loading.

3.10 atmospheric zone

part of the load-bearing *structure* (3.51) that is above the *splash zone* (3.50)

3.11 caisson

major portion of *concrete* (3.12) offshore *structure* (3.51), providing buoyancy whilst afloat and the possibility of oil storage within the structure

Note 1 to entry: The caisson is generally divided into watertight compartments, which can be subdivided into intercommunicating cells for structural reasons. The caisson can also be filled, or partly filled, with ballast water and *solid ballast* (3.49).

3.12 concrete

material formed by mixing cement, coarse and fine *aggregate* (3.8) and water, with or without the incorporation of *admixtures* (3.7) and *additions* (3.6), which develops its properties by hydration of the cement

3.13 condition monitoring

evaluation of the condition and behaviour of the load-bearing *structure(s)* (3.51) in service using data from design, *inspection* (3.29) and *instrumentation* (3.31)

3.14 construction afloat

fabrication, construction and related activities taking place on a *structure* (3.51) that is afloat, normally at an inshore location and restrained by a temporary mooring system

3.15

deck mating

marine operation (3.35) in which the platform *topsides* (3.55) is floated into position and connected to the substructure

Note 1 to entry: This operation is normally conducted by ballasting and deballasting of the substructure.

3.16

deep water construction site

site for construction of the *structure* (3.51) while afloat

Note 1 to entry: The use of a deep water site might not always be required, depending on the construction method. It might or might not be the same location as that where mating of *topsides* (3.55) to the substructure takes place.

3.17

design rule

rule in accordance with the chosen reference standard for *concrete* (3.12) design

Note 1 to entry: See 8.2.

3.18

design wave

deterministic wave used for the design of an offshore *structure* (3.51)

Note 1 to entry: The design wave is an engineering abstraction. Most often it is a periodic wave with suitable characteristics (e.g. height H , period T , steepness, crest elevation). The choice of a design wave depends on:

- the design purpose(s) considered;
- the wave environment;
- the geometry of the structure;
- the type of *action(s)* (3.4) or *action effect(s)* (3.5) pursued.

Note 2 to entry: Normally, a design wave is only compatible with design situations in which the action effect(s) are quasi-statically related to the associated wave action on the structure.

[SOURCE: ISO 19901-1:2015, 3.5]

3.19

dynamic amplification factor

ratio of a dynamic *action* (3.4) effect to the corresponding static *action effect* (3.5)

Note 1 to entry: An appropriately selected dynamic amplification factor can be applied to static actions to simulate the effects of dynamic actions.

3.20

extreme level earthquake

ELE

earthquake with a severity which the *structure* (3.51) should sustain without major damage

Note 1 to entry: The ELE event is comparable to the extreme environmental event in the design of structures which are described in ISO 19901-2 and ISO 19902. When exposed to an ELE, a structure is supposed to retain its full capacity for all subsequent conditions.

3.21

execution

activities carried out for the physical completion of the *works* (3.55), including procurement, *inspection* (3.29) and documentation thereof

Note 1 to entry: The term covers work on site; it might also signify the fabrication of components off-site and their subsequent erection on site.

3.22**exposure level**

classification system used to establish relevant criteria for a *structure* (3.51) based on consideration of life-safety and of environmental and economic consequences of failure

Note 1 to entry: The method for determining exposure levels is described in ISO 19900. An exposure level 1 platform is the most critical and an exposure level 3 the least. A normally manned platform that cannot be reliably evacuated before a design event will be an exposure level 1 platform.

[SOURCE: ISO 19900:2019, 3.20, modified — “consideration of life-safety and of environmental and economic” has been added to the definitions and the Note 1 to entry has been added.]

3.23**finite element analysis**

analysis method whereby a *structure* (3.51) or a part thereof is subdivided into small elements of known or assumed behaviour, then analyzed by numerical matrix methods to determine *action* (3.4) effects, static or dynamic

3.24**fixed concrete offshore structure**

concrete (3.12) *structure* (3.51) designed to rest on the sea floor

Note 1 to entry: Sufficient structural stability can be achieved through its own weight, or in combination with suction in skirt compartments, or founding of the structure on piles into the seabed. It includes the mechanical outfitting of the structure.

3.25**fixed structure**

structure (3.51) that is bottom founded and transfers most *actions* (3.4) on it to the seabed

[SOURCE: ISO 19900:2019, 3.24, modified — “all” has been changed to “most”.]

3.26**floating concrete offshore structure**

concrete structure (3.51) where the full weight is supported by buoyancy

3.27**float-out**

transfer of a major assembly from a dry construction site to a self-floating condition

Note 1 to entry: Typically, it is the transfer of the lower part of the *concrete* (3.12) *structure* (3.51) from a flooded drydock.

3.28**global analysis**

determination of a consistent set of either internal forces and moments or of stresses for a complete *structure* (3.51) usually resulting from the *finite element analysis* (3.23).

3.29**inspection**

conformity evaluation by observation and judgement accompanied, as appropriate, by measurement, testing or gauging to verify that the *execution* (3.21) is in accordance with the *project work specification* (3.44)

3.30**installation**

marine operation (3.35) in which the platform is positioned and set down on the sea floor at the *offshore site* (3.38)

**3.31
instrumentation**

outfitting of a *concrete* (3.12) offshore *structure* (3.51) with instruments for data measurement and recording

**3.32
interface manual**

document defining all interfaces between the various parties and disciplines involved in the design and construction, ensuring that responsibilities, reporting and information routines, as appropriate, are established and maintained

**3.33
lightweight aggregate**

aggregate (3.8) of mineral origin having an oven-dry particle density 2 000 kg/m³ or a loose oven-dry bulk density 1 200 kg/m³

**3.34
local analysis**

determination of a consistent set of internal forces and moments, or stresses, in a cross-section of a structural component, or in a subset of structural components forming part of the structural system, that are in equilibrium with the boundary conditions

**3.35
marine operation**

planned and controlled vertical or horizontal movement of a *structure* (3.51) or component thereof over, in or on water

**3.36
method statement**

document stating the methods and *procedures* (3.42) used to perform the *work* (3.56)

**3.37
normal-weight aggregate**

aggregate (3.8) with an oven-dry particle density between 2 000 kg/m³ and 3 000 kg/m³

**3.38
offshore site**

offshore location where the *structure* (3.51) is installed for its operational life

**3.39
operations manual**

document giving the requirements and restrictions related to a safe operation of the *concrete* (3.12) *structure* (3.51) and all its systems

**3.40
owner**

representative of the companies which own a development

Note 1 to entry: The owner will normally be the operator on behalf of co-licensees.

**3.41
primary structure**

all main structural components [*concrete* (3.12) or steelwork] that provide the *structure's* (3.51) main strength and stiffness

**3.42
procedure**

document that describes a specified way to carry out an activity or a process, the detailed sequence and interrelationships required for the completion of a particular task

3.43**project specification**

document giving the overall technical requirements provided by the *owner* (3.40)

3.44**project work specification**

information and technical requirements necessary for the *execution* (3.21) of the *works* (3.56), including documents and drawings, etc., as well as references to relevant regulations, specifications, etc.

3.45**quality plan**

document specifying the *procedures* (3.42) and associated resources to be applied, and by whom and when, covering the entire project or defined parts of the project and all relevant products, processes or contracts

3.46**secondary structure**

structural components that do not contribute significantly to the overall strength and stiffness of the *structure* (3.51) but which support individual items of equipment, transferring the *actions* (3.4) thereon onto the *primary structure* (3.41)

3.47**shaft**

compartment extending from the *caisson* (3.11) of the *concrete* (3.12) offshore *structure* (3.51) to the *topsides* (3.55)

Note 1 to entry: A shaft is generally used to house and support the wells (drill shaft), mechanical systems (utility shaft) and risers and J-tubes (riser shaft). The part of a shaft extending above a caisson is also often referred to as a leg.

3.48**skirt**

structural component constructed in *concrete* (3.12) and/or steel that is part of the foundation and penetrates into the seabed

Note 1 to entry: Skirts are used to increase the capacity of the foundation to resist vertical and horizontal *actions* (3.4) and improve erosion resistance. Skirts can also be needed to form compartments facilitating the under-base grouting.

3.49**solid ballast**

non-structural material added to a *structure* (3.51)

Note 1 to entry: Solid ballast is normally applied in order to increase the self-weight of the structure or to lower the centre of gravity for floating stability purposes.

3.50**splash zone**

area of a *structure* (3.51) that is frequently wetted due to waves and tidal variations

3.51**structure**

combination of physically connected structural components designed to withstand *actions* (3.4) and provide adequate rigidity

[SOURCE: ISO 19900:2019, 3.53, modified — added text from "designed".]

3.52**submerged zone**

part of the *structure* (3.51) that is normally submerged and exposed to the constant influence of sea water

3.53

subsidence

part of the settlement of the *structure* (3.51) that results from extraction of reservoir hydrocarbons and factors other than the weight of the structure

3.54

summary report

document including the most important assumptions on which the design, construction and *installation* (3.30) work is based with regard to the load-bearing *structure* (3.51)

3.55

topsides

structure (3.51) and equipment placed on a supporting *structure* (3.51) (fixed (3.25) or floating (3.26)) to provide some or all of a platform's functions

Note 1 to entry: A separate fabricated deck or module support frame is part of the topsides.

[SOURCE: ISO 19900:2019, 3.54, modified — Notes 1 and 2 to entry have been omitted.]

3.56

works

construction work described in the *project work specification* (3.44)

3.57

works certificate

mill certificate

document issued by the manufacturer or a testing institute certifying the materials delivered, and giving

- test method, specifications and criteria (e.g. test standard used),
- all relevant test data,
- certification that the tests have been carried out on samples taken from the delivered products, and
- all necessary information for identification of product, producer and purchaser.

Note 1 to entry: A works certificate is normally required for construction materials that are not subject to an accepted certification scheme.

4 Symbols and abbreviated terms

4.1 Symbols

A	accidental action
A_c	actual surface area to be protected
a	mass content of the active addition (type II)
C_a	total current capacity of the anodes
c	cement mass content
c_a	current capacity of an anode
D	action due to imposed deformation
d	depth from the compressive side of the cross section to the centre of the tensile longitudinal reinforcement on the opposite side

E	environmental action
E°_a	design closed-circuit anode potential
E°_c	design protective potential
f_c	coating breakdown factor for any coated surfaces ($f_c = 1$ for bare steel)
F_{ck}	characteristic compressive strength of concrete
F_{cn}	nominal compressive strength of concrete
F_{yk}	characteristic strength of steel
G	permanent action
I_a	anode current output
$I_{a,initial}$	initial current output
$I_{a,final}$	final current output
I_c	current demand
$I_{c,average}$	average current demand
$I_{c,initial}$	initial current demand
$I_{c,final}$	final current demand
i_c	design current density
k	factor which takes into account the activity of a type II addition
L	lap length
M_x, M_y, M_{xy} N_x, N_y, N_{xy}	six force components giving stresses in the plane of the member
m	effective water/cement ratio
m_T	total net anode mass
n	number of anodes
Q	variable action
R	radius
R_a	anode resistance
t	thickness
t_f	design life of the cathodic protection system
u	utilization factor of the anode
w	water mass content in concrete
X	distance from the support
γ_A	partial factor for accidental actions

γ_D	partial factor for actions resulting from imposed deformations
γ_E	partial factor for environmental actions
γ_F	partial factor for action taking account of model and geometrical uncertainties
γ_G	partial factor for permanent actions, also accounting for dimensional variations
γ_M	partial factor for material resistance properties taking account of material, model and geometric uncertainties
γ_Q	partial factor for variable actions
ε	anode material's electrochemical efficiency
ν	Poisson's ratio

4.2 Abbreviated terms

ALS	accidental limit state
CFD	computational fluid dynamics
FLS	fatigue limit state
GRP	glass-fibre reinforced plastic
HAZOP	hazard and operability analysis
HVAC	heating, ventilation and air conditioning
MIC	microbiologically induced corrosion
ROV	remotely operated vehicle
SLS	serviceability limit state
SRB	sulphate-reducing bacteria
ULS	ultimate limit state

5 General requirements

5.1 General

Concrete offshore structures shall be designed in accordance with ISO 19900, this document and the requirements given in the project specification.

The structure shall be designed, constructed, transported and installed in such a way that

- the installed structure meets the intended reliability level, and
- all functional and structural requirements are met.

General principles for the verification of the reliability of the structure shall be in accordance with ISO 19900.

This document assumes that the owners will operate an organization that supervises and monitors the project, and will ensure that an appropriate level of independent verification of design and construction is performed.

This document is intended to be used in conjunction with a suitable reference standard for basic concrete design. The designer may use suitable national or regional design standards that provide the required level of safety and structural reliability.

5.2 Overall planning requirements

5.2.1 General

A concrete offshore structure shall be planned in such a manner that it meets all requirements related to its functions and use, while at the same time providing adequate levels of structural safety, reliability and durability.

All functional requirements, including operational issues and environmental conditions affecting the layout and design of the structure, shall be established in a clear format such that these can form the basis for the engineering process and the structural design. All functional requirements in temporary and operational design situations, as well as robustness against accidental situations that can influence the layout and the structural design, shall be considered. The exposure level shall be defined according to 6.6.

Site-specific data, such as water depth, environmental conditions and soil properties, shall be sufficiently known and documented to serve as a basis for the design.

Investigation of site-specific data, such as seabed topography, geo-hazards (shallow gas, boulders, etc.), soil conditions and environmental conditions including sea ice and icebergs, as appropriate, shall be carried out in accordance with the requirements of ISO 19901-1, ISO 19901-2, ISO 19901-4, ISO 19901-8 and ISO 19906.

5.2.2 Quality system

The quality system shall conform with the requirements of ISO 19900 and the specific requirements quoted for the various engineering disciplines in this document.

All work performed in accordance with this document shall be subject to quality control in accordance with an implemented quality plan. There can be one quality plan covering all activities or one overall plan with separate plans for the various phases and activities that are performed.

The quality plan shall ensure that all responsibilities are defined. An interface manual should be developed that defines all interfaces between the various parties and disciplines involved, and ensures that responsibilities, reporting and information routines are established as appropriate.

5.2.3 Qualifications of personnel

The qualifications of personnel shall conform with the requirements of ISO 19900 and specific requirements quoted for the various engineering disciplines in this document.

5.2.4 Documentation

Documentation shall be prepared for all activities that are performed in the engineering, design, construction, transportation, installation and possible removal of concrete offshore structures.

This documentation shall be sufficient to give complete information about the structure including the following:

- investigations establishing data on which the design is based;
- design briefs for major elements of design, such as concrete, mechanical outfitting, foundation, etc.;
- engineering reports, design reports and calculations;
- drawings, specifications, etc.

Documentation shall also be prepared showing records of all inspection and control of materials used and execution work performed that has an impact on the quality of the final product. This documentation shall be in accordance with the requirements in ISO 22966. ISO 22966:2009, Annex A provides guidance to the project team to determine the minimum list of documents and content of execution specification required from contractors and suppliers.

Necessary procedures and manuals shall be prepared to ensure that the construction, transportation, installation and in-service inspection are performed in a controlled and safe manner in full conformity with all assumptions of the design.

The assumptions on which the design, construction and installation work is based with regard to the load-bearing structures shall be presented in a summary report. The summary report shall be available and suitable for use in connection with operation, maintenance, alterations and possible repair work.

An operations manual shall be prepared giving all necessary information for the safe operation of the concrete offshore structure including all systems.

5.3 Functional requirements

5.3.1 General

The engineering of a concrete offshore structure shall be performed in such a way that all functional and operational requirements relating to its safety and its operation as an offshore platform are met.

The functional requirements affect the layout of the structure as well as the design situation that shall be considered in the design of the structure. The functional requirements are related both to the site-specific conditions and to the structure as a production or storage facility for the production of hydrocarbons, or any other activities in the operation of a field.

5.3.2 Position on site

The structure shall be positioned and oriented on site taking into account the reservoir, construction requirements, other platforms in the vicinity, operations, accessibility by ships and helicopters, and safety in case of fire or leakages of hydrocarbons. Position tolerance shall be defined by the owner.

5.3.3 Environmental considerations

There shall be a site-specific evaluation of all types of environmental conditions that can affect the layout and design of the structure, including rare events with a low probability of occurrence.

The deck elevation shall be determined such that it provides an adequate air gap or clearance, based on site-specific data, allowing the passage of wave crests higher than the design wave crest and icebergs or sea ice, in accordance with ISO 19901-1 and ISO 19906, as appropriate.

Green water effects on the deck of floating structures shall be in accordance with ISO 19904-1.

Due account shall be taken of wave crest modifications caused by the structure, caisson effect, local or regional features of the sea floor, storm surge, uncertainty in water depth including platform placement tolerance, wave diffraction by nearby structures, and wave run-up along the shafts.

It can be impractical to set the deck elevation to avoid impact from wave run-up along the shafts of multi-leg structures or up the sides of caissons. Potential detrimental effects of wave run-up along shafts of multi-leg structures or up the sides of caissons may be mitigated by use of wave deflectors or other structural components that can resist those actions.

The water depth used in establishing layout and in design shall be based on site-specific data taking due account of potential settlements, including subsidence, etc.

A wave model test early in the design phase may be used to determine the air gap.

5.3.4 Platform operational requirements

The functional requirements related to the production system shall be determined by the owner and could include the following:

- design life;
- layout of production wells, risers and pipelines, etc.;
- storage volume, compartmentalization, densities, temperatures, etc., in the case of stored products;
- safeguards against hydrocarbon spillage, leakage and contamination;
- access requirements, both internal and external, for operation, inspection and condition monitoring, etc.;
- interface to topsides;
- requirements for supply boats and other vessels servicing the platform;
- future tiebacks;
- hydrocarbon loading or offloading systems.

All hazards (fire, explosions, loss of intended pressure differentials, flooding, leakages, rupture of pipe systems, falling objects, ship impacts, etc.) that can be reasonably foreseen during operations shall be established and evaluated.

5.4 Structural requirements

5.4.1 General

Structures and structural members shall perform satisfactorily during all design situations, with respect to structural strength, ductility, durability, displacements, settlements and vibrations. The structure and its layout shall be such that it serves as a safe and functional base for all the mechanical and other installations that are needed for it to operate. Adequate performance shall be demonstrated in design documentation.

5.4.2 Structural concept requirements

The structural concept, details and components shall be such that the structure fulfils the following requirements:

- has adequate robustness (reserve strength, ductility) where local damage (dropped objects, vessel collision) will neither impair overall structural integrity nor hydrocarbon containment;
- can be constructed in a controlled and efficient manner;
- is adequately protected from corrosion and other degradation throughout the design life;
- is suitable for condition monitoring, maintenance and repair, if required;
- fulfils requirements for decommissioning and removal, if required;
- maintains deflections and motions within acceptable limits both during floating conditions and at permanent location;
- meets water/oil leak-tightness requirements.

5.4.3 Materials requirements

The selected materials shall be suitable for the purpose and meet requirements of the design standard. The material properties and the verification that these materials fulfil the requirements shall be documented.

It shall be ensured that the specified quality of the materials, all structural components and the physical structure itself is maintained during all stages of construction.

5.4.4 Execution requirements

Requirements for execution, testing and inspection of the various parts of the structure shall be specified on the basis of the significance of the various parts with regard to the overall safety of the completed and installed structure as well as to the structure in temporary phases.

5.4.5 Temporary phases requirements

The structure shall be designed for all phases with the same intended reliability as for the final condition unless otherwise agreed. This applies also to temporary moorings or anchorage systems used during those construction phases when the structure is afloat.

For all floating phases during marine operations or construction, sufficient positive stability and reserve buoyancy shall be ensured. Both intact and damaged stability shall be evaluated on the basis of an accurate geometric model for each condition. Adequate freeboard shall be provided. One-compartment damage stability should normally be provided. For short transient phases, the one-compartment damage stability may be waived, provided this can be justified by a risk analysis.

Weight control required for temporary phases should be performed by means of a well-defined, documented, robust and proven weight control method. Procedures shall be in accordance with ISO 19901-5. The system should provide up-to-date weight reports containing the necessary data for all operations.

5.5 Design requirements

5.5.1 General

The structural design of a concrete offshore structure and its foundation design shall be in accordance with this document. The design shall be performed according to the principles of limit state design as defined in ISO 19900.

The design shall provide adequate strength and serviceability in all design situations, such that the assumptions made are conformed with.

The design of structural steel components shall be in accordance with ISO 19902 and ISO 19901-3, as applicable.

5.5.2 Design actions

The representative values of actions shall be selected according to [6.2](#).

The partial factors for actions shall be chosen with respect to the limit states and the combination of actions concerned. Values are given in [6.4](#).

5.5.3 Design resistance

The characteristic resistance of a cross-section or a member shall be derived from characteristic values of material properties and nominal geometrical dimensions.

The design resistance is obtained by amending the characteristic values by the use of appropriate partial factors for materials.

5.5.4 Characteristic values for material strength

The characteristic strength of materials shall be determined according to the relevant design standards and recognized standards for material testing.

For concrete, the 28 days characteristic compressive strength F_{ck} is defined as a 5 % fractile value (5th percentile) found from statistical analysis of testing 150 mm × 300 mm cylindrical specimens.

NOTE 1 In some standards, a nominal compressive strength F_{cn} is used, which is less than F_{ck} ; this considers transition of test strength into in situ strength and ageing effects due to high sustained stresses. If this nominal value is used for the calculation of design strength, reduced partial factors for materials reflecting this can be applied.

NOTE 2 In some design standards, limits are placed on the upper characteristic strength, which can reflect local construction practice. Such limits can be relaxed if adequate justification can be provided, including testing of the concrete mix and aggregates, where appropriate.

For reinforcement steel, the specified minimum yield stress shall be taken as the characteristic strength F_{yk} ; for prestressing, the 0,1 % proof stress may be applied.

Values for geotechnical analyses shall be determined in accordance with ISO 19901-4. Any deteriorating effects during the operation design situation shall be taken into consideration.

For the fatigue limit state (FLS), the characteristic material strength shall be determined statistically as a 5 % fractile for reinforcement, prestressing assemblies, couplers, welded connections, etc., unless other values are specified in the reference standard for design. For concrete, normally a design reference strength shall be used. For other materials, acceptance criteria shall be specified which offer a safety level equivalent to that of the requirements in this document. The reference standard used for design should give key fatigue parameters for concrete, reinforcement and prestressing in the marine environment.

Where high resistance of a member is unfavourable (e.g. in weak link considerations), an upper value of the characteristic resistance shall be used in order to give a low probability of failure of the adjoining structure. The upper value shall be chosen with the same level of probability of exceedance as the probability of lower values being underscored. In such cases, the partial factor for material shall be 1,0 for calculating the resistance that is used when actions are applied on adjoining members.

5.5.5 Partial factors for structural materials

The partial factors for the materials in reinforced concrete shall be chosen in accordance with the reference standard for the design and for the limit state considered.

For structural steel members in the mechanical outfitting, embedment, skirts, etc., the partial resistance factor shall be in accordance with ISO 19902.

5.5.6 Design by testing

Where actions acting on a structure or the resistance of materials or structural members cannot be determined with reasonable accuracy, model tests should be considered.

Characteristic resistances of structural details, structural members or parts may be verified by a combination of tests and calculations.

A test structure, a test structural detail or a test model shall be sufficiently similar to the structure to be considered representative of the actual structure. The results of the tests shall provide a basis for a reliable interpretation in accordance with a recognized standard. Scale effects shall be taken into account where relevant.

6 Action and action effects

6.1 General

6.1.1 Classification of actions

In accordance with ISO 19900, actions are classified as the following:

- environmental actions (*E*) ([6.2](#));
- permanent actions (*G*) ([6.3.1](#));
- variable actions (*Q*) ([6.3.2](#));
- accidental actions (*A*) ([6.3.4](#)).

Although ISO 19900 defines actions resulting from imposed deformation (*D*) as permanent actions, in this document they are treated differently (see [6.3.3](#)).

The actions shall include the corresponding external reactions. The representative actions shall be chosen according to the design situation under investigation. The following design situations are distinguished:

- operational situations;
- temporary and transient situations including construction (dry-dock and deep water site) transportation, and installation;
- accidental and abnormal situations;
- damaged situations;
- decommissioning situations.

6.1.2 Determination of action effects

Action effects shall be determined by means of recognized methods that take into account the variation of the action in time and space, the configuration and stiffness of the structure, relevant soil conditions and the limit state that is under consideration. For floating structures, reference may be made to ISO 19904-1 for the determination of action effects.

Dynamic or non-linear action effects shall be considered where appropriate.

Hydrodynamic and aerodynamic actions, and the associated action effects, shall be determined by methods which take the kinematics of the liquid or air into account. For hydrodynamic actions, the interaction between liquid, structure and soil shall be considered. For calculation of overall action effects from wind, simplified methods normally suffice.

Seismic actions shall be considered in accordance with ISO 19901-2 and [7.5.7](#).

When determining the soil reactions used in the calculation of action effects in the structure, the soil-structure interaction shall be accounted for. An appropriate range of design parameters should be used to ensure that all realistic patterns of action effect distribution are included, considering long- and short-term effects, unevenness of the sea floor, degrees of elasticity and plasticity in the soil and, if relevant, in the structure.

6.2 Environmental actions

6.2.1 General

Wind, wave, tide and current are important sources of environmental actions (E) on many structures located offshore. In addition, seismic actions (see 6.2.4) and ice actions (see 6.2.5) can be significant actions, depending on location.

The determination of actions due to wind, wave and current requires an appropriate description of the physical environment in the form of sea state severity and direction, associated wind speed and direction, and relevant current descriptions in terms of current velocity profiles through the depth and associated directional information. The derivation of wind, wave and current combinations required for the calculation of actions is described in ISO 19901-1.

Actions from wind, wave and current occur as a result of various mechanisms. The most important sources of action are the following:

- viscous or drag effects, which are generally of most importance for relatively slender bodies;
- inviscid effects due to inertia of the water particles and wave diffraction, which are generally of most importance in terms of global effects for relatively large-volume bodies.

For fixed concrete offshore structures, static analyses can be adequate, but the possibility that dynamic analysis is required for local behaviour of components or for the global behaviour of the whole platform shall be investigated. In the specific case of wave action, the possibility that non-linear effects can lead to responses at frequencies either above or below the frequency range in the wave spectrum shall be investigated. This applies to fixed and floating structures.

Possible ringing effects shall be included in the considerations of wave actions on particular types of concrete offshore structures, normally single-shafted. When a steep, high wave encounters a shaft, non-linear, higher-order frequency components of wave actions can coincide with natural frequencies of the structure causing resonant transient response. Such ringing effects are only of significance in combination with extreme first order wave frequency effects. Computational fluid dynamics (CFD) analysis procedures may be used to evaluate the magnitude of the wave actions.

Potential dynamic effects due to local or global actions from wind and current shall also be investigated.

Environmental actions shall also be considered for temporary design situations of the structure during construction, tow and installation, including any inertial actions resulting from accelerations of the structure. The complete life cycle of the structure, from initial construction to removal, shall be considered and appropriate combinations of actions shall be determined to define design situations.

6.2.2 Wave actions

6.2.2.1 General

Wave actions shall be determined by means of an appropriate analysis procedure and supplemented by a model test programme, if required. Global actions on the structure and local actions on various appurtenances, attachments and components shall be determined.

Impulsive global and local wave actions shall be considered, e.g. slamming. These action effects can be significant for structures where the water depth above the caisson is small compared to the wave-height.

The appropriate analysis procedure for computing wave actions generally depends on the ratio of wavelength to a characteristic dimension of the structure, such as the diameter of a cylinder or caisson. For ratios less than approximately five, a procedure that accounts for the interaction of the structure with the incident wave-field, such as diffraction analysis, shall be applied. For higher ratios, a slender-body theory, such as the Morison equation, may be used. Where drag forces are important in global actions, both procedures should be applied in combination. In some cases, such as in the computation of local actions on various external attachments to a structure, both procedures can be required.

Model testing and CFD analyses should be considered for supplementing analytical results, particularly in cases where it is anticipated that non-linear effects can be significant, or where previous experience is not directly applicable because of the configuration of the structure.

6.2.2.2 Slender-body theory

The Morison equation can be appropriate for application to determine wave actions on slender members. The local wave kinematics are considered to be unaffected by the presence of the structural component under investigation, but local kinematics can be significantly influenced by adjacent structures.

The required inertia and drag coefficients for application in the Morison equation shall be based on recognized procedures, such as those given in ISO 19902.

The Morison equation shall be applied:

- with a regular (single-period) design wave;
- with irregular sea states in the time domain;
- with spectral representations in the frequency domain using appropriate linearization of the drag term.

The Morison equation may also be applied to calculate local actions from the kinematics around a global structure derived from diffraction theory.

The Morison equation does not account for various non-linear or higher order interactions between wave and structure, such as slamming or ringing.

6.2.2.3 Diffraction analyses

6.2.2.3.1 General

Global actions on large-volume bodies shall generally be determined by applying a validated diffraction analysis procedure. In addition, the design of various appurtenances shall be evaluated, including incident kinematics, diffraction and (if necessary) radiation effects.

The fundamental assumption of diffraction analysis is that the fluid is inviscid and that the oscillatory motions of both the waves and of the structure are sufficiently small to permit the assumption of linearity. The hydrodynamic interaction between waves and a structure can then be predicted based on linearized three-dimensional potential theory.

CFD analysis procedures may be employed on shallow water structures, on surface-piercing structures that will be overtopped by the progressing wave or on structures with significantly varying cross-section near the waterline, within the likely wave-affected zone. The CFD analysis may either complement or replace the diffraction analysis.

6.2.2.3.2 Methods

Diffraction procedures shall generally be implemented through well-verified computer programs, typically based on source/sink (Green's function) panel methods or similar procedures.

6.2.2.3.3 Special considerations for panel methods

Diffraction analysis using panel methods shall be executed with an adequate grid density to provide a solution with the required accuracy.

Diffraction models shall be combined with Morison models in the assessment of various relatively slender attachments to large-volume structures. Diffraction methods provide the required kinematics field, the Morison equation may be applied to compute resulting actions on slender attachments.

The proximity of additional relatively large-volume structures shall be included in assessing actions. Disturbances to the kinematics field around two or more structures can interact and this interaction shall be accounted for in the analysis.

Careful consideration shall be given to possible pressure fluctuations on the underside of a structure during the passage of a wave. If the foundation conditions are such that pressure fluctuations are expected to occur, then such pressure fluctuations shall be included in the analysis.

Diffraction analysis programs may be used to determine coefficients required in the evaluation of various non-linear effects, typically involving sum and/or difference frequencies.

6.2.2.4 Additional requirements for dynamic analysis

In cases where the structure can respond dynamically, the additional effects associated with the motions of the structure shall be determined. Typically, these additional effects shall be captured in additional inertia and damping terms in the dynamic analysis. Structures can, for example, respond dynamically in the as-installed situation due to wave or seismic actions, or in floating situations due to wave or wind actions.

The effects of motions of the structure on internal fluids, such as ballast water in tanks, shall also be evaluated. Sloshing in tanks generally affects the pressures, particularly near the free surface of the fluid.

6.2.2.5 Model testing

6.2.2.5.1 Role of model testing

Model testing should be considered in the following circumstances:

- Verification of analytical procedures: to confirm the results of analytical procedures, particularly for cases with structures of unusual shape, for structures in shallow water with steep or breaking waves, for the assessment of potential for sea-bed scouring or for any other case where known limitations of analytical procedures are present.
- Complementing analytical procedures: where various effects, such as ringing, wave run-up, potential occurrence of slamming are suspected, or in cases where the higher order terms that are neglected in analytical procedures can be important.

6.2.2.5.2 Scaling of model tests

Froude scaling is normally appropriate for typical gravity-driven processes, such as waves acting on large-volume structures. However, in any decision to apply Froude scaling, the possible influence of viscosity and Reynolds number effects should be considered.

6.2.2.5.3 Validation of model tests

Actions determined by model test shall be validated by comparison with analytical solutions or with the results of prior appropriate test programmes.

6.2.2.5.4 Estimation of actions

Sufficient data shall be gathered to perform reliable statistical analysis to determine wave actions. Data can include the following:

- the time history of the local instantaneous air/water surface elevation at various locations;
- local particle kinematics;
- global actions, such as base shear, vertical load or overturning moment, as well as local actions in the form of the pressure distribution on individual components;

- structural response, such as displacements and accelerations, particularly if dynamic response occurs.

Model test data shall be converted to full scale by appropriate factors consistent with the physical scaling procedures applied in the test programme.

6.2.2.5.5 Limitations of model testing

Analogous with analytical procedures, model test results have inherent limitations that shall be considered in assessing the validity of resulting actions. The primary sources of inherent limitations include the following:

- Surface tension effects: these are not allowed for in model test programme definition in general and can be significant, particularly where large-scale factors are applied.
- Viscous effects: the Reynolds number is not accurately scaled in general, and these effects are important where viscosity is significant, such as in the prediction of drag or damping effects.
- Air/water mixing and air entrainment: various actions that are influenced by this phenomenon, such as slamming actions, will not be accurately scaled in typical Froude-scale-based model tests in general.

The influence of particular effects on actions determined in model tests shall be assessed and steps shall be taken in the testing programme to reduce or minimize them. Such effects can be as follows:

- wave reflections from the ends of model test basins;
- scattering of waves from large-volume structures;
- reflection of spurious scattered waves from model basin sidewalls interfering with target design wave conditions;
- breakdown of wave trains representing the target design wave due to various instabilities leading to an inaccurate realization of design wave conditions;
- difficulties in the inclusion of wind or currents in association with wave fields.

6.2.3 Current actions

6.2.3.1 General

Currents, including directionality over the water column, shall be combined with the design wave conditions.

The disturbance of the incident current field due to the presence of the structure shall be accounted for.

6.2.3.2 Methods

Current actions shall be determined using recognized procedures. Typical methods are based on the use of empirical coefficients accounting for area, shape, shielding, etc. Such empirical coefficients shall be validated. Model tests or analytical procedures or both shall be considered to validate computed current actions.

Analytical procedures based on CFD may be used in the evaluation of current actions or other effects associated with current. Only well-validated implementations of the CFD procedure shall be used in the computation of current effects. The method can provide a more economic and reliable procedure for predicting drag forces than physical modelling techniques.

6.2.3.3 Local effects

Disturbances of the incident current field lead to modifications in the local current velocity in the vicinity of the structure. Actions on local attachments to the structure shall be computed based on the modified current field. The possibility of vortex-induced vibrations on various attachments shall be investigated.

6.2.3.4 Scour around the base

The presence of water motions in the vicinity of the base of a structure can lead to scour or sediment transport around the base. The potential for sediment transport shall be investigated. Typical procedures require the computation of fluid velocities using either CFD or model test results. In general, these velocities are evaluated with empirical procedures to predict scouring or sediment transport.

NOTE There is a substantial body of mostly empirical data (including data related to coastal and port engineering fields) that can be consulted for additional insight into sediment transport processes and the prevention of scour.

6.2.3.5 Wind action

Wind actions on a concrete offshore structure consist of two parts:

- wind actions on the topsides;
- wind actions on the concrete offshore structure above sea level.

Global wind actions shall either be determined based on the appropriate design wind velocity in combination with recognized calculation procedures or by wind tunnel testing. In a typical case, global wind action may be estimated by simplified procedures, such as a block method.

In this type of procedure, wind actions may be based on calculations that include empirical coefficients for simple shapes for which data are available, an appropriate exposed area and a pressure that is a function of the square of the wind speed normal to the exposed area.

The wind action on the exposed part of the concrete offshore structure is normally small compared to the wind action on the topsides and to wave actions. A simplified method of applying the effect of wind to the concrete structure is using the wind actions on the topsides only.

NOTE For a more complete description of wind actions, see ISO 19901-1 and ISO 19902.

Global dynamic effects of wind action shall be investigated if relevant. By way of example, a structure that is afloat or in a temporary condition during the construction, transportation or installation phases can be susceptible to wind dynamics. An appropriate description of the wind field, such as a wind spectrum, shall be included to determine global dynamic effects of wind action.

6.2.4 Seismic actions

Procedures for the determination of seismic actions and minimum return periods are provided in ISO 19901-2 at two levels, ELE and ALE. For the ELE event the structure shall meet the ULS requirements.

Seismic actions at ALE level may be considered as an abnormal design situation.

The action factors for ELE and ALE are specified in [Table 1](#).

6.2.5 Ice actions

The computation of ice actions (sea ice and icebergs) and action effects, such as vibration or impact, is highly specialized and location-dependent and shall be in accordance with ISO 19906.

6.3 Other actions

6.3.1 Permanent actions

Permanent actions (G) are actions that do not vary in magnitude, position or direction during the time period considered. These include the following:

- self-weight of the structure, including topsides;
- weight of permanent ballast;
- weight of permanently installed parts of mechanical outfitting, including risers, etc.;
- external hydrostatic pressure up to the mean water level;
- prestressing.

The expected variation in the centre of gravity position shall be accounted for.

NOTE Prestressing can alternatively be considered as actions from imposed deformations.

6.3.2 Variable actions

Variable actions (Q) change on magnitude, position and direction during the time period considered. They include actions from the following:

- personnel;
- temporary equipment, any mechanical outfitting and structure planned to be added or removed during the operational design situation;
- weight of gas and liquid in pipes and process plants;
- stored goods, tanks, etc.;
- weight and pressure in storage compartments and ballasting systems;
- temperatures;
- actions caused by drilling, workover or enhanced oil recovery operations, etc.;
- low energy boat impact, fendering and mooring;
- tidal variation about mean water level;
- external hydrostatic pressure experienced due to heave, pitch and roll in floating conditions.

NOTE Variable actions from temperatures can also be considered as actions from imposed deformations.

The assumptions that are made concerning variable actions shall be reflected in the summary report (see 5.2.4) and shall be conformed with in the operations. Possible deviations shall be evaluated and, if appropriate, shall be considered in the assessment of accidental actions.

6.3.3 Actions from imposed deformations

Certain actions, which can be classified as either permanent or variable, may be treated as resulting from imposed deformations (D). Action effects caused by imposed deformations shall be treated in the same way as action effects from normal actions or by demonstration of strain compatibility and equilibrium between applied actions, deformations, and internal forces.

Potential imposed deformations are derived from sources that include the following:

- thermal effects;

- prestressing effects (including effects of prestressing sequences, etc.);
- creep and shrinkage effects;
- differential settlement of across the foundation;
- locked-in deformations due to construction stages.

6.3.4 Accidental actions

6.3.4.1 General

Accidental actions (A) can occur from abnormal environmental events, malfunction, mal-operation or accident. The accidental actions considered in the design shall be based on an evaluation of the operational conditions for the structure, due account being taken of factors such as personnel qualifications, operational procedures, facilities and equipment, safety systems and control procedures. Evaluations of risk related to fire and explosions are covered in ISO 13702.

Primary sources of accidental actions include the following:

- abnormal environmental events;
- fires;
- spillage of refrigerated liquefied gas;
- explosions;
- flooding;
- dropped objects;
- collisions;
- unintended changes in pressure differences.

6.3.4.2 Abnormal environmental events

Abnormal environmental events include events such as the 10 000-year return period wave condition, when appropriate, and the ALE seismic event.

6.3.4.3 Fires

The principal fire and explosion events are associated with hydrocarbon leakage from flanges, valves, equipment seals, nozzles, etc.

The following types of fire scenarios shall at least be considered, where relevant:

- burning blowouts in wellhead area;
- fires related to releases from leaks in risers, manifolds, loading/unloading or process equipment, or storage tanks, including jet fire and fire ball scenarios;
- burning oil on sea;
- fires in equipment or electrical installations;
- pool fires on deck, in shafts or on the sea.

The fire action intensity may be described in terms of thermal flux as a function of time and space or, simply, as a standardized temperature-time curve for different locations.

The fire thermal flux may be calculated on the basis of the type of hydrocarbons, release rate, combustion, time and location of ignition, ventilation and structural geometry, using simplified conservative semi-empirical formulae or analytical/numerical models of the combustion process.

6.3.4.4 Spillage of refrigerated liquefied gas

Where relevant, leakage of refrigerated liquefied gas from process or equipment onto the concrete structure shall be considered during design in accordance with international standards for liquefied natural gas storage tanks, ACI 376, EEMUA 207^[16].

6.3.4.5 Explosions

The following types of explosions shall be considered:

- ignited gas clouds;
- explosions in enclosed spaces, including machinery spaces and other equipment rooms, as well as shafts and storage tanks.

The overpressure action due to expanding combustion products may be described by the pressure variation in time and space. It is important to ensure that the rate of rise, peak overpressure and area under the pressure-rise curve are adequately represented. The spatial correlation over the relevant area that affects the action effect should also be accounted for. Equivalent constant pressure distributions over panels could be established based on more accurate methods.

The damage due to explosion should be determined with due account of the dynamic character of the action effects. Simple, conservative single degree of freedom models may be applied. If necessary, non-linear time domain analyses based on numerical methods, such as the finite element method, should be applied.

Fire and explosion events that result from the same scenario of released combustibles and ignition should be assumed to occur at the same time, i.e. to be fully dependent. The fire and blast analyses should be performed by taking into account the effects of one on the other.

Damage done to the fire protection by an explosion preceding the fire should be considered.

6.3.4.6 Flooding

Unless otherwise mitigated, flooding of compartments in temporary and operational design situations shall be considered in the design. When the structure is afloat, the effect on tilt and waterline shall be considered. If mechanical systems are used to minimize the structural effects, these systems shall be designed to operate under the relevant conditions.

6.3.4.7 Dropped objects

Actions due to dropped objects should include the following types of incidents:

- cargo dropped from lifting gear;
- falling lifting gear;
- unintentionally swinging objects;
- loss of drilling equipment, pipes, etc.

The impact energy from the lifting gear shall be determined based on lifting capacity and lifting height, and on the expected weight distribution in the objects being lifted.

Unless more accurate calculations are carried out, the actions from falling objects may be based on the safe working action for the lifting equipment. The action shall be assumed to be due to objects falling from lifting gear from the highest specified height and at the most unfavourable place. Sideways

movements of the dropped object due to possible motion of the structure and the crane hook should be considered.

The trajectories and velocities of objects dropped in water should be determined on the basis of the initial velocity, impact angle with water, effect of water impact, possible current velocity and the hydrodynamic resistance.

The impact effect of long objects, such as pipes and drill stem equipment, shall be subject to special consideration.

6.3.4.8 Collisions

The effect of a vessel impact shall be evaluated if the annual probability of collision is greater than 10^{-4} . In such an evaluation, the nature of all vessel operations in the platform vicinity shall be taken into account. These can include the following:

- vessels in service to and from the installation, including supply vessels;
- tankers loading at the field;
- floating installations, such as flotels;
- ships and fishing vessels passing the installation.

Where appropriate, impacts from sea ice or icebergs and from aircraft servicing the field shall be treated in the same manner as impacts from vessels.

The most probable impact locations and impact geometry shall be established, based on the dimensions and geometry of the structure and vessel. This shall account for tidal changes, operational sea states, and motions of the vessel and structure in free vibration modes. Potential vessel impact on the structure's waterline members, risers and external wells shall be considered. Effective operational restrictions on vessel approach sectors can limit the exposure to impacts in some areas of the structure. Unless more detailed investigations are done for the relevant vessel and structure, the impact zone for supply vessels may be considered to be between 10 m below lowest astronomical tide (LAT) and 13 m above highest astronomical tide (HAT). Barge bumpers, boat landings and other external fendering may be used as protection.

Depending on the risk of collision and the consequences for the structural integrity of the structure, an analysis of vessel impact conditions can be required. Irrespective of whether an analysis is required, robustness in relation to vessel collisions should be incorporated into the design by indirect means, such as the following:

- avoiding weak elements in the structure;
- selecting materials with sufficient toughness;
- ensuring that critical components are not placed in vulnerable locations.

Impact actions are characterized by kinetic energy, impact geometry and the relationship between action and indentation. In a rigorous impact analysis, if required, accidental design situations shall be established representing bow, stern and beam-on impacts on all exposed components.

Two energy levels shall be considered:

- a) Low energy level: representing the frequent condition, based on the type of vessel which would routinely approach alongside the platform (e.g. a supply boat) with a velocity representing normal manoeuvring of the vessel approaching, leaving or standing alongside the platform.
- b) High energy level: representing a rare condition, based on the type of vessel that would operate in the platform vicinity, drifting out of control in the worst sea state in which it is allowed to operate close to the platform.

Level a) shall be checked for SLS and ULS. The owner can set their own requirements based on practical and economic considerations. Level b) shall be checked for ALS where progressive collapse shall not occur. In both cases, the analysis shall account for the vessel's mass, its added mass, any special characteristics (e.g. ice-class vessels), orientation and velocity. The possibility of leaks due to damages in the impact zone and flooding shall be assessed.

The collision energy can be determined on the basis of relevant masses, velocities and directions of vessels that can collide with the structure. All traffic in the relevant area shall be mapped and possible future changes in vessel operational patterns shall be accounted for. Design values for collisions are determined based on an overall evaluation of possible events.

The mass of supply vessels should be 8 000 tonnes unless a different value can be justified based upon the vessels operating in the area and accepted by the owner. A hydrodynamic (added) mass of 40 % for sideways and 10 % for bow and stern impact can be assumed. For low energy impacts, a vessel velocity of 0,5 m/s is commonly used, representing a minor "bump" during normal manoeuvring of the vessel while loading or unloading or while standing alongside the platform. For high energy conditions, a vessel velocity of 2 m/s is commonly used, representing a vessel drifting out of control in a sea state with significant wave height of approximately 4 m.

6.3.4.9 Unintended changes in pressure difference

Changes in intended pressure differences or buoyancy caused for instance by defects in, or wrong use of, separation walls, valves, pumps or pipes connecting separate compartments, as well as safety equipment to control or monitor pressure, shall be considered.

Unintended distribution of ballast due to operational or technical faults shall also be considered.

6.3.4.10 Floating structures in damaged condition

Floating structures that experience buoyancy loss or flooding have an abnormal floating position. The corresponding abnormal variable and environmental actions shall be considered.

Adequate global structural strength shall be documented for the abnormal floating conditions considered in the damage stability check, as well as tightness or ability to handle potential leakages in the tilted condition.

6.3.4.11 Combination of accidental actions

Where accidental actions occur simultaneously, the annual probability level (10^{-4}) applies to the combination of these actions. Unless the accidental actions are caused by the same phenomenon, such as hydrocarbon gas fires and explosions, the occurrence of different accidental actions may be assumed to be statistically independent.

NOTE While, in principle, the combination of two different accidental actions with exceedance probability of 10^{-2} , or one at 10^{-3} and the other at a 10^{-1} level, corresponds to a 10^{-4} event, individual accidental actions at a probability level of 10^{-4} will normally be most critical.

6.4 Partial factors for actions

Partial factors that shall be applied with representative actions, according to [Table 2](#), are given in [Table 1](#). The factors should be adjusted, as required, for consistency with the reference standard used to provide an equivalent level of safety.

In cases for ice actions, the partial factors in ISO 19906 shall be applied.

The ULS shall be checked for two sets of combinations of actions, ULS (A) and ULS (B) (see [Table 1](#)).

Table 1 — Partial factors γ_F for actions for different limit states

Limit state	Classification of action				
	γ_G	γ_Q	γ_E	γ_D	γ_A^a
ULS (A)	1,3	1,3	0,7 ^b	1,0	0
ULS (B)	1,0	1,0	1,3 ^b	1,0	0
SLS	1,0	1,0	1,0	1,0	0
FLS	1,0	1,0	1,0	1,0	0
ALS	1,0	1,0	1,0	1,0	1,0

^a A value of 0 for a partial factor for actions means that the action is not applicable to the design situation.

^b A factor of 0 should also be investigated if deemed more unfavourable. The tabulated values may have to be adjusted for areas with long-term distribution functions that differ from those for North Sea conditions.

The actions shall be combined in the most unfavourable way, provided that the combination is physically possible and permitted according to the action specifications. Combinations of actions that are physically possible, but not intended or permitted to occur in operations shall be included by assessing their probability of occurrence and shall be accounted for either as an accidental design situation in the ALS or shall be treated as part of the ordinary design situations included in the ULS. Such conditions may be omitted in cases where the annual probability of occurrence can be determined to be less than 10^{-4} .

For external hydrostatic pressure, and for internal pressures resulting from a free surface, an action factor of 1,2 may be used, provided that the action effect can be determined with normal accuracy. Where second order effects are important, a partial factor for action of 1,3 shall be used. Where an action is the result of the difference between independent and counteracting hydrostatic pressures, the pressure difference shall be multiplied by the partial factor for action. The pressure difference shall be taken as no less than the smaller of either one tenth of the highest pressure or 100 kPa, if not otherwise documented. This does not apply when the pressure is balanced by direct flow communication.

Prestressing actions may be considered as actions resulting from imposed deformations. Due account shall be taken of the time-dependent effects in calculation of effective internal forces. The more conservative value of 0,9 or 1,1 shall be used as a partial factor for action in the design.

A partial factor for action of 1,0 shall be applied to the weight of soil included in the geotechnical calculations.

For calculation of the soil capacity during cyclic actions, the design action effect shall be determined for the following two cases.

- Using a partial factor for action equal to 1,0 for the cyclic actions and 1,3 for the largest environmental action.
- Using a partial factor for action larger than 1,0 on the cyclic actions throughout the load history, including the greatest environmental action. Appropriate values of the partial factor for action shall be determined on the basis of an evaluation of the uncertainties associated with the cyclic action history.

The load history shall represent the wave conditions affecting the pore pressure build-up in a design storm, with respect to the distribution of load cycles, and their magnitude and number, prior to the time considered in the analysis. When the method in case b) is employed, a partial factor for action of 1,15 has been considered appropriate in a number of cases.

6.5 Combinations of actions

[Table 2](#) gives a more detailed description of how actions shall be combined. When environmental and accidental actions are acting together, the given probabilities apply to the combination of these actions.

Refer also to ISO 19901-2 that sets minimum requirements for annual probability of exceedance for ELE and ALE, which may differ from the values in [Table 2](#).

The consideration of companion environmental actions with ice actions shall follow ISO 19906.

For temporary design situations, where a progressive collapse in the installation does not entail the risk of loss of human life, injury, or damage to people or the environment, or of significant financial losses, a reduced return period for environmental actions may be considered in accordance with ISO 19901-6.

Table 2 — Representative actions and combinations of actions

	Operational design situations				
	Serviceability limit state (SLS)	Fatigue limit state (FLS)	Ultimate limit state (ULS)	Accidental limit state (ALS)	
				Abnormal situation	Damaged situation
Permanent actions	Representative value				
Variable functional actions	Specified value				
Environmental actions	Dependent on operational requirements ^c	Representative action history	Annual probability of exceedance = 10^{-2}	Annual ^b probability of exceedance = 10^{-4}	Annual probability of exceedance = 10^{-2}
Deformation actions	Representative extreme value				
Accidental actions	Not applicable			Annual probability of exceedance = 10^{-4}	Not applicable
	Temporary and transient design situations				
	Serviceability limit state (SLS)	Fatigue limit state (FLS)	Ultimate limit state (ULS)	Accidental limit state (ALS)	
				Abnormal situation	Damaged situation
Permanent actions	Representative value				
Variable functional actions	Specified value				
Environmental actions	Dependent on operational requirements ^c	Representative action history	Dependent on measures taken ^a		
Deformation actions	Representative extreme value				
Accidental actions	Not applicable		Dependent on operational requirements		Not applicable

^a See ISO 19901-6.

^b When an abnormal environmental load is applied in ALS as accidental load, the annual probability of exceedance for an ALE shall be agreed with relevant authorities; typically 10^{-4} has been used for fixed concrete offshore structures in low to moderate seismic areas.

^c Environmental actions equivalent to 50 % of those generated by events with an annual probability of exceedance of 10^{-2} may be taken instead of particular requirements stipulated by the owner.

6.6 Exposure levels

The exposure level applicable to a structure, as described in ISO 19900, shall be determined by the owner. Regulations might apply. Three exposure levels are considered, which relate to the intended service of the structure, see [Table 3](#).

Structures in exposure level L1 shall be designed in accordance with the requirements of this document for permanent, variable, environmental, deformation and accidental actions. Inspection of execution shall be according to inspection class 3 (extended inspection, see [8.5.3](#)).

For structures in exposure level L2, the same requirements apply as for L1 structures except that inspection of execution may be performed according to inspection class 2 (normal inspection, see [8.5.3](#)).

For structures in exposure level L3, the same requirements apply as for L2 structures except that accidental actions with a probability of less than 10^{-3} may be disregarded. Additionally, a reduction of the factor for environmental actions of not more than 15 % may be considered, if permitted by the project specification.

Table 3 — Determination of exposure level

Life-safety category	Exposure level (L1 to L3)		
	Consequence category		
	High consequence	Medium consequence	Low consequence
Manned–non-evacuated	L1	L1	L1
Manned–evacuated	L1	L2	L2
Unmanned	L1	L2	L3

NOTE The exposure levels, life-safety categories and consequence categories are defined in detail in ISO 19900.

7 Structural analyses

7.1 General

Appropriate structural analyses shall be performed to determine the action effects within a structure. These analyses shall define the responses of the structure during each stage of its life in accordance with [Clause 6](#).

Structural analysis refers to calculations based on numerical techniques including longhand calculations and/or computer-based methods. The development of action effects by model testing or by instrumentation of other similar structures is not precluded by this document.

Complex or unusual structural types can require forms of analysis not described within this document. If required, these shall be performed in accordance with the principle that a sufficient number of suitable analyses are carried out to accurately assess all significant action effects within the structure.

7.2 General principles

7.2.1 Planning

In order to ascertain that analysis of a concrete offshore structure is successful, the following are required:

- All necessary analyses shall be performed on the basis of an accurate and consistent structural model that defines the structural system to the appropriate level of detail and enables the required corresponding actions on the structure that is assessed.
- These analyses shall be performed using appropriate methods, shall have relevant boundary conditions and shall be of suitable type.
- Suitably verified results in the form of action effects shall be available in due time for use in design or reassessment.

Interfaces with structural designers, topsides designers, hydrodynamicists, geotechnical engineers and other relevant parties shall be set up. The schedule of supply of data on actions (including

reactive actions) shall be determined and monitored. Interfaces shall ensure that these data are in the correct format, cover all necessary locations, and are provided for all required limit states and for all appropriate stages in the lifetime of the structure.

7.2.2 Extent of analyses

Sufficient structural analyses shall be performed to provide action effects suitable for checking all parts and all structural components of the primary structure for the required design situations and limit states. At least one analysis should normally represent global behaviour of the structure during each relevant stage of its life.

The number and extent of the analyses performed shall cover all parts and all structural components of the structure through all stages of its life, i.e. construction, transportation, installation, in-service conditions and removal/retrieval/relocation. However, if it can be clearly demonstrated and documented that particular stages in the life of the structure will not govern the design of a part of the structure or of a structural component, such stages need not be analyzed explicitly for this part or component.

The simulation of a part of the structure or of a structural component shall, as a minimum, comprise a three-dimensional representation of the stiffness of all primary structure. In general, the stiffness of secondary structures may be omitted from structural analyses, although significant action effects due to secondary structure shall be incorporated. Secondary structure can provide such restraint to the primary structure that additional sectional forces are developed. Such effects shall be assessed and included where necessary.

Secondary components of the structure shall be assessed, by analysis if necessary, to determine their integrity and durability, and to quantify their contribution to action effects in the primary structure. Such analyses may be performed separately from analysis of the primary structure, but shall include deformations of the supporting primary structure, where relevant.

If present, the stiffness of the topsides and other steel primary structure shall be simulated in global analyses in sufficient detail to adequately represent the interface with the concrete, such that all actions from the topsides are appropriately distributed to the concrete structure. The relative stiffness of steel and concrete structures shall be accurately simulated where this has a significant effect on global load paths and action effects. Particular attention shall be paid to relative stiffness when assessing dynamic response.

Where appropriate, the analysis shall include a representation of the foundation of the structure, simulated by stiffness elements or by reactive actions.

7.2.3 Analysis requirements

All structural analyses required for the design of the structure shall be carried out in accordance with the planned analysis schedule using the most recent data on geometry, materials, boundary conditions, actions and other relevant information.

The structure shall be analyzed for appropriate actions during each stage of its life. Where simultaneous actions are possible, these actions shall be applied in combination in such a way as to maximize action effects at each checked location. The actions that contribute to these combinations shall include appropriate partial factors for action, as specified in [Clause 6](#), for each limit state being checked.

Appropriate analysis types shall be selected to provide accurate action effects covering all requirements of the design or assessment process of the concrete listed in [Clause 8](#). Requirements for typical analyses that shall be performed on a concrete offshore structure and its structural components, including the selection of appropriate analysis types and execution requirements for each design situation, are included in [7.5](#). Execution of an analysis for a particular stage in the life of the structure shall be performed in accordance with the specific requirements of the relevant clause.

7.2.4 Calculation methods

Various calculation methods may be used for the determination of action effects in response to a given set of actions. These include, but are not limited to, hand calculations and computer methods, such as spreadsheets or finite element analyses.

Where assumptions are made to simplify the analysis to enable performance of a particular calculation method, these shall be clearly recorded in the documentation or calculations. The effects of such assumptions on action effects shall be quantified and incorporated as necessary.

Analysis of the global structure or local components is normally performed by the finite element method. Computer software used to perform a finite element analysis shall conform with a recognized international standard on quality, such as that given in ISO/IEC/IEEE 90003, or shall be validated for its intended use prior to the start of the analysis. Element types, action applications, meshing limits and analysis types used in the structural analysis shall all be included in the validation.

Where finite element analysis is performed, consideration shall be given to the inaccuracy inherent in the element formulation, particularly where lower order elements or coarse element meshes are used. Validation and “benchmark” testing of the software shall be used to identify element limitations and the computer modelling shall be arranged to provide reliable results.

Hand calculations are generally limited to simple structural members (beams, regular panels, secondary structures, etc.) under simplified actions (i.e. uniform pressure, point or distributed actions). The methodology used shall reflect standard engineering practice with due consideration for the conditions of equilibrium and compatibility. Elastic or plastic design principles may be adopted dependent on the limit state being checked and the requirements for the analysis being performed.

Computer spreadsheets are electronic methods of performing hand calculations and shall be subject to the same requirements. Where such spreadsheets do not produce output showing the methodology and formulae used, adequate supporting calculations shall be provided to verify the results of comprehensive test problems. Sufficient checks shall be provided to verify all facilities in the spreadsheet that will be used for the structural component being assessed.

Special forms of analysis for concrete structures, such as the strut and tie approach, may also be used, but shall conform with contemporary, accepted theories and shall adhere to the general principles of civil/structural engineering. Unless the method is well-known and understood throughout the industry, references to source material for the method being used shall be provided in the documentation or calculations.

Non-linear finite element analysis may be used to demonstrate ultimate strength of the structure or the strength of complicated 2-D and 3-D regions. Software used for this purpose shall be subject to the same validation requirements as above. Validation of non-linear analysis software used in this way shall include at least one comparison with experimental results or with a reliable worked example of a similar detail.

7.2.5 Verification of analysis results

Structural analyses shall be thoroughly verified to provide confidence in the results obtained. Verification is required to check that input to the calculations is correct and to ensure that sensible results have been obtained. This verification is in addition to the validation of computer software described in [7.2.4](#).

Input data for a particular structural analysis shall be subject to, at least, the following checks:

- the structural model adequately represents the geometry of the intended structure or structural part;
- the specified material properties have been used;
- sufficient and correct actions have been applied;
- suitable and justifiable boundary conditions have been simulated;

- an appropriate analysis type and methodology have been used for the analysis.

Verification of the results of an analysis will, in general, vary depending on the nature of the analysis. Typical output quantities that shall be checked include the following:

- individual and summed reactions, to ensure that these balances the applied actions;
- deformations of the structure, to verify that these are sensible and that they demonstrate compatibility between structural components;
- natural periods and mode shapes, if appropriate, to verify that these are sensible;
- load paths, bending moment diagrams, stress levels, etc., to check that these satisfy equilibrium requirements.

7.2.6 Documentation

Successful execution of an analysis shall be recorded, and pertinent parties shall be informed of results and conclusions so that implications for the design process are formally recognized.

Each structural analysis shall be thoroughly documented to record its extent, applicability, input data, verification and the results obtained. The following information shall be produced as a minimum to document each analysis:

- the purpose and scope of the analysis and the limits of its applicability;
- references to methods used and the justification of any assumptions made;
- the assumed geometry, showing and justifying any deviations from the current structural geometry;
- material properties used in the analysis;
- boundary conditions applied to the structure or structural component;
- the summed magnitude and direction of all actions;
- pertinent results from the analysis and cross-checks to verify the accuracy of the simulation, in accordance with [7.2.5](#);
- a clear presentation of the results of the analysis that are required for further analysis, structural design or assessment.

Results of the analysis will normally take the form of action effects, which the structure shall be designed to withstand. Typical action effects required for the design of concrete offshore structures include the following:

- displacements and vibrations, which shall be within acceptable limits for operation of the platform;
- sectional forces, from which the capacity of concrete sections and necessary reinforcement requirements can be determined;
- sectional strains used to determine crack widths and water-tightness.

7.3 Physical representation

7.3.1 Geometrical definition

Dimensions used in structural analysis calculations shall represent the structure as accurately as necessary to produce reliable values of action effects. Changes in dimensions as a result of design changes shall be monitored both during and after the completion of an analysis. Where this impacts the accuracy of the analysis as described in [7.2.1](#), the changes shall be incorporated by reanalysis.

Nominal sizes and dimensions of the concrete cross-section in structural analysis may be considered, provided that tolerances are within the limits set out for the construction and appropriate partial factors for material are used. Geometrical and material tolerances considered in this document are defined in [Clause 8](#). These are consistent with the partial factors for materials defined in [5.5.5](#).

Where as-built dimensions differ from nominal sizes by more than the permissible tolerances, the effect of this dimensional mismatch shall be incorporated in the analysis. The effect of tolerances shall also be incorporated in the analysis where action effects and hence the structural design are particularly susceptible to their magnitude (imperfection bending in walls, implosion of shafts, etc.).

Concrete cover to nominal reinforcement and positioning of prestressing cables may be provided where these are defined explicitly in detailed local analysis. Again, this is subject to construction tolerances being within the specified limits and appropriate partial factors being applied to component material properties.

The effects of wear and corrosion shall be accounted for in the analysis where relevant and where adequate measures are not provided to limit such effects.

It will normally be sufficient to consider centre-line distances as the support spacing for beams, panels, etc. In certain circumstances, however, face-to-face distances can be permitted with suitable justification. The effect of eccentricities at connections shall be considered when evaluating local bending moments and stability of the supporting structure.

7.3.2 Material properties

Material properties used in the analyses of a new design shall reflect the materials specified for construction. For existing structures, material properties may be based on statistical observations of material strength taken during construction or derived from core samples extracted from the concrete.

For most limit states, it is normally acceptable to simulate the concrete by equivalent linear elastic properties. Unless a different value can be justified, the modulus of elasticity (E-modulus) of plain concrete may be used as the modulus of reinforced concrete in such an analysis. The value used shall be in accordance with the reference standard to concrete design in use. For actions that result in very high strain rates, the increase in concrete modulus of elasticity should be considered in the analysis of the corresponding action effects. The applicability of linear elastic analysis is discussed in [7.4.1](#).

Age effects of the concrete may be included, if permitted by the design rules in use. Effects of the duration of actions and resultant creep of the concrete shall also be considered, where relevant. Where actions can occur over a significant period in the life of the structure, the least favourable instance shall be considered in determining age effects.

Accurate evaluation of concrete stiffness can be particularly important for natural frequencies and for dynamic analysis, and for simulations that incorporate steel components, such as the topsides or conductor framing. Consideration shall be given to the expected range of concrete stiffness in such analyses, including the effects of any cracking.

Non-linear analysis techniques are often applied to local structural components. It is then typical to discretely model concrete, reinforcement and prestressing tendons in such simulations. Where this is the case, each material shall be represented by appropriate stress-strain behaviour, using recognized constitutive models.

The density of reinforced concrete shall be calculated based on nominal sizes using the specified aggregate density, mix design and level of reinforcement, with due allowance for design growth. For existing structures, such densities shall be adjusted on the basis of detailed weight reports, if available. Variation in effective density through the structure shall be considered where relevant.

Unless another value is shown to be more appropriate, a Poisson's ratio of $\nu = 0,2$ shall be assumed for uncracked concrete. For cracked concrete, a value of $\nu = 0$ may be used. A coefficient of thermal expansion of $1,0 \times 10^{-5}$ per degree Celsius shall be used for concrete and steel instead of other

information. Where the design of the concrete structure is particularly sensitive to these parameters, they shall be specifically determined for the materials in use.

7.3.3 Soil-structure interaction

The representation of the foundation of a fixed concrete structure will depend on both the type of analysis and the type of foundation. For static analysis, the soil should ideally be modelled in an integrated analysis together with a realistic representation of the foundation structure and the seabed-structure contact. Alternatively, an estimate of static reaction stresses on the foundation can be made with due consideration of potential seabed variations across the foundation base and potential variations in load distribution between skirts and base. The magnitude and distribution of the reaction stresses shall be governed by equilibrium and should consider possible failure surface geometries, soil resistance and soil-structure interaction. Sufficient reaction stresses shall be applied to resist the response in each direction of motion of the structure in the dominant directions of loading and response. Reactive actions on the structure from the foundation, derived either from distributed stresses or from integrated soil-foundation model, shall be based on general principles of soil mechanics in accordance with [Clause 9](#). In addition, the development of hydraulic pressures in the soil and possible free water should be considered where appropriate.

For dynamic and seismic analyses, an elastic or inelastic representation of the foundation will normally be required to provide suitable stiffness. For stiff foundations, it is often sufficient to represent the soil medium by uncoupled soil springs that are computed based on rigid base assumption and consistent with the level of shear strains expected in the soil. Alternatively, the non-linear soil response can be represented by non-linear force-displacement functions. For large foundations, the added dynamic soil mass is often large and should be included in the model. For flexible foundations, one should compute the actions on the foundation from a suitable finite element model of the soil-structure system. In such models, simplified representation of the concrete structure and the topside is sufficient. Further details of foundation modelling requirements for specific analysis types are given in [7.5](#).

If the structural response is sensitive to soil-structure-interaction effects, the computations shall reflect the uncertainties inherent in soil parameter values. While characteristic soil parameters are sufficient for most types of structure for the ALE event, low and high estimates of soil parameter values should be considered for the ELE event. The range of soil parameter values depends on the quality and extent of the soil investigation. If the soil data are not sufficient to establish a narrow band for the soil strength and stiffness profile, the low estimate should not be taken higher than 65 % of the characteristic profile and the high estimate profiles should not be taken less than 150 % of the characteristic soil profile. For the low-estimate case, the effect of pore-pressure generation on the soil stiffness and strength properties due to cyclic loading should be taken into account.

NOTE Recommendations about the definition of the characteristic soil profile are provided in ISO 19901-4 (see [9.4](#)).

Consideration shall also be given to the unevenness of the sea floor or soil layers in the seabed, which can potentially cause high local reactive actions. Foundation unevenness may be considered as actions resulting from imposed deformations in subsequent design checks, in accordance with [Clause 6](#). Other than this, foundation pressures shall be considered as reactive actions, their magnitude being sufficient to counteract all other factored actions.

The analyses shall include intermediate conditions during installation, such as initial contact and skirt penetration as well as the fully grouted permanent condition, where relevant. Disturbance of the seabed due to the installation procedure should be considered in calculating subsequent foundation pressures.

High estimate of soil resistance should be considered during analysis of the removal of the structure.

7.3.4 Other support conditions

Other than direct support from the seabed, a structural component can be supported by the following:

- external water pressure, while floating;

- other components of the structure;
- an air cushion;
- any combination of the above, together with the seabed.

The action of water pressure to support a structure while floating shall be evaluated by suitable hydrostatic or hydrodynamic analysis and shall be applied to appropriate external surfaces of the structure. Water pressure considered in this way is a reactive action. In order to maintain the waterline in the correct position the action and the reaction shall both be scaled with the same action factor(s) to maintain equilibrium.

NOTE To scale the reaction by the buoyancy actions to correspond to the applied action including action factors in order to maintain equilibrium can be seen as scaling the unit weight of water in order to respect the waterline and load the actually wetted areas. This is not physical, but an accepted way of simulating floating conditions while accounting for the uncertainties covered by the partial factors.

Representative boundary conditions shall be applied to the analysis of a structural part extracted from the global structure. These boundary conditions shall include possible settlement or movement of supports, based on a previous analysis of the surrounding structure.

In the absence of such data, suitable idealized restraints shall be applied to the boundary of the structural part to represent the behaviour of the surrounding structure. Where there is uncertainty about the effective stiffness at the boundaries of the component, a range of possible values shall be considered.

Internal force, stiffness or displacement may be applied as boundary conditions to support a structural member. Where there is uncertainty as to which will produce the most realistic stresses, a range of different boundary conditions shall be adopted, and the worst action effects chosen for design.

Where components of the structure are not fully restrained in all directions, such as conductors within guides and bearing surfaces for deck and bridge structures, allowance shall be made in the analysis for movement at such interfaces.

7.3.5 Actions

Actions shall be determined by recognized methods, taking into account their variation in time and space, in accordance with [Clause 6](#). Such actions shall be included in the structural analysis in a realistic manner, representing the magnitude, direction and time variance of such actions.

Permanent and variable actions shall be based on the most likely anticipated values at the time of the analysis. Consideration shall be given to minimum anticipated values as well as maximum anticipated values. The former govern some aspects of the design of gravity-based structures.

Hydrostatic pressures shall be based on the specified range of fluid surface elevations and densities. Hydrostatic pressures while the structure is afloat shall include the effects of trim and heel as well as pitch and roll of the structure, due to influences such as intentional trim, wind heel, wave action or differences in stable attitude of the structure when damaged.

Prestressing effects shall be applied to the model as external actions at anchorages and bends, or as compatible internal strain effects. In both cases, due allowance shall be made for all likely losses in prestressing force. Where approximated by external actions, relaxation in tendon forces due to the effect of other actions on the state of strain in the concrete shall be considered.

Initial prestressing forces at lock-off will normally have only local effect but should be considered in analysis if relevant.

Thermal effects are normally simulated by temperatures applied to the surface and through the thickness of the structure. Sufficient temperature conditions shall be considered to produce maximum temperature differentials across individual sections and between adjacent structural components. The temperatures shall be determined with due regard to thermal boundary conditions and material

conductivity. Thermal insulation effects, e.g. due to insulating concrete or drill cuttings, shall be considered if present.

Wave, current and wind actions shall include the influence of such actions on the motion of the structure while floating. In cases where dynamic response of the structure can be of importance, such response shall be considered in determining action effects. Quasi-static or dynamic analyses shall be used, in accordance with 7.4.

Uncertainties in the centre of gravity of the topsides and in built-in forces and deformations from the transfer of the topsides weight from barges to the concrete structure shall be represented by a range of likely values, the structure being checked for the most critical value.

7.3.6 Mass simulation

A suitable representation of the mass of the structure is required for the purposes of motion prediction, for actions due to accelerations of masses while floating, and for dynamic analyses. The mass simulation shall include relevant quantities from at least the following:

- the mass of all structural components, both steel and concrete, primary and secondary;
- the mass of all intended equipment, consistent with the design situation being considered;
- the estimated mass of temporary items, such as storage, lay-down, etc.;
- masses of any fluids contained within the structure, including equipment and piping contents, oil storage, flooding, etc.;
- the mass of solid ballast within the structure;
- the mass of snow and ice accumulation on the structure, where relevant;
- the mass of drill cuttings or other deposits on the structure;
- the mass of marine growth on the structure;
- added water mass;
- added soil mass.

The magnitudes of masses within the structure shall be distributed as accurately as necessary to determine all significant modes of vibration (including torsional modes) and all actions due to accelerations of masses for the structural analysis being performed. Particular attention shall be paid to the height of topsides equipment or modules above the structural steelwork.

For quasi-static analyses it is normally only necessary to consider the maximum mass associated with a given design situation for the structure. However, for dynamic analyses this does not necessarily produce the worst response, in particular with respect to torsional modes, and a range of values of mass and centre of gravity shall be considered. For a fatigue analysis, the variation in the history of actions shall be considered. If appropriate, an average value over the life of the structure may be used. In such cases, it is reasonable to consider a practical level of supply and operation of the platform.

Calculation of the added mass of water and entrained water moving with the structure shall be based on best available published information or suitable hydrodynamic analysis. Instead of such analysis, this mass may be taken as the full mass of displaced water for small submerged members, reducing to 40 % of the mass of displaced water for larger structural members. Added mass effects may be ignored along the axial length of prismatic members, such as the shafts.

7.3.7 Damping

Damping arises from a number of sources including structural damping, material damping, radiation damping, hydrodynamic damping and frictional damping between moving parts. Its magnitude is dependent on the deformation levels of structural members and soil.

NOTE Typical values for damping will be in the range from 1 % to 3 % of critical damping. For seismic analysis, see [7.5.7.3](#).

7.4 Types of analysis

7.4.1 Static linear elastic analysis

It is generally acceptable for the behaviour of a structure or structural part to be based on static linear elastic analysis, unless there is a likelihood of significant dynamic or non-linear response to a given type of actions. In such cases, dynamic or non-linear analysis approaches shall be performed, as defined in [7.4.2](#) and [7.4.3](#).

Static analysis is always permissible if all actions on the component being considered are substantially invariant with time. If actions are periodic, transient or impulsive in nature, the magnitude of dynamic response shall be evaluated in accordance with [7.4.2](#) and static analysis shall only be permitted if dynamic effects are small.

Reinforced concrete is typically non-linear in its behaviour, but it is generally acceptable to determine global load paths and sectional forces for ULS, SLS and FLS based on an appropriate linear elastic analysis, subject to the restrictions presented below. Non-linear analysis can be required for ALS, ALEs and local analysis.

Linear stiffness is acceptable provided that the magnitudes of all actions on the structure are not sufficient to cause significant redistribution of stresses due to localized yielding or cracking. In particular, response to actions caused by deformations is very susceptible to the level of non-linearity in the structure and shall be carefully assessed for applicability once the level of cracking in the structure is determined.

Reduction of the stiffness of components should be considered if it can be shown that, for example, due to excessive cracking, more accurate load paths can be determined by such modelling. This approach has been adopted for thermal actions, with a reduction to half the concrete material stiffness being typically employed. Such reduced stiffness shall be supported by appropriate calculations or by non-linear analysis.

A linear analysis preserves equilibrium between externally applied actions and internal forces. Linear solutions are thus always equilibrium states. The equations of a linear system need to be solved only once and the solution results may be scaled to any level of actions. Hence, a solution is always obtained, irrespective of the action levels. Linear analysis can be carried out for many independent load cases, after which the independent load cases may be superimposed into combined cases or load combinations representing complete design situations.

NOTE Experience has shown that the use of a structural analysis representing all actions as unit load cases that afterwards can be scaled in magnitude and added to represent complete load combinations, i.e. loading scenarios, is very effective. It is, however, important to ensure equilibrium between actions and reactions in such a way that there are no unbalanced reactions at the model support boundaries, for example, by creating equilibrium groups that are afterwards scaled and combined to represent the loading scenarios.

7.4.2 Dynamic analysis

7.4.2.1 General

Fixed structures with global natural periods greater than 2,5 s can be susceptible to dynamic response due to wave action during in-service conditions, at least for fatigue assessment. Structures in shallow water or subject to waves can exhibit significant dynamic response at lower natural periods due to the

higher frequency content in shallow water or unusually steep waves. Dynamic response to ice actions shall be calculated for cases where significant interactions from sea ice and icebergs exist.

For floating structures, rigid body motions shall be taken into account in design of the structures, mooring and components. Based on metocean or generic criteria, a quasi-static global analysis will provide the basis for retrieving accelerations for relevant return periods, associated with concurrent environmental local loading, as applicable, in accordance with [6.5](#); see also ISO 19901-1. Higher order wave actions can be of importance as they might interact with rigid body modes of the entire floater, and this should be considered. Design of the mooring systems should include relevant, local and global, and dynamic effects to ensure that the capacity is sufficient for all relevant load conditions.

The structure can be subjected to other situations such as waves during sea tow, wind turbulence, wave slamming, tank sloshing, vibration, impact or explosion, that can also impose dynamic actions of significant magnitude close to fundamental natural periods of the structure or its components. Structures that respond to a given set of actions by significant motion or vibration at one or more natural periods shall be assessed by dynamic analysis techniques.

Earthquakes are a particularly severe form of oscillatory excitation that shall always require detailed dynamic analysis if the zone of seismic activity produces significant ground motions.

Where dynamic effects can be significant, global dynamic response can often be evaluated using a simplified model representation of the structure. In some cases, dynamic effects can be assessed by the calculation of natural periods and the evaluation of dynamic amplification factors. In evaluating dynamic amplification factors for wave action, consideration shall be given to higher frequency components of wave and wind action that occur due to drag loading, sharp crested shallow water waves, ringing, etc.

Where substantial dynamic response of the structure is predicted, which have magnitudes at critical sections exceeding that predicted by static-only analysis, detailed dynamic analysis shall be required. Dynamic analysis shall also be required where more than one mode of motion or vibration of the structure is significantly excited by the applied actions, as is the case for seismic response. Dynamic analysis requirements are presented in [7.4.2.2](#).

Where dynamic effects are relatively insignificant, a quasi-static analysis of the structure or its components may be performed, and dynamic effects may be included in accordance with [7.4.2.3](#).

7.4.2.2 Dynamic analysis requirements

Where dynamic response is likely to be relatively important, a full dynamic analysis shall be performed to quantify such effects. Appropriate mass and damping simulations shall be applied to the structure to enable the natural modes of vibration to be determined with accuracy.

Dynamic analysis will normally require a linearized simulation of the soil stiffness for in-service conditions. This stiffness shall be determined with due allowance for the expected level of excitation on the foundation. Specific requirements for seismic analysis are presented in [7.5.7](#).

Actions applied to the structure or its components shall include all frequency content likely to cause dynamic response. The relative phasing between different actions shall be rigorously applied.

Harmonic or spectral analysis methods are suitable for most forms of periodic or random cyclic excitation. Where significant dynamic response is associated with non-linear excitation or non-linear behaviour of the structure, of a structural component or of the structure's foundation, then transient dynamic analysis shall be required.

Where modal superposition analysis is being performed, sufficient modes to accurately simulate structural response shall be included. Otherwise, a form of static improvement shall be applied to ensure that static effects are accurately simulated.

For impulsive actions, such as those due to ship impacts, slamming or explosions, dynamic amplification effects may be quantified by the response of single- or multi-degree of freedom systems representing

the stiffness and mass of the structural components being analyzed. Transient dynamic analysis will normally be required.

7.4.2.3 Quasi-static analysis

Quasi-static analysis refers to any analysis in which the influence of structural accelerations is small enough that dynamic actions can be represented approximately by a factor on static actions or by equivalent quasi-static actions. Both approaches are only appropriate if static and dynamic action effects give an essentially similar response pattern within the structure, but differ in magnitude.

For the former approach, dynamic amplification factors shall be used to factor static-only response. Such factors will, in general, vary throughout the structure to reflect the differing magnitudes of static and dynamic response. For columns or shafts of a structure, appropriate local values of bending moment should be used. Base shear, overturning moment and soil pressure are representative responses for the structure's base.

For the latter approach, additional actions shall be applied to the structure to represent the incremental effects due to acceleration of masses. All actions applied in a quasi-static analysis may be considered constant over time except in the case of non-linear response, where knowledge of the excitation history can be important, and the excitation should be applied to the simulation in appropriate steps.

Factored dynamic results shall be combined with factored static effects due to permanent and variable actions, etc., in accordance with the limit states being checked. Partial factors for action for dynamic actions should be consistent with the excitation that causes the dynamic response, normally environmental. The most detrimental magnitude and direction of dynamic excitation shall be considered in design combinations.

7.4.3 Non-linear analysis

Non-linear behaviour shall be considered in structural analysis when determining action effects in the following cases:

- where significant regions of cracking occur in a structure such that global load paths are affected;
- where such regions of cracking affect the magnitude of the actions effects (imposed deformations, dynamic response, thermal effects, hydrostatic effects etc.);
- where the structural component depends on significant non-linear material behaviour to resist a given set of actions, such as in response to accidents or abnormal level seismic events;
- where slender members are in compression and deflections can cause significant action effects (imperfection bending or buckling).

Non-linear solutions cannot be superimposed. This implies that a non-linear analysis shall be carried out for every design situation for which a solution is required.

Non-linear analysis of components to determine their ultimate strength may be performed, provided that the model can appropriately cover all failure modes (e.g. bending, axial force, shear, compression failure affected by reduced effective concrete strength) and that the concrete tensile stresses are covered by reinforcement. If one analysis is not sufficient to verify all failure mechanisms, separate additional verifications should be carried out. Material properties used in non-linear analysis should be reduced by appropriate partial factors for material, in accordance with 5.5.5. Where components of the structure rely upon non-linear or ductile behaviour to resist abnormal or accidental actions, such components shall be detailed to permit such behaviour, in accordance with 8.1.

Complex non-linear analysis of discontinuity regions (see 7.4.6 and 8.1.10) using finite element methods should not be used without prior calibration of the method against relevant experimental results.

7.4.4 Probabilistic analysis

It is generally acceptable to base in-service structural analysis of a concrete offshore structure subjected to wave action on the principles of deterministic analysis, predicting responses to specific events. However, where stochastic or probabilistic methods are more appropriate for a particular limit state these shall be substituted as needed.

Probabilistic methods typically require linearization of action effects. This can restrict their use where non-linear response of the structure or structural component is significant. If non-deterministic analysis methods are used, time domain response to transient excitation can be necessary.

Where spectral analysis methods are used for calculating responses to random wave action, a sufficient number of wave conditions shall be analyzed to ensure that dynamic response close to structural natural periods and close to peak wave energy is accurately assessed.

7.4.5 Reliability analysis

Reliability assessment of structures is permitted under the provisions of this document to assess the risk of failure of a structure and to ensure that this is below acceptable levels. However, such an analysis is beyond the scope of this document and shall be performed in accordance with state-of-the-art industry practice and by agreement between all parties involved.

7.4.6 Discontinuity region analysis

Specialized forms of analysis can be required in “D” or discontinuity regions, such as joints, transitions, concentrated support areas, embedments, penetrations, prestressing anchorages, etc. These methods may include the strut and tie approach, possibly coupled with a local elastic analysis of the associated detail. Non-linear finite element analysis including cracking and crushing models may also be used in these regions.

In all cases where specialized analysis is used, sufficient verification of the analysis based on conformity with recognized industry practice or comparisons with experimental data shall be provided.

7.5 Analysis requirements

7.5.1 General

All structural analyses performed shall simulate, with sufficient accuracy, the response of the structure or structural parts for the limit state being considered. This can be achieved by appropriate selection of the analysis type with due regard to the nature of applied actions and the expected response of the structure.

7.5.2 Analysis of construction stages

Sufficient analyses shall be performed for construction stages to ensure the integrity of parts of the structure at all significant stages of the construction and assembly process and to assess built-in stresses from restrained deformations. Construction stages shall include onshore and inshore operations.

Consideration shall be given to the sequence of construction in determining action effects and to the age of the concrete in determining resistance. Specific consideration shall be given to the stability of components during construction. Adequate support for temporary actions, such as crane footings, shall be provided in the analysis.

While linear static analysis are appropriate for most design situations, dynamic and non-linear effects shall be considered and accounted for also in construction stages when relevant.

7.5.3 Transportation analysis

Analysis of a concrete offshore structure shall include the assessment of structural integrity during sea tow of the structure, whether it is self-floating, barge supported or barge assisted. The modelling of the structure during such operations shall be consistent with the stage being represented, incorporating the correct amount of ballast and modelling only those components of the topsides that are actually installed.

Analysis during sea tow should normally be based on linear static analysis, representing the motion of the concrete offshore structure by an inclination of the permanent actions in accordance with the maximum angles of pitch and roll, and by mass inertial actions associated with peak heave, sway, surge, pitch and roll accelerations, as predicted by motion analysis. For such analysis to be valid, it shall be demonstrated that motions in the natural periods of major components of the structure, such as the shafts, will not be significantly excited by global motions of the structure. If dynamic and inertial effects of major parts and mechanical outfitting are deemed important, they shall be incorporated in accordance with [7.4.2](#).

Consideration shall be given to possible damage scenarios during sea tow. Sufficient structural analyses should be performed to ensure adequate integrity of the structure, preventing complete loss in the event of collision with tugs or other vessels present during the transportation stage. In particular, progressive collapse due to successive flooding of compartments shall be prevented.

7.5.4 Installation and deck mating analysis

Structural analysis shall be performed for critical stages during deck mating and installation. Such analyses shall, as a minimum, cover times of maximum pressure differential across various components of the concrete offshore structure. The configuration of the structure at each stage of the deck mating or setting down operation shall reflect the planned condition and inclination of the structure and the associated distribution of ballast.

Deck mating, ballasting down and setting down on the sea floor shall normally be analyzed by a linear static analysis. As these phases normally represent the largest external hydrostatic pressures implosion or buckling should be analyzed. The effect of unevenness of the seabed soil layers shall be considered in assessing seabed reactions in an ungrouted situation.

7.5.5 In-service strength and serviceability analysis

At least one global analysis of the structure shall be performed in its in-service configuration suitable for subsequent strength and serviceability assessment. The structural model shall allow simulations of built-in stresses or deformations from the different stages of construction, if relevant.

Local analysis shall be performed to assess secondary structures and details that appear from the global analysis to be heavily loaded, that are loaded in a complex manner or that are complex in form. Such analyses may be based on non-linear methods if these are more appropriate to the component behaviour.

It is generally acceptable to base all strength analysis of an in-service concrete platform on deterministic analysis, predicting response to specific waves. Sufficient wave periods, directions and wave phases shall be considered to obtain maximum response in each type of structural member checked. Consideration shall be given to waves of lower than the maximum height if greater response can be obtained due to larger dynamic effects at smaller wave periods.

In-service analysis may normally be performed using linear static methods, the behaviour of the reinforced concrete being represented in accordance with [7.3.2](#). However, whenever significant dynamic effects are expected, quasi-static or full dynamic analysis shall be performed in accordance with [7.4.2](#).

7.5.6 Fatigue analysis

Fatigue analysis shall be based on a cumulative damage assessment performed over the design service life of the structure and shall consider the effects of the range of sea states and directions to which the structure will be subjected, in accordance with [Clause 5](#). Where relevant, fatigue damage accrued during construction and/or transportation from the construction site to the permanent location shall be included in the accumulation of fatigue damage.

A linear model of the overall structure is generally acceptable for the evaluation of global action effects. Dynamic effects are likely to be more significant for the relatively short wave periods causing the majority of fatigue damage. Fatigue analysis shall, therefore, consider the effects of dynamic excitation in appropriate detail, either by quasi-static or by dynamic response analysis in accordance with [7.4.2](#). Deterministic or stochastic types of analysis are both permissible, subject to the following requirements.

Where deterministic analyses are deemed adequate, the selected individual waves to which the structure is subjected shall be based on a representative spread of wave heights, periods and directions. For structures that are dynamically sensitive, these shall include several wave periods at or near each natural period of the structure to ensure that dynamic effects are accurately assessed. Consideration shall also be given to the higher frequency content in larger waves that can cause dynamic excitation.

As noted in [7.4.4](#), for probabilistic analysis sufficient wave cases shall be analyzed to adequately represent the stress-transfer functions of the structure. Where relevant, non-linear response of the structure shall be incorporated into the analysis using appropriate methods.

7.5.7 Seismic analysis

7.5.7.1 General

Two levels of seismic excitation on a structure shall be considered in accordance with [Clause 6](#):

- extreme level earthquake (ELE), which shall be assessed as a ULS condition;
- abnormal level earthquake (ALE), for which ductile behaviour of the structure assuming extensive plasticity is permissible provided the structure survives.

Where ductile response of specific components of the structure under the ALE event is predicted or considered in the analysis, such components shall be designed for ductile behaviour in accordance with [Clause 8](#). Expected best estimates of stress/strain parameters associated with ductile behaviour may be adopted in the analyses. Due consideration shall be given to the effects of greater than representative strength with respect to the transfer of forces into adjoining members, and for the design of those failure modes that are not ductile, such as shear failure. For those cases where the structure can be designed to the ALE event applying normal elastic analysis and ALS criteria, no special detailing for ductility is required.

NOTE 1 Experience with fixed concrete offshore structures installed at locations with low to moderate seismic activity has shown that even for the ALE event analyzed based on an elastic structural model, the action effects from seismic excitation are less than those for other actions. In such cases, a more refined seismic response analysis considering plastic behaviour will not be necessary.

Seismic events may be represented by input response spectra or by time histories of significant ground motion in accordance with ISO 19901-2. If the global response of the structure is essentially linear, a dynamic spectral analysis shall normally be appropriate. If non-linear response of the structure is significant, transient dynamic analysis shall be performed.

NOTE 2 In ISO 19901-2 a seismic reserve capacity factor, C_r , is employed. There is little or no experience in establishing realistic C_r values for fixed offshore concrete structures. An appropriate value can be established based on the actual structure. Normally, for concrete structures with continuity and good ductility, a factor of more than 1,4 is assumed acceptable.

Seismic response of a structure is highly dependent on the natural periods of the structure over a range of modes. This relies on accurate assessments of the structure's mass and stiffness, and a best estimate of soil stiffness. Such parameters shall be carefully assessed and, if necessary, the sensitivity of the response of the structure to changes in these parameters shall be evaluated.

7.5.7.2 Structure and foundation simulation

Interaction of the structure with its foundation is particularly significant for seismic analysis. The foundation shall be modelled with sufficient accuracy for global structural analysis to ensure an accurate assessment of natural periods of vibration and a suitable distribution of soil actions into the structure.

Two principal types of seismic analyses can be performed for fixed concrete offshore structures:

- direct soil-structure analysis;
- structural analysis using impedance functions.

For direct soil-structure analysis, the base of the structure may be modelled as a rigid structure connected to a flexible model of the foundation. In an analysis of the structure, the base of the structure may be considered as a rigid circular disk for the computation of impedance functions.

Consideration shall be given to the range of likely values of soil stiffness in the analysis. In particular, the possible degradation of soil properties during high-level seismic events, such as the ALE, shall be considered. Appropriate non-linear or reduced soil stiffness properties shall be used.

Soil properties, particularly shear wave velocity, dynamic shear modulus and internal damping are dependent on the shear strains used. These values should be adjusted for the expected strains appropriate to the seismic excitation and the variation in vertical effective stress and voids ratio due to the presence of the structure.

7.5.7.3 Mass and damping

The simulation shall include a representation of the mass of the structure in accordance with [7.3.6](#). Enclosed fluids can be included as lumped masses where the heights of the water columns are small and where sloshing is not significant.

Unless a detailed evaluation is made, internal damping of not more than 5 % shall be used to simulate damping from joint structural and hydrodynamic origins for seismic analysis. Any increased value shall be subject to justification based on the expected response. Values of soil damping shall be determined based on the soil type present.

7.5.7.4 Analysis procedures

For the ELE, linear dynamic global structural analysis may be performed using the response spectrum approach. Spectra used shall be in accordance with ISO 19901-2, but the analysis shall incorporate the effect of the structure's response on soil motions, if appropriate. Where degradation of soil properties and non-linear soil-structural interaction or base sliding are important, a non-linear dynamic time history analysis procedure should be adopted to address these effects; the structure itself may be modelled as linear elastic. Where seismic isolation or passive energy dissipation devices are employed to mitigate the seismic risk, a non-linear time history procedure shall be used.

Sufficient modes shall be included in the analysis to provide an accurate estimate of total global response. At least two modes shall be considered in each of the two principal horizontal directions, as well as a torsional mode about a vertical axis. This requirement may be considered satisfied if it is demonstrated that, with the modes considered in the analysis, at least 90 % of the participating mass of the structure is included in the calculation of the response for each principal horizontal direction.

One design spectrum may be used in each principal horizontal direction, combined with 2/3 of this spectrum in the vertical direction unless a lesser value can be justified based on site-specific data. These

spectra may be combined modally using the complete quadratic combination method and directionally using a square root of the sum of squares approach. Alternative methods are permitted with suitable justification that all seismic action effects are included.

Secondary spectra may be developed for the analysis of structural parts, such as the topsides or conductor frames, to evaluate the response of parts, appurtenances and equipment not modelled for the global analysis. Alternatively, the design of local components may be based on equivalent quasi-static analysis of such components, based on maximum vertical and horizontal accelerations obtained from the global seismic analysis.

Action effects from seismic analysis shall be combined with similar results from permanent and variable actions to produce action effects for structural design. Appropriate directions of seismically induced actions shall be considered to maximize these action effects.

For the ALE, non-linear seismic analysis may be performed using a time history or transient approach. Unless time histories are available by scaling or by other means, they may be developed numerically from the design spectra. Multiple time histories are required to represent the random nature of seismic ground motions.

The computer model for the ALE analysis shall include discrete models of all primary components of the structure using either linear elastic or material non-linear simulations. Deflection effects shall be evaluated, and permanent and variable actions shall be included in the analysis to ensure that second order effects are modelled with sufficient accuracy.

The action effects on structural members that are simulated as linear elastic in either the ELE or the ALE analyses shall be evaluated and used to confirm that these components satisfy ULS criteria. Components that demonstrate ductile response shall be so designed and shall be assessed against acceptance criteria relevant for the actual limit state with respect to all relevant response parameters.

7.5.8 Analysis of accidental or abnormal design situations

Analysis of the structure for accidental events, such as ship, helicopter or iceberg collision, shall consider the following:

- local behaviour of the impacted area;
- global strength of the structure against overall collapse;
- post-damage integrity of the structure.

The resistance of the impact area may be studied using local models. The contact area and perimeter shall be evaluated based on predicted non-linear behaviour of the structure and of the impacting object. Non-linear analyses can be required since the structure will generally deform substantially under the accidental actions. Appropriate boundary conditions shall be provided far enough away from the damaged region for inaccuracies to be minimized.

Global analysis of the structure under accidental actions can be required to ensure that a progressive collapse is not instigated. The analysis should include the weakening effect of damage to the structure in the impacted area. If ductile response of the structure is likely for the impact actions determined, global non-linear analysis can be required to simulate the redistribution of action effects as section resistances are exceeded. The global analysis may be based on a simple model of the structure sufficient to simulate progressive collapse. Deflection effects shall be included where relevant.

Energy absorption of the structure will arise from the combined effect of local and global deformation. Sufficient deformation of the structure to absorb the impact energy from the collision not absorbed by the impacting object shall be documented.

Analysis of the structure in its damaged condition may normally be performed using linear static analysis. Damaged components of the structure shall be removed from this analysis, or appropriately weakened to simulate their reduced strength and stiffness.

8 Concrete works

8.1 Design

8.1.1 Reference standard for design

The design shall be performed in accordance with a recognized reference standard, covering all aspects relevant for the structural design of concrete offshore structures. This subclause identifies areas of design that can be relevant, dependent on circumstances. If these areas are applicable, they shall be appropriately covered by the selected reference standard, supplemented, where necessary, with additional requirements. Where relevant, the testing standards referred to in the reference standard shall be part of the evaluation, to ensure consistency with the assumptions of the reference standard. For complex structures, where higher grades of concrete are used, and where the loading conditions are severe, all appropriate items listed in [8.1.2](#) to [8.1.9](#) shall be covered.

The reference standard shall be agreed at an early stage in a project, as the choice of reference standard can strongly influence the platform geometry and dimensions, while standards not intended for offshore use can be unnecessarily conservative on certain aspects relevant to offshore conditions.

The reference standard shall conform with the basic principles of ISO 19900.

The reference standard shall give the design parameters required for the type of concrete, e.g. normal-weight or lightweight concrete, and the strength class used. For lightweight concretes, the effect of reduced ductility shall be considered. This applies, in particular, to the stress/strain diagram in compression, to the design parameter used for the tensile strength in the calculation of bond strength and to the transverse shear resistance.

NOTE Historically, NS 3473.E was widely used in the design of fixed offshore concrete structures, and was recognized as meeting the requirements of this subclause. However, as part of the Eurocode programme in Europe, NS 3473.E has been withdrawn and replaced with Eurocode 2. It is consequently no longer maintained and may cease to be suitable as a reference standard in the future. However, any standard can be used as a reference standard provided that it is supplemented by additional requirements, where necessary, to ensure that all relevant aspects for the design are properly covered within a consistent safety concept. Where Eurocode 2 (EN 1992-1-1:2004) is used, the Scope indicates that particular aspects might need to be supplemented. [8.1.2](#) to [8.1.17](#) can be used as a checklist when selecting the reference standard to be used for a specific project.

8.1.2 Design principles for shell members

Shell types of members are typical in concrete offshore structures. The reference standard shall cover design principles applicable to members that cannot be categorized as beams or columns, such as walls, domes and cylinders. The design methods shall be general in nature, considering equilibrium and compatibility of all six force components giving stresses in the plane of the member (N_x , N_y , N_{xy} , M_x , M_y , M_{xy}) and all limit states.

8.1.3 Design principles for transverse shear

The reference standard shall give the principles required for the design for transverse shear, where the general situation of combinations of simultaneously acting in-plane action effects (e.g. tension and compression) and directionality of transverse action effects (e.g. principal transverse shear direction) shall be covered. The interaction, which is dependent on the directionality of in-plane action effects in members such as shells, plates and slabs, shall be included. Due consideration shall be given to the handling of action effects caused by imposed deformations.

8.1.4 Design principles for fatigue

The reference standard shall give the principles required for the design against fatigue for all possible failure modes. This includes the following:

- concrete in compression/compression or compression/tension;

- transverse shear considering both shear tension and shear compression;
- reinforcement considering both main bars and stirrups, including bond failure;
- prestressing reinforcement.

Material standards can include certain fatigue-related requirements; these are normally not adequate for offshore applications. The fatigue properties for offshore applications are significantly different, also for materials that pass such general material requirements for fatigue. SN-curves representing the 5 % fractile should be prepared for the design of rebars, and, in particular, for items that have stress concentrations, such as couplers, end anchors and T-heads.

8.1.5 Design principles for durability

The reference standard shall give the design principles and design criteria applicable to ensure a durable design in a marine environment. Important in this context are the following:

- the selection and combination of the appropriate materials, which shall be in accordance with 8.2;
- adequate concrete cover of reinforcement, a minimum of 50 mm in the splash zone and a minimum of 40 mm elsewhere; for prestressing tendons, a minimum of 90 mm (these are minimum values; permitted tolerance (negative deviation) on the position of reinforcement should be added to give the nominal cover ($c_{\text{nom}} = c_{\text{min}} + |\Delta c_{\text{minus}}|$). A typical value is $\Delta c_{\text{minus}} = -10$ mm);
- limitation of crack widths at the nominal cover under SLS conditions;
- where there are multiple layers of reinforcement and, in order to estimate the crack width, the reference standard requires evaluation of the strain in the reinforcement, it is usually more appropriate to take the strain in the outermost layer, and not at the centroid of reinforcement;
- where the reference standard requires an area of concrete associated with the bars in tension, and the bar spacing or section shape is irregular, it is usually more appropriate to consider individual bars and the local area of concrete surrounding them, rather than the overall zone in tension;
- crack width design limits may be exceeded during temporary or transient conditions, such as installation, provided an adequate margin remains on yield of reinforcement.

8.1.6 Design principles for liquid tightness

The reference standard shall give the design principles for liquid tightness control, which shall be considered under SLS conditions. This shall apply to the ingress of water in structures while afloat and during the installed condition in situations where there is internal underpressure. It shall also apply to the possibility of leakage, in particular of stored hydrocarbons, from structures having internal overpressure. Leakage shall also be considered in the design of members for which maintaining a pressure gradient is vital, such as occurs in suction foundations and when using air cushions.

NOTE Where gas tightness is relevant, the provisions given in ACI 376 can be appropriate.

Adequate liquid tightness or leakage control shall also be required for ULS and ALS conditions where leakage could cause collapse or loss of the structure due to flooding or where a pressure differential required to maintain equilibrium can be lost.

8.1.7 Design principles for prestressed concrete

The reference standard shall give the principles required for the design of prestressed concrete, including principles for partial prestressing, when appropriate.

The effect of the presence of empty ducts during certain phases of the execution period shall be considered. For the final condition, the effect of the presence of ducts on the capacity of cross-sections shall be considered, in particular if the strength and stiffness of the grout is less than that of the

concrete. This also applies if the ducts are not of steel but of flexible materials. Anchorages shall be placed in positions and protected in such ways that they are not susceptible for wear or damages.

8.1.8 Design principles for second order effects

The reference standard shall give the principles required for the design of all relevant types of members for second order effects, including buckling in the hoop direction of shell types of members.

NOTE For slabs and walls, an equivalent buckling length and axial load can be derived for each orthogonal direction using the theory of elastic stability or finite element methods. Buckling assessments can then be performed for equivalent one-way spanning members using the reference standard.

8.1.9 Principles for handling water pressure in pores and cracks

The reference standard shall include methodologies for determining the action effects, strength and serviceability of members that will permit the effects of pressure from water or stored fluids penetrating into cracks and pores of the concrete to be included. As water pressure will penetrate into shear cracks, shear capacity enhancement for actions near supports ($x < 2,5 d$) cannot be applied for shear caused by water pressure.

8.1.10 Design principles for discontinuity regions

The reference standard shall give the principles for the local design of discontinuity regions where strut and tie models, or other appropriate methods, can be used to demonstrate the mechanisms for force transfer.

8.1.11 Design principles for imposed deformations

The reference standard may additionally give the principles required to permit design against imposed deformations based on strains rather than forces, in all limit states. Where brittle failure modes are involved, such as shear failure in members with no transverse reinforcement, conservative design parameters shall be assumed in order to not underestimate the risk of potential brittle failure modes.

Imposed deformations can often be seen as imposed additional strain that affects crack widths in SLS, but with minor effect on section capacity for bending and axial force in ULS. While the effects with respect to transverse shear are more complex, modifications to shear forces due to cracking can be made only where it can be demonstrated that the assumed reduction will take place, using upper values for cracking strength and stiffness, before failing in shear.

8.1.12 Increase in strength of concrete with time

The reference standard may give guidance for assessing the effect of a gain in strength beyond 28 days and also for assessing the effect of sustained actions, or repeated actions at high stress levels, on the reduction in strength of concrete, where the gain in strength is intended for use in the design.

8.1.13 Design for fire resistance

The reference standard shall give design principles required for demonstrating adequate fire resistance of members subjected to fire, including relevant material and strength parameters at elevated temperatures.

8.1.14 Design for earthquakes

In zones with low to moderate seismic activity, the action effects obtained from an analysis in which the structure is modelled as linear elastic will normally be such that the structural design can be performed based on conventional linear elastic strength analyses, employing normal design and detailing rules for the reinforcement design.

In cases where the seismic action causes large amplitude cyclic deformations, which can only be sustained by employing plasticity considerations, the reference standard shall give adequate requirements concerning design and detailing. The regions of the structure that are assumed to go into plasticity and to experience excessive deformations shall be carefully detailed to ensure appropriate ductility and confinement.

8.1.15 Design of embedments

The reference standard shall give design principles for the anchorage of load-bearing embedments into concrete. Additional reinforcement/prestressing system adequate to transfer all tensile action effects into the concrete and anchoring the pull-out action effects on the opposite face should normally be provided.

8.1.16 Treatment of early-age and drying shrinkage effects

The reference standard shall give methods for the assessment of early-age and drying shrinkage effects arising where sections are subject to restraint following concreting.

NOTE It is commonly considered that cracks associated with early-age and drying shrinkage effects are independent of cracking occurring in service.

8.1.17 Partial factors for material

The partial factors for material, γ_M , shall be such that a safety level consistent with that inherent in ISO 19900 and this document is obtained, and is consistent with the partial factors that are used.

NOTE The material factors will depend on how the design parameters are defined and specified in the reference standard, as well as on the corresponding partial factors for actions. Where EN 1992-1-1:2004 is used as a reference standard, material factors recommended in that standard can be applied with the action factors of [Table 1](#), provided that the factors α_{cc} and α_{ct} are taken as 0,85. Where the guidance of EN 1992-1-1:2004, Annex A, is used, the material factors for concrete and reinforcement cannot be taken to be less than 1,40 and 1,10, respectively. For other standards, the material factors can require a separate evaluation.

8.2 Materials requirements

8.2.1 General

Constituent materials for structural concrete are cement, aggregate and water. Structural concrete may also include admixtures and additions. Guidance on material selection for durability is given in ISO 16204.

Constituent materials shall be sound, durable, free from defects and suitable for making concrete that will attain and retain the required properties. Constituent materials shall not contain harmful ingredients in quantities that can be detrimental to the durability of the concrete or cause corrosion of the reinforcement, and shall be suitable for the intended use. Further guidance on constituent materials is given in ISO 22965-2.

Approval of concrete constituents and reinforcements shall be based on material testing where chemical composition, mechanical properties and other specified requirements are tested according to, and checked against, applicable international standards and approved specifications. Instead of relevant international standards for specific test methods and requirements, other recognized national standards may be used. In the absence of such standards, recognized recommendations from international or national bodies may also be used.

NOTE Fibre reinforcement can be applied in order to improve certain aspects of structural behaviour (e.g. cracking, fire resistance) but are not be included in the general calculation of section resistance, unless covered by the design provisions in the reference standard used.

Material specifications shall be established for all materials to be used in the manufacture of concrete, in the reinforcement system and the prestressing system.

Materials conforming with recognized product standards are acceptable, provided the requirements of this document are met.

All testing shall be performed in accordance with recognized standards as stated in the project work specification or otherwise agreed upon.

Material can be rejected at any stage of the execution process, notwithstanding any previous acceptance or certification, if it is established that the conditions upon which the approval or certification was based were not fulfilled.

8.2.2 Concrete constituents

8.2.2.1 Cement

Only cement with established suitability shall be used. Its track record for good performance and durability in marine environments, and for good performance and durability in exposure to stored oil or other fluids if relevant, shall be demonstrated. Cement shall be tested and delivered in accordance with a standard recognized in the place of use.

The cement shall be delivered with a mill certificate giving, as a minimum, the chemical and mineralogical composition, and the test values for all those properties for which there are requirements. Cement shall be tested according to approved methods. [Table 4](#) lists different types of tests that can be required.

The tricalcium aluminates (C_3A) content should not exceed 10 %. However, as the corrosion protection of embedded steel is adversely affected by a low C_3A content, it is not advisable to aim for values lower than approximately 5 %.

The mill certificate shall, in addition to demonstrating conformity with specified requirements, also state the type/grade of cement with reference to the approved standard/project work specification, the batch identification and the tonnage.

The requirement for a mill certificate may be waived provided the cement is produced and tested under a national or international certification scheme, and all required properties are documented based on statistical data from the producer.

Table 4 — Cement testing

Physical properties	Chemical properties
Strength in mortar	Loss on ignition
Initial/settling time	Insoluble residue
Soundness	Sulphate content
Fineness	Chloride content
	Pozzolanicity

The following types of cement are, in general, assumed to be suitable for use in structural concrete and/or grout in a marine environment, if unmixed with other cements:

- Portland cements;
- Portland composite cements (with silica, fly ash or slag and minimum 80 % clinker).

Provided suitability is demonstrated, the following types of cement may also be considered:

- Portland composite cements (with other pozzolanas or clinker content below 80 % clinker);
- blast-furnace cements (less than 64 % clinker);
- pozzolanic cements (less than 64 % clinker);

- composite cement (less than 64 % clinker).

NOTE The above types of cement have characteristics specified in regional and national standards, while no international standards for cement exist. Cements can be specified in grades based on the 28 day strength in mortar (e.g. 32,5 MPa; 42,5 MPa; 52,5 MPa).

Cements shall normally be classified as normal-hardening, rapid-hardening or slowly-hardening cements.

8.2.2.2 Mixing water

Only mixing water with established suitability shall be used. The mixing water shall not contain constituents in quantities that can be detrimental to the setting, hardening and durability of the concrete or can cause corrosion to the reinforcement. Drinking water from public supply may normally be used without further investigation.

Water resulting in a concrete strength of less than 90 % of that obtained by using distilled water tested at 7 days shall not be used. Neither shall water be used that reduces the setting time to less than 45 min or changes the setting time by more than 30 min relative to distilled water.

Salt water (e.g. raw sea water) shall not be used as mixing or curing water for structural concrete.

Water sources shall be investigated and approved for their suitability and dependability for supply.

8.2.2.3 Normal-weight aggregate

Only aggregates with established suitability shall be used. Aggregates for structural concrete shall have sufficient strength and durability. They shall not become soft, be excessively friable, expand or shrink.

They shall be resistant to decomposition when wet. They shall not react with the products of hydration of the cement and shall not affect the concrete adversely. Marine aggregates shall not be used unless they are properly and thoroughly washed to remove chlorides (see [8.2.3.1](#)).

Aggregate sources shall be investigated and approved for their suitability and for supply dependability. Aggregate shall be delivered with a test report that at least contains the following:

- description of the source;
- description of the production system;
- particle size distribution (grading) including silt content;
- particle shape, flakiness, etc.;
- porosity and water absorption;
- content of organic matter;
- density and specific gravity;
- potential reactivity with alkalis in cement;
- petrographic composition and properties that can affect the durability of the concrete.

Normal-weight aggregate shall be of natural mineral substances. They shall be either crushed or uncrushed with particle sizes, grading and shapes, such that they are suitable for the production of concrete. Relevant properties of aggregate shall be defined, e.g. type of material, shape, surface texture, physical properties and chemical properties. Aggregate shall be free from harmful substances in quantities that can affect the properties and the durability of the concrete adversely. Examples of harmful substances are clay-like and silty particles, organic materials, sulphates and other salts.

Aggregate shall be evaluated for risk of alkali aggregate reaction (AAR) in concrete according to recognized test methods. Suspect aggregate shall not be used unless specifically tested and approved. The approval of an aggregate that can combine with the hydration products of the cement to cause AAR shall state to which cement the approval applies.

Aggregates of different grading shall be stockpiled and transported separately.

Testing of aggregate shall be carried out at regular intervals both at the quarry and at the construction site during concrete production. The frequency of testing shall be determined after taking the quality and uniformity of supply and the concrete production volume into account, in accordance with requirements of national standards in the place of use.

An appropriate grading of the fine and coarse aggregate for use in concrete shall be established. The grading and shape characteristics of the aggregate shall be consistent throughout the concrete production.

Maximum aggregate size shall be specified based on considerations of concrete properties, spacing of reinforcement and cover to the reinforcement. The largest specified aggregate size should not be less than 16 mm.

8.2.2.4 Lightweight aggregate

Lightweight aggregate in load-bearing structures should be made from expanded clay, expanded shale, slate or sintered pulverized ash from coal-fired power plants, or from other aggregates with corresponding documented properties. Only aggregates with established suitability shall be used.

Lightweight aggregate shall have uniform strength properties, stiffness, density, degree of burning, grading, etc. The dry density shall not vary more than $\pm 7,5$ %.

8.2.2.5 Additions

Additions shall conform with the requirements of recognized standards, and only additions with established suitability shall be used.

Additions shall not be harmful or contain harmful impurities in quantities that can be detrimental to the durability of the concrete or the reinforcement. Additions shall be compatible with the other ingredients of the concrete. The use of combinations of additions and admixtures shall be carefully considered with respect to the overall requirements of the concrete. The effectiveness of the additions shall be checked by trial mixes.

Latent hydraulic or pozzolanic materials, such as silica fume, fly ash and granulated blast furnace slag, may be used as additions. The amount is dependent on requirements to workability of fresh concrete and required properties of hardened concrete. The content of silica fume used as additions should normally not exceed 10 % of the weight of Portland cement clinker. When fly ash or other pozzolanas are used as additions, their content should normally not exceed 35 % of the total weight of cement and additions. When Portland cement is used in combination with only ground granulated blast furnace slag, the slag content may be increased. The clinker content shall normally not be less than 30 % of the total weight of cement and slag.

8.2.2.6 Admixtures

Only admixtures with established suitability shall be used. Admixtures to be used in concrete shall be tested under site conditions with the cement and additions to be used to verify that these products will yield the required effects without impairing the other properties required. The risks involved in over-dosage shall be assessed. A test report shall be prepared to document such verification. The test report shall form a part of the concrete mix design documentation.

The extent of testing of admixtures shall normally be in accordance with the requirements given in national standards or recognized international standards.

Air-entraining admixtures may be used to improve the properties of hardened concrete with respect to frost-resistance, or to reduce the tendency of bleeding, segregation or plastic cracking.

8.2.2.7 Repair materials

The composition and properties of repair materials shall be such that the material fulfils its intended use. Only materials with established suitability shall be used. Emphasis shall be given to ensure that such materials are compatible with the adjacent material, particularly with regard to elasticity and temperature-dependent properties.

Requirements for non-cementitious materials shall be subject to case-by-case consideration and approval. Deterioration of such materials when applied for temporary use shall not be allowed to impair the function of the structure at later stages.

The extent of testing of repair materials shall be specified in each case.

8.2.3 Concrete

8.2.3.1 Concrete

The concrete composition and the constituent materials shall be selected to satisfy the requirements of this document and the project work specifications for the fresh and hardened concrete, such as consistence, density, strength, durability and protection of embedded steel against corrosion. Due account shall be taken of the methods of execution to be applied. The requirements of the fresh concrete shall ensure that the material is fully workable in all stages of its manufacture, transport, placing and compaction.

The required properties of fresh and hardened concrete shall be specified. These required properties shall be verified by the use of recognized testing methods, international standards or recognized national standards. Compressive strength shall always be specified; in addition, tensile strength, modulus of elasticity (*E*-modulus) and fracture energy can be specified. Properties which can cause cracking of structural concrete shall be accounted for, i.e. creep, shrinkage, heat of hydration, thermal expansion and similar effects. The durability of structural concrete is related to permeability, absorption, diffusion and resistance against physical and chemical attacks in the given environment; a low water/cement ratio is generally required in order to obtain adequate durability. Unless equivalent durability is documented, the concrete shall have an effective water/cement ratio not greater than 0,45, and in the splash zone this ratio shall not be higher than 0,40; this also applies to areas that can be exposed to severe frost action.

Chemical attack by hot oil and gases should be considered in the mix design if applicable. The aggressiveness of hot oil with respect to the concrete and the build-up of H₂S shall be considered (see [10.2.5](#)).

Where pozzolanic or latent hydraulic additions are used in the production of concrete, in combination with Portland cement or Portland composite cement, these materials may be included in the calculation of an effective water/cement ratio, *m*, expressed by [Formula \(1\)](#):

$$m = w / (c + k a) \tag{1}$$

where

- w is the mass of water;
- c is the mass of cement;
- k is an efficiency factor for active additions (type II), such as silica, fly ash and slag, where the efficiency of the material as replacement of cement with respect to durability in the given environment is considered;
- a is the mass of the active addition (type II).

In this calculation, the total quantity of such additions ground into the cement and/or added in the mixer shall not exceed the limits permitted by the cement standard for Portland composite cements or for blast-furnace cement, if slag is the only addition added to the clinker. Instead of other values, the following values of k may be used:

- $k = 1$ to 2 for silica
- $k = 0,5$ to $0,7$ for slag
- $k = 0,2$ to $0,4$ for fly ash

Concrete subjected to freezing and thawing shall have adequate frost resistance. This frost resistance shall be demonstrated by appropriate test methods. For Portland and Portland composite cements with fly ash or silica and with more than 80 % clinker, this requirement may be considered satisfied when entrained air is used if the air content, at the form, of the fresh concrete made with natural aggregate is at least 4 % for a maximum particle size of 40 mm, or at least 5 % for a maximum particle size of 20 mm. With clinker contents less than 80 % the frost resistance shall be demonstrated by appropriate testing methods to evaluate scaling and freezing and thawing resistance. In concrete with slag content of more than 35 %, the concrete shall be carbonated prior to testing of frost resistance. The entrained air should give an evenly distributed air void system. In areas with severe frost, the specific surface should be larger than 25 mm²/mm³ and the spacing factor should not exceed 0,25 mm.

The total chloride ion content of the fresh concrete shall not exceed 0,10 % of the weight of cement in ordinary reinforced concrete and in concrete containing prestressing steel.

In the splash zone, the cement content shall not be less than 400 kg/m³. For reinforced or prestressed concrete outside the splash zone, the minimum cement content shall be dependent on the maximum size of aggregate, as follows:

- up to 20 mm aggregate requires a minimum cement content of 360 kg/m³;
- from 20 mm to 40 mm aggregate requires a minimum cement content of 320 kg/m³.

For concrete exposed to seawater and stored oil, the characteristic cylinder strength at 28 days should not be less than 40 MPa.

Where lightweight aggregate with a porous structure is used, the mean value of oven dry (105 °C) density for two concrete specimens after 28 days shall not deviate by more than 50 kg/m³ from the required value. Any individual value shall not deviate by more than 75 kg/m³. The mean value for the entire production should lie within +20 kg/m³ to -50 kg/m³.

Where the water absorption of the concrete in the final structure is important, this property shall be determined by testing under conditions corresponding to the conditions to which the concrete will be exposed.

Special attention shall be paid to setting times for concrete used for slipforming.

8.2.3.2 Grout and mortar

The mix design of grout and mortar shall be specified for its designated purpose.

The constituents of grout and mortar shall meet the same type of requirements for their properties as those given for the constituents of concrete.

The properties of fresh and hardened grout and mortar shall be specified as required for the intended use. The cement grout for injection in prestressing ducts and the ingredients used shall have adequate properties conforming with the specifications for design. The strength and stiffness shall be given due attention, and be consistent with design requirements. In order to obtain stiffness commensurate with that of the concrete, special fine-grain aggregate or admixture shall be considered.

All materials shall be batched by mass, except the mixing water, which may be batched by volume. The batching shall be within an accuracy of 2 % for cement and admixtures and 1 % for water. The water/cement ratio shall not be higher than 0,44. Batching and mixing shall be such that specified requirements for fluidity and bleeding in the plastic condition, volume change when hardening, and strength and stiffness when hardened are complied with.

8.2.4 Reinforcement

8.2.4.1 Reinforcing steel

Reinforcing steel shall conform with ISO 6935-1 and ISO 6935-2, or relevant national standards on reinforcing steel. Consistency shall be ensured between material properties assumed in the design and requirements of the standard used. In general, hot-rolled, ribbed bars of weldable quality and with high ductility shall be used. Where the use of seismic detailing is required, the reinforcement provided shall meet the ductility requirements of the reference standard used in the design.

Fatigue properties and S-N curves shall be consistent with the assumptions of design.

Reinforcing steel shall be delivered with a works certificate. The requirement for a works certificate may be waived, if the reinforcement is produced and tested under a national or international certification scheme, and all the required test data are documented based on statistical data from the producer. All steel shall be clearly identifiable.

Galvanized reinforcement may be used where requirements are made to ensure that there will be no reactions with the cement that have a detrimental effect on the bond to the galvanized reinforcement.

Stainless steel may be used provided it meets the requirements for mechanical properties of ordinary reinforcement steel.

8.2.4.2 Mechanical splices and end anchorages for reinforcement

Anchorage devices and couplers shall conform with national standards and be as defined in the project work specification. Fatigue properties and S-N curves shall be consistent with the assumptions of the design and be documented for the actual combinations of rebars, couplers or end anchorages.

Couplers that give a permanent slip on unloaded specimen of more than 0,1 mm after 10 cycles of loading to 75 % of nominal yield strength should not be used in structures where tightness and fatigue is a concern.

Mechanical splices and end anchorages shall be delivered with a works certificate.

Friction-welded end anchorages on rebars (T-heads) shall be qualification tested in advance with the actual type of rebar and be routinely tested during production. The test programme shall include a tension test and a bend test to document strength and ductility of the connection. The friction weld shall not fail before the rebar.

8.2.4.3 Approval of weld procedures

Weld procedures, together with the extent of testing for weld connections relevant to reinforced concrete and concrete structures, shall be specified and approved in each case.

8.2.5 Prestressing steel

Prestressing steel as a product shall conform to the applicable parts of the ISO 6934 series and/or applicable national standards.

Tendons (wires, strands, bars), anchorage devices, couplers and ducts or sheaths are part of a prestressing system described in the project work specification. All parts shall be compatible and clearly identifiable.

Prestressing systems shall conform with the requirements of the project work specifications and shall have the approval of an authorized institution or national authority.

Sheaths for post-tensioning tendons shall in general be of a semi-rigid or rigid type, watertight and with adequate stiffness to prevent damages and deformations. The ducts shall be of steel unless other types are specified by design.

Components for the prestressing system shall be delivered with a works certificate.

8.2.6 Embedded materials

Embedded materials, such as steel and composites, shall be suitable for their intended service conditions and shall have adequate properties with respect to strength, ductility, toughness, weldability, laminar tearing, corrosion resistance and chemical composition. The supplier shall document these properties.

8.3 Execution

8.3.1 Falsework and formwork

8.3.1.1 Basic requirements

Falsework and formwork, including their supports and foundations, shall be designed and constructed so that they are

- capable of resisting any actions expected during the construction process, and
- stiff enough to ensure that the tolerances specified for the structure are satisfied and the integrity of the structural member is not affected.

Form, function, appearance and durability of the permanent structure shall not be impaired due to falsework and formwork or their removal.

8.3.1.2 Materials for formwork and falsework

Any material that leads to the fulfilment of the criteria given for the structure may be used for formwork and falsework. The materials shall conform with relevant product standards where these exist. Properties of the specific materials, such as shrinkage, shall be taken into account if they can affect the end product.

The materials employed shall be consistent with any special requirements for the surface finish or later surface treatment.

8.3.1.3 Release agents

Release agents shall neither be harmful to the concrete nor shall they be applied in a manner that will affect the concrete, the reinforcement or the bond between the two.

Release agents shall not have a detrimental effect on the surface finish, or subsequent coatings if any.

Release agents shall be applied in accordance with the manufacturer's specification.

8.3.1.4 Falsework

The method statement shall describe the method of erection and dismantling of temporary structures. The method statement shall specify the requirements for handling, adjusting, intentional pre-cambering, loading, un-keying, striking and dismantling.

Deformations of formwork during and after concreting shall be limited to prevent deleterious cracking in the young concrete. This can be achieved by limiting the deformations and by organizing the casting operations in a manner so as to avoid harmful deformations.

8.3.1.5 Formwork

Formwork shall keep the concrete in its required shape until it has hardened.

Formwork and the joints between boards or panels shall be sufficiently tight against loss of water and fines.

Formwork that absorbs moisture or facilitates evaporation shall be suitably wetted to minimize water loss from the concrete, unless the formwork was designed specifically for that purpose.

The internal surface of the formwork shall be clean. When slipforming is used, the form panels shall be thoroughly cleaned and a grease-like mould-release agent shall be applied prior to assembling of the form.

8.3.1.6 Slipform systems

Where using the slipforming method, the design and erection of the form and the preparation of the works shall take into account the difficulties of controlling the geometry and the stiffness of the entire working platform. The entire slipform structure shall be designed with the appropriate stiffness and strength. Due account shall be taken of friction against hardening concrete, weight of materials stored on the form, systems for adjusting geometry, such as diameter and wall thickness, as well as climatic conditions that are to be expected during the slipforming period.

The lifting capacity of the jacks shall be adequate. The climbing rods shall be sufficiently strong not to buckle. Normally, the climbing rods are left totally encased within the concrete. If the climbing rods are removed, the holes thus left in the concrete shall be properly filled with grout via grouting inlets at the bottom or by injection hoses threaded in from the top. The grout consumption shall be monitored to confirm complete filling.

The materials applied in the form may be either steel or wood and shall conform with the requirements for formwork materials. The form shall have a height and batter consistent with the concrete used. The slipforming rate and other conditions affecting the hardening process of the concrete shall be such as to reduce or eliminate the tendency for lifting cracks.

The slipform shall have a hanging platform below the main form, giving access for application of curing as well as inspection and, if necessary, light repair of the hardening concrete when appearing from under the slipform.

The concrete cover to the reinforcement shall be kept within the tolerances using sufficiently long and stiff steel guides between the reinforcement and the form, adequately distributed around the form.

There shall be contingency plans prepared for unintended situations, such as break-down in concrete supply, problems with the lifting devices, hardening of the concrete, etc.

8.3.1.7 Jumpforming systems

Jumpforming systems, when used, shall have adequate strength and stiffness for all actions exerted during the erection and casting period. There shall be a robust system for support of the forms in the previously cast concrete. Inserts for support shall be approved for the actual application.

The jumpform, when installed, shall allow the necessary preparation and cleaning of construction joints. The jumpform system shall accommodate the necessary walkways and access platforms to ensure that the concreting works can be performed in an appropriate manner.

8.3.1.8 Inserts in formwork, recesses and block-outs, temporary openings

Temporary inserts to keep the formwork in place (bars, ducts and similar items cast within the section) and embedded components (e.g. anchor plates, anchor bolts) shall

- be fixed robustly enough to ensure that they will keep their prescribed position during placing and concreting,
- not introduce unacceptable loading on the structure,
- not react harmfully with the concrete, the reinforcement or prestressing steel,
- not produce unacceptable surface blemishes,
- not impair functional performance, tightness and durability of the structural member, and
- not prevent adequate placing and compaction of the fresh concrete.

Any embedded item shall have sufficient strength and stiffness to preserve its shape during the concreting operation and be free of contaminants that would affect the item, the concrete or the reinforcement.

Recesses used for temporary works shall be filled and finished with a material of similar quality as the surrounding concrete, unless it is otherwise specified. Block-outs and temporary holes shall generally be cast with normal concrete. Their surfaces shall be keyed or slanted and prepared as construction joints.

Temporary opening shall be focused. Three-dimensional analysis shall be used to determine the effects of post tensioning sequence on concrete shell without and with the access opening unless justified by alternative methods. Emphasis shall be placed on the stress state within the access opening due to the absence of self-weight in this area. The state of stress determined by this analysis shall conform with the minimum performance required for both temporary and operating design situations. Interfaces between first and second concrete shall be treated as construction joint.

8.3.1.9 Removal of formwork and falsework

Falsework and formwork shall not be removed until the concrete has gained sufficient strength to:

- resist damage to surfaces that can arise during the striking;
- take the actions imposed on the concrete member at that stage;
- avoid deflections beyond the specified tolerances due to elastic and inelastic (creep) behaviour of the concrete.

Striking shall be made in a manner that will not subject the structure to overload or damage.

Propping or re-propping may be used to reduce the effects of the initial loading, subsequent loading and/or to avoid excessive deflections. Propping can be required in order to achieve the intended structural behaviour of members cast in two or more casting operations.

If formwork is part of the curing system, the time of its removal shall take into account the requirements of [8.3.4.5](#).

8.3.2 Reinforcement

8.3.2.1 Bending, cutting, transport and storage

The surface of all reinforcing steel shall be free from loose rust, mill-scale and deleterious substances that can adversely affect the steel or concrete or the bond between them. It shall be stored free of the ground, and protected from mechanical damage, rupture of welds and reduction of cross-section through corrosion.

The cutting and bending of reinforcing steel shall be performed conforming to national standards or other relevant documents. Particular care shall be taken in cases where the execution, reinforcement supply and design is not performed according to a consistent suite of standards. The following requirements shall apply:

- bending shall be done at a uniform rate;
- bending of reinforcement with temperature below 0 °C shall only be performed as permitted by national standards, and in accordance with procedures prepared for the particular construction site;
- unless specifically permitted by the project work specification, bending using heat treatment is not permitted.

For bars, wires, welded reinforcement and fabric bent after welding, the diameter of the mandrel used should be as specified by the design and in accordance with the standard relating to the type of reinforcement. Under no circumstances shall reinforcement be bent over a mandrel with a diameter that is less than 1,5 times that of the test mandrel used for bending tests to document what strains can be sustained by the steel without cracking or damage.

In-place bending of steel in the formwork can be allowed if it can be demonstrated that the prescribed bending radius is obtained, and the work can be performed without displacing the reinforcement.

The straightening of bent bars is prohibited unless it can be documented that the bars remain undamaged. A procedure for such work shall be prepared and approved.

Reinforcement delivered on coil shall be handled using the appropriate equipment. Straightening shall be performed according to approved procedures and all required mechanical properties shall be maintained.

Prefabricated reinforcement assemblies, cages and elements shall be adequately stiff and strong to retain their shape during transport, storage, placing and concreting. They shall be accurate so that they meet all the requirements regarding placing tolerances for reinforcement.

8.3.2.2 Welding

Welding is only permitted on reinforcing steel that is classified as weldable in the relevant product standard, or in accordance with the applicable parts of the ISO 6935 series or national standards, and only if specified in the project work specification.

Welding shall be used and performed in accordance with specifications by design and shall conform with special requirements in national standards as relevant.

Welding should not be executed at or near bends in a bar, unless specifically approved by design.

Welding of galvanized or epoxy-coated reinforcement is only permitted when a procedure for repair is specified and approved.

All welding shall be performed to a qualified welding procedure, and only by qualified welders.

8.3.2.3 Joints

Joints on bars shall be made by laps or couplers. Only couplers whose effectiveness is tested and approved may be used. Butt welds can be permitted to a limited extent, but only when subjected to prequalification testing with non-destructive examination and visual quality inspection of all welds during execution.

The length and position of lapped joints and the position of couplers shall be in accordance with design drawings and the project work specification. Staggering of such joints shall be considered in design, the overlapping bars should be placed in contact and preferably tied together.

8.3.2.4 Assembly and placing of reinforcement

The reinforcement shall be placed according to the design drawings and fixed within the tolerances for fixing of reinforcement in this document, and secured so that its final position is within the tolerances given in this document.

Assembly of reinforcement should be done by tie wire. Spot or tack welding is not allowed for the assembling of reinforcement unless permitted by national standards and the project work specification, and due account has been taken of the risk of fatigue failure of the main rebar at the weld.

The specified cover of the reinforcement shall be maintained by the use of suitable chairs and spacers. Spacers in contact with the concrete surface in a corrosive atmosphere shall be made from concrete of at least the same quality as the structure.

In areas of congested reinforcement, measures shall be taken to ascertain that the concrete can flow and fill all voids without segregation and can be adequately compacted.

8.3.3 Pre- and post-tensioning

8.3.3.1 Transport and storage

All components of the entire prestressing assembly or system, consisting, for example, of prestressing steel, ducts, sheaths, anchorage devices, couplers, as well as prefabricated tendons and tendons fabricated on site, shall be protected from harmful influences during transport and storage and also while placed in the structure prior to permanent protection. Materials that have been damaged or corroded shall be replaced.

8.3.3.2 Fabrication of prestressing assembly

The prestressing assembly, e.g. all components of the tendons, shall be assembled in accordance with the relevant standards, where these exist, or suppliers' specifications or approval documents, and as shown in the construction drawings.

Approval documents, identification documents and certification of tests on materials and/or tendons shall be available on site. Each item or component shall be clearly identified and traceable.

Documentation of prestressing steel of different deliveries shall be made in the as-built records.

Cutting shall be done by an appropriate method in a way that is not harmful.

Prestressing steel shall not be subjected to welding. Steel in the vicinity of prestressing steel shall not be subjected to oxygen cutting or welding, except when sufficient precautions have been taken to avoid damage to prestressing steel and ducts.

8.3.3.3 Placing of the prestressing assembly

The prestressing assembly shall be placed in conformity with the project's/supplier's specification and in accordance with the relevant construction drawings. The tendon and all components shall be placed

and secured in a manner that maintains their location within the permissible tolerances for position, angular deviation, straightness and/or curvature. Tendons shall not sag or have a kink of any kind.

8.3.3.4 Post-tensioned tendons

The straight entry into anchorages and couplers as well as the coaxiality of tendon and anchorage shall be as specified by the supplier's specifications or system approval documents.

Vents and drains on the sheaths shall be provided at both ends, and at all points where air or water can accumulate. In the case of sheaths of considerable length, inlets, vents and drains can be necessary at intermediate positions. As an alternative to drains, other documented methods of removing water may be considered.

Inlets, vents and drains shall be properly marked to identify the cable.

The sheaths and their joints shall be sealed against ingress of water and the ends shall be capped to avoid rain, dirt and debris of any kind. They shall be secured to withstand the effects of placing and compacting of the concrete.

Sheaths shall be checked after pouring of concrete to ensure sufficient passage for the tendons.

Sheaths shall be cleared of any water immediately prior to tendon threading.

8.3.3.5 Tensioning of tendons

Tensioning shall be done in accordance with an approved method statement giving the tensioning programme and sequence. The jacking force/pressure and elongation at each stage/step in the stressing operation until full force is obtained shall be recorded in a log. The obtained pressures and elongations at each stage/step shall be compared to pre-calculated theoretical values. The results of the tensioning programme and its conformity or non-conformity to the requirements shall be recorded. All observations of problems during the execution of the prestressing works shall also be recorded.

Stressing devices shall be as permitted for the prestressing system.

The valid calibration records for the force-measuring devices shall be available on site before the tensioning starts.

Application and/or transfer of prestressing forces to a structure shall be at a concrete strength that meets the requirements as specified by design, and under no condition shall it be less than the minimum compressive strength stated in the approval documents of the prestressing system. Special attention in this respect shall be paid to the anchorage areas.

8.3.3.6 Pre-tensioning

If, during stressing, the calculated elongation cannot be achieved within a range of $\pm 3\%$ for a group of tendons or $\pm 5\%$ for a single tendon within the group for the specified tensioning force, action shall be taken in accordance with the method statement, with regard either to the tensioning programme or to the design.

The release of prestressing force in the rig/bed shall be done in a careful manner in order not to affect the bond in the anchorage zone of the tendon in a negative manner.

Where the fresh concrete cannot be cast in due time after tensioning, temporary protective measures shall be taken which will not affect the bond or have detrimental effects on the steel and/or the concrete.

8.3.3.7 Post-tensioning

Tensioning shall not take place when concrete temperatures are below $+5\text{ }^{\circ}\text{C}$ within the structure, unless special arrangements can ensure the corrosion protection of non-grouted tendons. Tensioning is prohibited if there is a risk of the grout freezing. Tensioning is prohibited at air temperatures below $-10\text{ }^{\circ}\text{C}$.

Where, during the stressing operation, the calculated elongation cannot be achieved within a range of $\pm 5\%$ for a group of tendons or $\pm 10\%$ for a single tendon within the group for the specified tensioning force, action shall be taken in accordance with the method statement, with regard either to the tensioning programme or to the design.

In the case of deviations from the planned performance during tensioning, tendon-ends shall not be cut off and grouting is not permitted. Works that can impair re-tensioning shall not be carried out. No tendons shall be cut if the obtained elongations deviate from the theoretical by more than 5% , without design approval. Further work shall be postponed until the tendon has been approved or further action decided.

NOTE In case of deviations between theoretical and obtained results, tests to confirm friction factors and *E*-modulus of the tendon assembly can be necessary.

The prestressing tendons should be protected from corrosion in the period from threading to prestressing. This period should normally not be allowed to exceed four weeks without special precautions being taken.

8.3.3.8 General protective measures

Tendons placed in sheaths in the concrete, couplers and anchorage devices shall be protected against detrimental corrosion. This protection shall be ensured by filling all voids with a suitable grouting/injection material, such as cement grout, grease or wax. Anchorage areas and end caps shall be filled and protected as well as the tendons; inlets and outlets shall be suitably sealed.

In case of post-tensioning with required bond, cement grouting of sheaths shall conform with recognized international or national standards. Grouting/injection shall follow as soon as possible after tensioning of the tendons, normally within two weeks. If a delay is likely to permit corrosion, protective measures should be considered in accordance with recommendations by the supplier.

A method statement shall be provided for the preparation and execution of the grouting/injection. All important data/observations from the grouting shall be reported in a log, e.g. volume consumed compared to theoretical volume, temperature of the structure and mix proportions and problems/stops.

Grouting devices shall be as permitted for the prestressing system.

8.3.3.9 Protective measures for unbonded tendons

Anchorage areas of unbonded tendons or single strands, their sheaths and end caps shall be filled by non-corrosive grease or wax. End caps shall be encased in concrete tied to the main structure by reinforcement.

Sheathed unbonded tendons shall be adequately sealed against penetration of moisture at their ends.

8.3.3.10 Grouting operations

Grouting with cement-based grouts shall only be done at temperatures in the structural element in the range of $+2\text{ °C}$ to $+35\text{ °C}$. The temperature of the grout shall neither be less than $+10\text{ °C}$ nor above $+25\text{ °C}$. If a frost-resistant grout is used, grouting at lower temperatures than $+2\text{ °C}$ can be permitted.

Where the temperature in the structure is above $+35\text{ °C}$, grouting can be permitted provided special precautions valid in the place of grouting can ensure a successful grouting.

Grouting shall be carried out at a continuous and steady rate from the lowest inlet until the emerging grout through anchor heads and outlets has the appropriate quality, not affected by evacuated water or preservation oil from the duct. In vertical ducts, the grouting pressure shall be given particular attention. Normally the grout pressure inside the duct should not be allowed to exceed 2 MPa , unless permitted by the design. Non-retarded grout and grout with an expanding admixture shall be used within 30 min after mixing.

In vertical or inclined ducts or ducts of particularly large diameter, post-injection can be necessary in order to remove bleed water or voids. Post-injection shall be performed before the grout has stiffened. If voids are detected at inlets or outlets after the grout has stiffened, post-grouting shall be carried out, if required, by vacuum grouting.

In case of vacuum injection, the free volume in the ducts shall be measured. The amount of grout injected shall be comparable with this volume. Vacuum grouting procedures, particularly in the case of vertical tendons, should be prequalified by trials of relevant geometry.

Requirements for vacuum grouting or re-injection shall be made in case of discovery of a blockage in the duct. Ducts shall, under no circumstances, be left empty and ungrouted without specific approval by design.

After completion of grouting, unintended loss of grout from the ducts shall be prevented by sealing them under a minimum pressure of 0,5 MPa for a minimum of 1 min.

If grouting of a duct is interrupted, corrective actions, such as washing out all fresh grout, shall be taken. No ducts shall be left with incomplete filling of grout.

A full-scale mock-up shall be performed to qualify the grout mix and procedure. The mock-up should replicate the actual conditions under which grouting will be performed including temperature and humidity ranges.

8.3.3.11 Greasing operations

Greasing shall be carried out at a continuous and steady rate. After completion of greasing, unintended loss of grease from the ducts shall be prevented by sealing them under pressure.

The volume of the injected grease shall be checked against the theoretical free volume in the duct. The change of volume of the grease with change in temperature shall be taken into account.

8.3.4 Concreting

8.3.4.1 Concrete production

All the required properties for the concrete to achieve its service functions shall be identified. The properties of the fresh and hardened concrete shall take account of the method of execution of the concrete works, e.g. placing, compacting, formwork striking and curing.

Prior to any concreting, the concrete shall be documented by pretesting to meet all the requirements specified. Testing may be performed based on laboratory trial mixes, but should also include a full-scale test from the batch plant used. Documented experience from earlier use of similar concrete produced on a similar plant with the same constituent materials can be regarded as valid pretesting. The quality control procedures shall be available on site. The procedures shall include the possible corrective actions to be taken in the event of non-conformity with the project work specification or agreed procedures.

Fully automatic stationary batching plants should be used for concrete production. All mixing and batching equipment shall conform with the requirements for stationary mixers included in the national standard.

NOTE In order to ensure uninterrupted concrete placement, industry practice has been to utilize two identical independently operated, fully automatic, highly efficient stationary concrete batching plants.

All aggregates, cement and pozzolans shall be measured by weight on separate balances.

The certificate of the accuracy for the scales or measuring devices shall be obtained initially after completion of the plants at the site and at least every 180 days during concrete production. Additional verification may be performed immediately before major pours.

The delivery of concrete ingredients to the mixer shall be within the tolerances specified in the national standard.

The design of the batching plants shall ensure adequate storage for all mixing materials. The storage provisions shall ensure positive segregation and identification of each aggregate size as well as the cement and pozzolans (to guard against inadvertent substitution).

8.3.4.2 Procedures in connection with each delivery

Concrete shall be inspected at the point of placing and, in the case of ready-mixed concrete, also at the point of delivery. Samples for testing of conformity with given requirements shall be taken at the point of placing. In the case of ready-mixed concrete produced and certified according to a recognized certification scheme covering all given requirements, only identity testing at the point of delivery may be applied.

NOTE Identity testing is testing to verify that the concrete comes from a conforming population.

Detrimental changes of the fresh concrete, such as segregation, bleeding, paste loss or any other changes, shall be minimized during loading, transport and unloading, as well as during conveyance or pumping on site.

Concrete may be cooled or heated either during mixing, during transport to the site or at the site, if documented acceptable by pretesting. The temperature of the fresh concrete shall be within the specified or declared limits.

Concrete may be retempered by post-dosing of admixtures, if documented acceptable by pretesting.

8.3.4.3 Pre-concreting operations

Initial testing of concreting by trial casting shall be documented before the start of execution. An assessment of construction phases shall be performed to determine critical operations and/or structural components that require mock-ups to test materials, equipment, and placement methods to verify the expected quality.

If pumping of concrete is used, adequate back-up or emergency plans shall be prepared to ensure that blockage of piping will not lead to an unacceptable end result.

All preparation works shall be completed, inspected and documented as required for the inspection class before the casting is initiated.

Construction joints shall be prepared and roughened in accordance with project work specifications. In monolithic structures, an adequately roughened surface can be obtained by the application of a surface retarder on the fresh concrete and later cleaning by water jetting. Construction joints shall be clean, free of laitance and thoroughly saturated with water, but surface dry.

Construction joints in contact with the section cast shall have a temperature that does not result in freezing of the adjoining concrete.

The form shall be free of detritus, ice, snow and standing water.

If the ambient temperature is forecasted to be below 0 °C at the time of casting or in the curing period, precautions shall be planned to protect the concrete against damage due to freezing.

If the ambient temperature is forecasted to be above 30 °C at the time of casting or in the curing period, precautions shall be planned to protect the concrete against damaging effects of high temperatures.

8.3.4.4 Placing and compaction

The concrete shall be placed and compacted in order to ensure that all reinforcement and cast-in items are properly embedded in compacted concrete and that the concrete achieves its intended strength and durability.

Appropriate procedures shall be used where cross-sections are changed, in narrow locations, at box-outs, at dense reinforcement arrangements and at construction joints. Settlement cracking over reinforcement in the top surface shall be avoided by re-vibration.

The rate of placing and compaction shall be high enough to avoid cold joints and low enough to prevent excessive settlements or overloading of the formwork and falsework. The concrete shall be placed in layers of a thickness that is compatible with the capacity of the vibrators used. The concrete of the new layer should be vibrated systematically and include re-vibration of the top of the previous layer in order to avoid weak or inhomogeneous zones in the concrete. The vibration shall be applied until the expulsion of entrapped air has practically ceased, but not so as to cause segregation or a weak surface layer.

Concrete shall be placed in such a manner as to avoid segregation. Free fall of concrete from a height of more than 2 m shall not occur unless the mix is demonstrated to allow this without segregation. Concrete shall be compacted by means of high-frequency vibrators or by alternative methods that can be demonstrated to give adequate compaction. Contact between internal vibrators and reinforcement or formwork shall be avoided as much as possible. Vibrators shall not be used for horizontal transportation (spreading) of concrete.

Alternative methods to the use of vibrators in order to obtain an adequately compacted concrete are permitted, provided they are able to be documented for the relevant type of conditions by trial casting; this can include the use of self-compacting concrete (SCC), provided the concrete composition conforms with [8.2](#).

During placing and compaction, the concrete shall be protected against adverse solar radiation and wind, freezing, water, rain and snow. Surface water shall be removed during concreting, if the planned protection fails.

8.3.4.5 Curing and protection of hardening concrete

Concrete in its early life shall be cured and protected to

- minimize plastic shrinkage and losses in strength and durability,
- ensure adequate surface strength,
- ensure adequate surface zone durability,
- prevent freezing, and
- prevent harmful vibration, impact or damage.

The curing methods employed shall prevent significant evaporation from the concrete surface. This may be achieved by keeping the surface permanently wet during the required curing period. Sea water shall not be used for curing. Fresh concrete shall not be permitted to be submerged in sea water until an adequate strength of the surface concrete is obtained.

On completion of compaction and finishing operations on the concrete, the surface shall be cured without delay. If needed to prevent plastic shrinkage cracking on free surfaces, measures to reduce loss of water shall be applied prior to finishing.

The duration of applied curing shall be a function of the development of the concrete properties in the surface zone and depends on the climate conditions prevailing in the region where the concrete member is located. Curing shall be applied until the strength of the concrete has reached a degree of hydration, characterized by strength proportions, given in [Table 5](#).

Table 5 — Minimum values of proportions of the strength of concrete at the end of curing

Climatic conditions when curing			Strength proportion ^a		
			Submerged zone	Splash zone	Other zones
H	Humid	RH > 80 %	0,5	0,6	0,5
M	Moderate	65 % < RH ≤ 80 %	0,6	0,7	0,6
D	Dry	45 % < RH ≤ 65 %	0,6	0,7	0,6
VD	Very dry	RH ≤ 45 %	0,7	0,8	0,7

a- The strength proportion is defined as the ratio between the mean concrete strength at the end of the curing period and the mean strength at the age of 28 days, made, cured and tested in accordance with ISO 1920-3 and ISO 1920-4.

The duration of curing may be estimated based on testing of strength or, alternatively, by the maturity of the concrete on the basis of either the surface temperature of the concrete or the ambient temperature. The maturity calculation should be based on an appropriate maturity function proven for the type of cement or combination of cement and addition used.

The equivalence of curing may also be proven by applying suitable methods to measure the surface permeability or the strength of the concrete cover at the end of curing.

The curing methods given in [Table 6](#) shall be used individually or in sequence; method C should normally be used in combination with method A or B.

Table 6 — Methods of curing

Method		Measure
A	Without adding water	Keeping the formwork in place. Covering the concrete surface with vapour-proof sheets that are secured at the edges and joints to prevent through-draughts.
B	Keeping the concrete moist by addition of water	Placing of wet coverings on the concrete surface and protection of these coverings against drying by vapour-proof sheets. Keeping the concrete surface visibly wet by spraying with clean water. Ponding the concrete surface with clean water.
C	Use of curing compounds	Curing compounds shall have an established suitability. Suitability may be based on testing, comparing the effectiveness of the curing compound to the effectiveness of water. Curing compounds may be used in accordance with international or national standards.

Curing compounds are not permitted on construction joints and on surfaces where bonding of other materials is required, unless they are fully removed prior to the subsequent operation or they are proven to have no detrimental effects on bonding.

Early-age thermal cracking resulting from thermal gradients or restraints from adjoining members and previously cast concrete shall be minimized. In general, a differential temperature across a section should not be allowed to exceed 10 °C per 100 mm.

The concrete surface temperature shall not fall below 0 °C until the concrete surface has reached a compressive strength of at least 5 MPa and until the strength is also adequate for all actions in frozen and thawed conditions until the specified full strength is gained. Curing by methods using water shall not be adopted, if freezing conditions are likely. In freezing conditions, concrete slabs and other parts that can become saturated shall be protected from the ingress of external water for at least seven days.

The peak temperature of the concrete within a member shall not exceed 70 °C unless data are provided documenting that higher temperatures will have no significant adverse effects, such as reduced strength or delayed ettringite formation.

The set concrete shall be protected from vibrations and impacts that could damage the concrete or its bond to reinforcement.

The surface shall be protected from damage by heavy rain, flowing water or other mechanical influences.

8.3.4.6 Post-concreting operations

After removal of formwork, all surfaces shall be inspected for conformity to the requirements.

The surface shall be protected from damage and disfigurement during construction.

8.3.4.7 Special execution methods

Special execution methods can be required in cases where concrete with lightweight or heavyweight aggregate is used and in the case of underwater concreting. In such cases, procedures for the execution shall be prepared and approved prior to the start of the work. In order to address most of the particular effects of this method, mock-up and trials are strongly recommended.

Special execution methods shall be stated in the project work specification and agreed.

Special execution methods shall not be permitted if they can have an adverse effect on the structure or its durability.

8.3.4.8 Finish and repair

Formed finishes shall be obtained by the use of properly designed formwork of timber, plywood, plastic, concrete or steel. Small blemishes caused by air or entrapped water can be expected, but the surface shall be free from voids, honeycombing or other blemishes.

Unformed finishes shall be screeded to produce a uniform and smoothed surface. After the concrete has stiffened sufficiently, this finish shall be floated by hand or by a machine producing a satisfactorily uniform surface.

Prior to construction, plans and procedures shall be prepared and agreed for remedying any foreseen defective work. It shall be clearly established what types of repair will require involvement by design.

Mock-up can be required to confirm that the required quality and finish can be achieved by the proposed concrete mix and method of construction, and to serve as a reference standard by which the quality of the works can be assessed.

8.3.5 Execution with precast concrete elements

8.3.5.1 General

8.3.5 gives requirements for construction operations involving precast concrete elements, whether produced in a factory or a temporary facility at or outside the site, and are applicable to all operations from the time the elements are available on the site, until the completion of the work and final acceptance.

The manufacture and design of precast concrete elements, when used in concrete offshore structures, are covered by this document, and shall meet all requirements to materials, strength and durability as if they were cast in situ.

Where precast concrete elements are used, these shall be designed for all temporary conditions as well as for the structural performance in the overall structure. This shall at least cover the following:

- joints, with any bearing devices, other connections, additional reinforcement and local grouting;
- completion work, such as integral in situ casting, toppings and reinforcement;
- load and arrangement conditions due to transient situations during execution of the in situ works;

— differential time-dependent behaviour for precast and in situ concrete.

Precast concrete elements shall be clearly marked and identified with their intended positions in the final structure. As-built information and records of conformity testing and control shall be available.

A complete erection work programme with the sequence of all on site operations shall be prepared, based on the lifting and installation instructions and the assembly drawings. Erection shall not be started until the erection programme is approved.

8.3.5.2 Handling and storage

Instructions shall be available giving the procedures for the handling, storage and protection of the precast concrete elements.

A lifting scheme defining the suspension points and forces, the arrangement of the lifting system and any special auxiliary provisions shall be available. The total mass and centre of gravity for the concrete elements shall be given.

Storage instructions for the precast concrete element shall define the storage position and the permissible support points, the maximum height of the stack, the protective measures and, where necessary, any requirements to maintain stability.

8.3.5.3 Placing and adjustment

Requirements for the placing and adjustment of the precast concrete elements shall be given in the erection programme, which shall also define the arrangement of the supports, the necessary props and possible temporary stability provisions. Access and work positions for lifting and guiding of the concrete elements shall be defined. The erection of the precast concrete elements shall be performed in accordance with the assembly drawings and the erection programme.

Construction measures shall be applied which ensure the effectiveness and stability of temporary and final supports. These measures shall minimize the risk of possible damage and of inadequate performance.

During installation, the correct position of the precast concrete elements, the dimensional accuracy of the supports, the conditions of the precast concrete element and the joints, and the overall arrangement of the structure shall be checked, and any necessary adjustments shall be made.

8.3.5.4 Jointing and completion works

The completion works are performed on the basis of the requirements given in the erection programme and taking climatic conditions into account.

The execution of the structural joints shall be made in accordance with the project work specifications. Joints that are concreted shall have a minimum size to ensure a proper filling. The faces shall normally meet the requirements to construction joints.

Connectors of any type shall be undamaged, correctly placed and properly executed to ensure an effective structural behaviour.

Steel inserts of any type used for joint connections shall be properly protected against corrosion and fire by an appropriate choice of materials or covering.

Welded structural connections shall be made with weldable materials and shall be inspected.

Threaded and glued connections shall be executed according to the specific technology of the materials used.

8.3.6 Embedded components

8.3.6.1 General

Components that are cast-in and form an integral part of the permanent structure, serving either structural or functional purposes for either permanent or temporary use, shall be produced and installed in accordance with specifications and drawings. Embedded items shall be stiff enough to preserve their shape unaffected by the concreting operation. They shall

- be fixed robustly enough to ensure that they will keep their prescribed position during placing and concreting within the tolerances,
- not introduce unacceptable actions on the structure,
- not react harmfully with the concrete, the reinforcement or prestressing steel,
- not produce unacceptable surface blemishes,
- not impair functional ability and durability of the structural member, and
- not prevent adequate placing and compaction of the fresh concrete.

Components that are cast-in shall be inspected and approved while access for an appropriate inspection is available.

Embedded components that receive heat treatment after concreting shall be inspected for damage caused by the heat treatment and thermal expansion, such as warping of the embedment; concrete spalling or cracking shall be rectified.

NOTE In cases where extensive welding is performed on embedded components that are intended for transfer of significant shear forces, special provisions can be necessary to ensure that the concrete in areas important for the transfer of the shear forces has not had a significant reduction in concrete strength due to the heat input.

8.4 Geometrical tolerances

8.4.1 General

In addition to the class 1 tolerance requirements of ISO 22966 and ISO 16204 that shall apply, 8.4 defines the types of geometrical deviations relevant to offshore structures. Indicative values for normal tolerances are given for certain parameters. For other dimensions, only the type of requirement is indicated; numerical values are left to be specified in the project work specifications.

In general, tolerances on dimensions are specified in order to ensure the following:

- the geometry is such as to allow parts to fit together as intended;
- geometrical parameters used in the design are satisfactorily accurate;
- construction work is performed with a satisfactorily accurate workmanship;
- weights are sufficiently accurate for weight control and floating stability considerations (see ISO 19901-5).

All these factors shall be considered when tolerances are specified. Tolerances assumed in design and tolerances specified for construction shall be in agreement.

The requirements relate to the completed structure. Where components are incorporated in a structure, any intermediate checking of such components shall be subordinate to the final checking of the completed structure.

Changes in dimensions following temperature effects, concrete shrinkage, creep, post-tensioning and application of actions, including those resulting from different construction sequences, are not part of the construction tolerances. When deemed important, these changes shall be considered separately.

8.4.2 Reference system

A system for setting out tolerances and the position points, which mark the intended position for the location of individual components, shall be in accordance with ISO 4463-1.

Deviations of supports and components shall be measured relative to their position points. If a position point is not established, deviation shall be measured relative to the secondary system of ISO 4463-1. A tolerance of position in plane refers to the secondary lines in plane. A tolerance of position in height refers to the secondary lines in height.

8.4.3 Tolerances of structural members

Requirements shall be given for the following types of tolerances, as relevant.

a) Skirts:

- 1) deviation from intended centre for circular skirts;
- 2) deviation from intended position for individual points along a skirt;
- 3) deviation from best fit circle for circular skirts;
- 4) deviation from intended elevation for tip and top of skirts;
- 5) deviation from intended plumb over given heights.

b) Slabs and beams:

- 1) deviation from intended elevation for centre plane;
- 2) deviation from intended planeness measured over given lengths (2 m and 5 m);
- 3) deviation from intended slope.

c) Walls, columns and shafts:

- 1) deviation from intended position of centre plane or horizontal centre-line;
- 2) deviation from intended planeness — horizontal direction;
- 3) deviation from intended planeness — vertical direction;
- 4) deviation from intended plumb over given heights.

d) Domes:

- 1) deviation of best fit dome centre from intended centre — horizontal and vertical directions;
- 2) deviation of best fit inner radius from intended radius;
- 3) deviation of individual points from best fit inner dome;
- 4) deviation of individual points from best fit exterior dome.

e) Circular members:

- 1) deviation of best fit cylinder centre from intended centre-line;
- 2) deviation of best fit inner radius from intended inner radius;

- 3) deviation of individual points from best fit inner circle over given lengths;
 - 4) deviation of individual points from best fit exterior circle over given lengths;
 - 5) deviation from intended plumb over given heights.
- f) Shaft/deck connections:
- 1) deviation of best fit centre from intended centre of shaft;
 - 2) deviation in distances between best fit centres of shafts;
 - 3) position of temporary supports — horizontal and vertical;
 - 4) position of anchor bolts — horizontal and vertical.

8.4.4 Cross-sectional tolerances

Requirements shall be given for the following type of tolerances. Where tolerances are given, these are the recommended values.

- a) Thickness:
- 1) individual measured points, Δt -10/+30 mm;
 - 2) overall average for area, Δt -10/+20 mm.
- b) Reinforcement position:
- 1) tolerance on concrete cover, -10/+10 mm;
 - 2) tolerance on distance between rebar layers in the same face, -5/+10 mm;
 - 3) tolerance on distance between rebar layers at opposite faces, -20/+40 mm;
 - 4) tolerances on spacing of rebars in same layer;
 - 5) tolerances on lap lengths, $(L), L_{\min} > 0,95L$.
- c) Prestressing:
- 1) tolerance on position of prestressing anchors;
 - 2) position of ducts/straightness at anchors;
 - 3) position of ducts in intermediate positions, $0,05t < 20$ mm;
 - 4) tolerances on radius for curved parts of tendons, $\Delta R < 0,05R$.

8.4.5 Embedments and penetrations

Tolerances shall be for items individually or for groups, as appropriate. Requirements shall be given for the following type of tolerances, as relevant.

- a) Embedded plates:
- 1) deviation in plane parallel to concrete surface;
 - 2) deviation in plane normal to concrete surface;
 - 3) rotation in plane of plate.
- b) Attachments to embedments: deviation from intended position (in global or local system).

c) Penetrations:

- 1) deviation of sleeves from intended position of centre;
- 2) deviation of sleeves from intended direction;
- 3) deviation of manholes from intended position and dimension;
- 4) deviation of block-outs from intended position and dimensions.

8.5 Quality control — Inspection, testing and corrective actions

8.5.1 General

Supervision and inspection shall ensure that the works are completed in accordance with ISO 22966 and the requirements of the project work specification.

Three execution classes are defined in ISO 22966; however, execution class 1 shall not be used for offshore concrete structures.

Execution class may refer to the complete structure, to certain members of the structure or to certain operations of execution.

8.5.2 Inspection of materials and products

The inspection of the properties of the materials and products used in the works shall be in accordance with ISO 22966.

8.5.3 Inspection of execution

8.5.3.1 General

Inspection of execution according to this document shall be performed in accordance with ISO 22966 and [Table 7](#) unless otherwise stated in the project work specification. For inspection classes, refer to [6.6](#).

Table 7 — Inspection of execution

Subject	Execution class		
	1 ^a	2	3
Scaffolding, formwork and falsework	Random checking	Major scaffolding and formwork shall be inspected before concreting	All scaffolding and formwork shall be inspected before concreting
Ordinary reinforcement	Random checking	Major reinforcement shall be inspected before concreting	All reinforcement shall be inspected before concreting
Prestressing reinforcement	N/A	All prestressing components shall be inspected before concreting, threading, stressing Materials are identified by appropriate documentation	
Embedded items	According to project work specification		
Erection of precast elements	N/A	Prior to and at completion of erection	Prior to and at completion of erection
Site transport and casting of concrete	Occasional checks	Basic and random inspection	Detailed inspection of entire process
Curing and finishing of concrete	Occasional checks	Occasional checks	Regular inspection
Inspection class 1 included for completion but shall not be used for offshore concrete structures.			

Table 7 (continued)

Subject	Execution class		
	1 ^a	2	3
Stressing and grouting of prestressing reinforcement	N/A	Detailed inspection of entire process, including evaluation of stressing records prior to cutting permission	
As-built geometry	N/A	According to project work specification	
Documentation of inspection	N/A	Required	
Liquid tightness	N/A	Tested according to project work specification	
Inspection class 1 included for completion but shall not be used for offshore concrete structures.			

8.5.3.2 Inspection of falsework and formwork

Before casting operations start, inspections according to the relevant inspection class shall include the following:

- geometry of formwork;
- stability of formwork and falsework and their foundations;
- tightness of formwork and its parts;
- removal of detritus, such as saw dust, snow and/or ice and remains of tie wires and debris from the formwork, etc., from the section cast;
- treatment of the faces of the construction joints;
- wetting of formwork and/or base;
- preparation of the surface of the formwork;
- openings and blockouts.

The structure shall be checked after formwork removal to ensure that temporary inserts have been removed.

8.5.3.3 Inspection of reinforcement

Before casting operations start, inspections according to the relevant inspection class, shall confirm the following:

- the reinforcement shown on the drawings is in place at the specified spacing;
- the cover is in accordance with the specifications;
- reinforcement is not contaminated by oil, grease, paint or other deleterious substances;
- reinforcement is properly tied and secured against displacement during concreting;
- space between bars is sufficient to place and compact the concrete.

After concreting, the starter bars at construction joints shall be checked to ensure that they are correctly located.

8.5.3.4 Inspection of prestressing works

Before casting operations start, inspections shall verify the following:

- the position of the tendons, sheaths, vents, drains, anchorages and couplers is in accordance with the design drawings, including the concrete cover and the spacing of tendons;
- the tendons and sheaths are securely fixed, also against buoyancy, and that the stability of their supports is ensured;
- the sheaths, vents, drains, anchorages, couplers and their sealing are tight and undamaged;
- the tendons, anchorages and/or couplers are not corroded;
- the sheaths, anchorages and couplers are clean.

Prior to tensioning, or prior to releasing the pretension force, the actual concrete strength shall be checked against the strength required.

The relevant documents and equipment according to the tensioning programme shall be available on site.

The calibration of the jacks shall be checked. Calibration shall also be performed during the stressing period if relevant.

Before grouting starts, the inspection shall ensure the following:

- the results of preparation/qualification tests for grout are as required;
- the results of any trial grouting on representative ducts are as required;
- ducts are open for grout through their full length and free of harmful materials, e.g. water and ice;
- vents are prepared and identified;
- materials are batched and sufficient to allow for overflow.

During grouting, the inspection shall include checking of the following:

- the conformity of the fresh grout tests, e.g. fluidity and segregation;
- the characteristics of the equipment and of the grout;
- the actual pressures during grouting;
- the order of blowing and washing operations;
- the precautions to keep ducts clear;
- the order of grouting operations;
- the actions in the event of incidents and harmful climatic conditions;
- the location and details of any re-injection.

8.5.3.5 Inspection of the concreting operations

The inspection and testing of concreting operations shall be planned, performed and documented in accordance with the execution class as shown in [Table 8](#).

Execution class 3 shall be used for concreting operations unless otherwise specified in the project work specification.

Different parts in a structure may be assigned different execution classes, depending on the complexity and the importance in the completed structure.

Table 8 — Requirements for planning, inspection and documentation

Subject	Execution class		
	1	2	3
Planning of inspection programme	N/A	Inspection plan, procedures and work instructions	
		Actions in the event of a non-conformity	
Inspection	Random	Frequent but random inspection	Continuous inspection of each casting
Documentation	Records from all inspections	All planning documents	
	All non-conformities and corrective action reports	Records from all inspections	
		All non-conformities and corrective action reports	

8.5.3.6 Inspection of precast concrete elements

Where precast concrete elements are used, inspection shall include the following:

- visual inspection of the concrete element at arrival on site;
- delivery documentation;
- conditions of the concrete element prior to installation;
- conditions at the place of installation, e.g. supports;
- conditions of the concrete element, any protruding rebars, connection details, position of the concrete element, etc., prior to jointing and execution of other completion works.

8.5.3.7 Hydrotesting

Due consideration shall be given to hydrotesting components of the structure to demonstrate leak tightness.

8.5.3.8 Actions in the event of a non-conformity

Where inspection reveals a non-conformity, appropriate action shall be taken to ensure that the structure remains fit for its intended purpose. As part of this, the following should be investigated:

- the implications of the non-conformity for the execution and the work procedures being applied;
- the implications of the non-conformity for the structure with regard to its safety and functional ability;
- the measures necessary to make the member acceptable;
- the necessity of rejection and replacement of non-conforming members.

Documentation of the procedure and materials used shall be approved before repair or corrections are made.

9 Foundation design

9.1 General

Foundation design applies to the geotechnical aspects of the interface between structural elements and the seabed soils or fill placed on the sea floor, which provides support to the structure and its associated appurtenances. The mechanisms for transfer of actions from the structure to the supporting soil shall be verified and the need for grouting of the voids between the structure and the sea floor assessed.

9.2 Principal elements

The following principal elements and considerations involved in the design of foundations for fixed concrete offshore structures are addressed in this subclause:

- soil investigation (9.3);
- selection of representative soil properties (9.4);
- partial factors (9.5);
- design principles (9.6);
- stability analyses (9.7);
- soil-structure interaction (9.8);
- installation and removal (9.9);
- scour (9.10).

NOTE This document supplements and amplifies many of the topics covered in ISO 19901-4.

9.3 Marine site investigation

9.3.1 Purpose of investigation

The purpose of soil investigation is to ascertain the soil conditions and to obtain the geotechnical data necessary for the determination of characteristic material properties.

A soil investigation shall be performed utilizing professional personnel with skills in the fields, e.g. geology, geophysics, seismology and geotechnics, as appropriate to the investigation. It should include evaluation of all relevant existing data.

Potential geohazards, such as submarine slope instability, liquefaction, faulting, shallow gas and subsidence, shall be considered and investigated as necessary.

9.3.2 Soil investigation

Marine soil investigations shall be carried out in accordance with ISO 19901-8, which specifies requirements for planning, equipment, execution, in situ testing, laboratory testing and reporting.

9.3.3 Laboratory investigation

A laboratory programme shall provide appropriate test data to enable relevant analyses to be performed. The laboratory programme should comprise, among other things, the following:

- classification, consolidation and permeability tests;
- static and cyclic soil testing for the determination of strength, deformation and pore pressure generation parameters in the relevant stress and strain ranges;
- stiffness and damping parameters of the foundation for calculating the dynamic behaviour of the structure.

9.4 Characteristic soil parameters

ISO 19901-4 provides guidance and principles for selecting characteristic values of soil properties in line with the partial factors format.

NOTE See also DNV-RP-C207.

Characteristic strength and deformation parameters shall be determined for all soil layers, and for the relevant stress ranges, taking due account of stress history, soil anisotropy and sample disturbance effects. In these evaluations, caution should be exercised in the utilization of strength that depends on dilatancy of the soils.

The effect of cyclic stresses induced by environmental actions on the structure (e.g. due to hydrodynamic, seismic and ice actions), which are transferred to the soils, shall be determined when such effects are relevant to the particular issues under consideration.

9.5 Partial factors for actions and materials

9.5.1 General

The safety level in geotechnical engineering depends on the extent and reliability of the basic data, their interpretation, the analysis method, and the monitoring and maintenance procedures. The choice of partial action and material factors is only one of several factors influencing foundation safety.

9.5.2 Partial factors for actions

Requirements regarding partial factors for actions and the combination of actions into design situations are given in 6.4 and 6.5. In geotechnical analyses, combinations of actions shall be selected such as to give the most unfavourable result for each of the stability mechanisms and deformation analyses performed.

9.5.3 Partial factors for materials

The material factor for soil may be expressed as the ratio of the undrained shear strength to the shear stress mobilized for equilibrium, or as the ratio of the tangent of the characteristic friction angle to the tangent of the friction angle mobilized for equilibrium.

For the ULS, the material factor shall not be lower than 1,25 in accordance with ISO 19901-4. Dependent on the consequences of failure and failure mechanism a higher value can be required. Consideration should be given to what is recognized practice for the calculation procedures applied and the stability mechanisms analyzed.

The material factor should be increased in the case of new types of structure and/or soil conditions with which no previous experience has been gained.

In the SLS, FLS and ALS, the material factor shall be 1,0.

9.6 Geotechnical design principles

9.6.1 General

The design shall be in accordance with ISO 19901-4.

In the analysis of the interaction between soil and structure, consideration shall be given to whether the stiffness of the structure should be taken into account. The analysis should be based on representative deformation properties of the soil.

All significant effects from environmental actions shall be considered, including the stability of adjacent sea floor slopes. Structures located in the vicinity of each other should be considered with respect to possible reciprocal or unilateral effects, where relevant.

The drainage condition of the soils should be the most representative with respect to soil permeability, length of drainage path, loading rate, etc. In case of significant uncertainty, the most unfavourable condition should be used.

9.6.2 Dynamic analysis for action effects

In some circumstances, it can be appropriate that analyses are based on a quasi-static simplification of structural response to environmental actions and soil resistance. Dynamic analyses can be necessary, however, for certain types of structure where the frequency content of the action is such that foundation design cannot be treated in a quasi-static manner under environmental, ice or earthquake actions. The results can be sensitive to variations in stiffness and damping properties of the soil and the structure. A probable range of variation of soil properties should therefore form the basis of such analyses.

Soil parameters and calculation methods shall be selected in accordance with the histories of actions included in the analysis of the structure and the stress and strain levels resulting from the calculations.

Ice induced vibration or earthquake response shall be calculated on the basis of dynamic properties of all significant soil layers. The effect of interaction between soil and structure shall be taken into account.

9.6.3 SLS

In predicting the evolution of settlements with time, the drainage conditions and uncertainties related thereto shall be considered, including possible assumptions regarding watertight structural components and draining soil layers.

Assessment of settlements and displacements shall include, but is not limited to

- immediate settlement, consolidation settlement, secondary compression and creep,
- differential settlement across the appropriate footprint of the structure,
- dynamically and cyclically induced settlements and deformation,
- lateral displacements and tilts, and
- potential subsidence of the foundation due to reservoir depletion or depressurization.

The possibility of erosion or other deterioration of the soils shall be considered, including effects on skirts.

The consequences of seepage or compression of shallow gas should be considered where relevant.

Actual settlements can be measured in situ for calibrating/updating the calculated settlements over the structure lifetime

9.6.4 FLS

Fatigue analyses shall be based on unfactored representative soil properties, with due regard for the effects of cyclic degradation of soil stiffness and strength.

9.6.5 ULS

The design resistance of the soil under and around the foundation shall be demonstrated to be sufficient to resist the action effects caused by the design actions. The development of the design resistance over a period of time shall be assessed.

Displacements of the foundation due to design actions should be calculated using characteristic deformation parameters. These displacements shall be considered when checking the ULS of the structure or of vital appurtenances, such as conductors, casings and risers.

The effects of cyclic actions on the generation and accumulation of pore pressures and deformations in the soil and the consequential potential reduction in shear strength shall be analyzed. The combined effects of cyclic actions during several storms and subsequent consolidation over a period of time should be considered.

9.6.6 ALS

The foundation, as well as any skirts or other structural components for transfer of actions to the soil, shall be designed to prevent either local yield in structural parts or the soil spreading, leading to collapse.

In ALE, the characteristic soil properties shall be used.

9.7 Bearing capacity

Bearing capacity analyses (including bearing, sliding and overturning) shall be in accordance with ISO 19901-4.

All potential rupture surfaces in the soil mass shall be investigated, with special consideration given to the influence of weak layers or zones.

In a drained condition of the soil, the horizontal and vertical actions for limit equilibrium methods shall be assumed to be acting on the effective foundation area only.

In an undrained condition, particularly where skirts are present, the actions may be assumed to be distributed over all, or a greater part of, the total foundation area.

Wave pressures acting on the seabed around the structure shall be included in the analyses. The potential for wave uplift pressures under the base as a result of partial contact between the base and the sea floor shall be considered.

The potential for destabilization of the foundation due to liquefaction of seabed soils in earthquakes, ice or during drilling activities (e.g. for conductor installation) shall be assessed.

9.8 Soil reactions on structures

The action effects from soil reactions acting on all foundation elements, which either bear upon or penetrate into the seabed, shall be calculated. The foundation system and the structures shall be designed for these reactions.

Design actions and soil properties shall be used in determining the distribution of soil reactions. The reactions should then be considered as design actions that are multiplied by the partial factors for action for those combinations that give the most unfavourable results with respect to the various limit states. Reasonable alternative distributions of soil reactions, which follow from the uncertainties in the calculation models used and the properties of the soil and the foundation system, shall be assessed.

Different distributions of soil reactions can govern the design of different parts of the foundation and structure.

The potential extent and distribution of partial contact between the sea floor and the base of the structure, due to sea floor irregularity and/or the structural form, shall be taken into account.

The potential for drag-down (negative skin friction) acting on foundation skirts and/or conductors shall be assessed. Drag-down on foundation skirts can arise from differential settlement between the foundation and the surrounding consolidating soil. Drag-down on conductors can arise from soil settlement under the imposed weight of the structure relative to the conductor.

Installation effects, changes in soil properties over a period of time, changes in properties of grout below the foundation, as well as local effects of pipes or other structures carried through the foundation or placed in the ground, shall be taken into account.

9.9 Installation and removal

9.9.1 Sea floor preparation

Where applicable, the sea floor shall be prepared to receive the platform, and this may include the following, as appropriate:

- removal of obstacles, debris, boulders, etc.;
- dredging and removal of unsuitable materials;
- levelling the sea floor, i.e. by placement of a rock/gravel/sand bed of suitable materials.

9.9.2 Installation

Where the design requires that dowels, skirts or ribs shall penetrate into the seabed during installation, it shall be demonstrated that the planned penetration can be achieved, and that the maximum moment due to uneven penetration resistance is less than the available ballasting moment.

The potential for “piping” of enclosed water under the tip of the skirts during penetration shall be considered when planning the rate of penetration and the skirt evacuation system.

The soil resistance against skirts or other penetrating components shall be analyzed with respect to its estimated maximum and minimum value. These values shall be used in the evaluation of the installation process.

The consequences of heave of the seabed resulting from soil displaced during skirt installation should be considered.

The structure shall be demonstrated to be stable during touch-down as well as before and during any foundation grouting.

The stability during installation shall be calculated on the basis of planned progress of the operations and the expected setting time of grouts, if used.

Where an underpressure is required during installation, the geotechnical and hydraulic stability of the foundation soils should be analyzed.

9.9.3 Removal

Where removal of the structure is anticipated, an analysis shall be made of the likely upper bound actions on the underbase and on the skirts to ensure that removal can be achieved with the means available.

In the calculation of the extraction forces, the effects of soil adhering to the foundation shall be considered.

Where an overpressure is used under the base, the geotechnical and hydraulic stability of the foundation soils should be analyzed.

9.10 Scour

The possibility of sea floor sediment transport shall be considered, as well as the effects of the structure in modifying the sediment transport regime.

Where there is a risk of scour occurring around the foundation, precautions shall be taken based on one of the following principles:

- the foundation is designed to tolerate the erosion of material from the sea floor,
- adequate scour protection is placed around the structure during installation, or

- the foundation is regularly inspected, and scour resistant materials are immediately placed if unacceptable scour occurs (the adoption of this procedure pre-supposes that a critical extent of scour cannot develop during a single storm).

Foundation observations may be based on a project specific inspection programme, which takes into account the severity and return period of the environmental event and results of observations to set and adjust the frequency of inspections.

10 Mechanical systems

10.1 General

Mechanical systems contained within a concrete offshore structure can generally be classified as temporary or permanent. Temporary systems are those required during construction afloat, tows and installation at the offshore site. Permanent systems are those required during the operational life and removal of the structure. Some portions of permanent systems can also be used in temporary systems. Examples of temporary systems are grouting, skirt air/water evacuation, air cushion, temporary and construction ballast water. Permanent systems are defined in the project requirements and can include such systems as crude oil storage and export, sea water supply and return, service water, fire water, vents, drains, ballast water, risers, J-tubes, conductors, shale chutes, foundation and structure condition monitoring, cathodic protection monitoring, dropped object protection and removal of the structure.

The provision of access, a suitable working environment and the required level of safety for personnel can result in the need for other systems and facilities, such as heating, ventilation and air conditioning (HVAC), stairs, ladders, elevators, active and passive fire protection, fire and gas detection, safety showers and eyewash, communications and lighting.

The support of both permanent and temporary systems generally requires the provision of decks (frequently of steel) within the structure. These systems are generally located in the utility shaft and other shafts where present.

The support of decks, ancillary structures and piping within the concrete offshore structure generally requires the use of steel plates embedded in the concrete (embedment plates). The embedment plates can be held in place by a passive (anchor bolts) or an active (cables/bars) system.

Concrete penetrations to allow the passage of piping should be used, if necessary, and can be accomplished by the use of cast-in sleeves, cast-in spools, block-outs subsequently completed with cast-in spool or sleeve, or holes cast into the concrete. The effect of service temperatures shall be considered in the design of piping and its supports.

Mechanical systems used during construction and during marine operations shall be able to operate under the relevant conditions, including wave action and tilt under accidental conditions.

For structures installed in cold climates, it shall be ensured that the mechanical systems are protected from freezing that can cause damage or prevent them from being operable as required.

10.2 Permanent mechanical systems

10.2.1 General

The permanent systems included shall be defined in the project work specification. Permanent mechanical systems for the operational life of the structure and for its removal at the end of its operational life shall have a design life as defined in the project work specification.

Permanent mechanical systems are generally designed in accordance with the same specifications as for topsides or to specifications providing a similar level of integrity and safety. The design, sizing and construction of permanent mechanical systems shall take into account that access and the ability to perform maintenance or repairs is limited or can even be infeasible in some cases. Full capacity testing of many systems is also not practical until the structure is installed and in operation at the offshore site.

National standards shall be conformed with in all relevant disciplines, such as pressure vessels, piping, electrical, access, elevators, lifting devices, fire protection, noise levels, escape routes and emergency lighting, communications and area classification.

A hazard and operability analysis (HAZOP) shall be performed on all hydrocarbon systems and on all systems affecting the safety and operability of the structure and/or the topsides. The HAZOP for the structure shall be carried out, where relevant, in conjunction with topsides/subsea systems HAZOPs.

10.2.2 Crude oil storage system

10.2.2.1 General

Where applicable, the crude oil storage system can be either dry (see [10.2.2.2](#)) or wet (see [10.2.2.3](#)). Only stabilized crude oils shall be stored in a concrete offshore structure. Means to avoid problems when storing waxy crudes shall be considered.

Oil storage containment walls and roof subject to external impact shall be designed to meet the requirements in [8.1.6](#) or alternate protection measures should be considered.

For any crude oil (or other fluid) stream from the topsides to storage compartments, the location and elevation of any control valve(s) should be determined such as to prevent vacuum or damaging cavitation/flashing conditions at the outlet(s) of the valve(s).

10.2.2.2 Dry storage

The dry storage system is a system whereby the crude oil is stored within the structure (e.g. in the caisson), with a vapour space above the crude oil. For the dry-type storage, the vapour space shall be filled with inert gas before any hydrocarbon is introduced and thereafter maintained filled with inert gas as the crude oil level rises or falls.

Sizing of the inert gas supply and venting system shall ensure that crude oil filling and offloading operations do not cause pressures in any portion of the system to fall below atmospheric pressure or the minimum design pressure of any component within the system.

Guidance is provided in standards such as API Std 2000 for the supply of inert gas and the venting of the inert gas/crude oil vapours due to oil movement.

The minimum inert gas supply capacity should be 1,1 times the maximum crude oil offloading rate, while use of API Std 2000 would result in a minimum vent capacity of 2,15 times the maximum crude oil filling capacity for crude oils with flash point below 38 °C. Supply and vent capacities are expressed as actual volumes at system temperature and pressure.

The inert gas system shall be equipped with pressure, control and relief devices, as required, to safeguard against under- and over-pressurization of the oil storage compartments. Materials in the gaseous mixture shall be selected to be resistant in the potentially sour/reducing atmosphere due to hydrogen sulphide.

In the same manner, protection devices shall be provided to prevent overfilling and over-pressurization of the storage compartments by an oil column in the feed piping.

The crude oil export system shall be able to pump out the oil fully from the storage space. Auxiliary pumps, slopes in storage bottoms, increase of inert gas pressure, flushing systems with water, etc., may be considered for this purpose. The possibility of accumulation of an oil/water emulsion (sludge) and water at the bottom of the storage should be taken into consideration.

For all glass-fibre reinforced plastic (GRP) piping systems, if used in dry storage, consideration shall be paid to risk of static discharge. Therefore, the appropriate type of glass-fibre reinforced epoxy pipes shall be specified.

10.2.2.3 Wet storage

The wet storage system is a system whereby the crude oil is stored on top of sea water provided by the permanent ballast water system. The storage compartments are always full of liquid whereas the oil/water interface varies in elevation.

The wet storage system may be under-pressurized, balanced or over-pressurized with respect to the sea water pressure. All the approaches have their respective merits and are acceptable provided that;

- actions due to pressurization of the storage system are recognized in the design of the structure, including the actions arising from accidents, mal-operation, faulty control system, erroneous interface level indication, etc.;
- the risk of crude oil escape to sea in the lifetime of the structure meets the project requirements.

The wet storage system shall be provided with a venting system to remove gas accumulation at the top of the storage if such potential exists, unless the storage compartment is self-venting through the crude oil piping.

Consideration shall be given in the design to the possibility of a sludge being formed at the oil/water interface and the need to remove this substance periodically by means of the crude oil piping system.

For a storage system that is spread over several compartments, greater operational flexibility can be achieved by designing it in such a way that one compartment can be decommissioned while the others are kept in operation.

Where the storage is split into several independent compartments, each compartment shall have its own independent level-measurement system. The system shall be provided with alarms to stop further filling/emptying of crude oil when the interface is close to the top or bottom of the compartment during operational design situations.

NOTE The system that has predominantly been selected for North Sea structures is based on thermal conductivity sensors located at multiple elevations within a rod passing vertically through the cell. Ultrasonic systems have also been used.

A back-up level-measurement system, which can be based on pressure or differential pressure measurements, should be considered where maintenance of the primary system is impractical.

The crude oil distribution piping in multi-compartment storage should be designed to ensure that the oil is distributed evenly during operation. For this purpose, pressure drops in each distribution line of the crude oil and ballast water systems should be similar.

Fluid velocities in crude oil and permanent ballast water distribution piping should be limited to avoid imbalance, vibration and erosion effects in these inaccessible lines. Crude oil piping within storage compartments should terminate in such a manner as to minimize the disturbance of the stored liquids.

Experience has shown that standing waves several metres in height can occur at the oil/water interface due to disturbances in the inlet/outlet flows and/or deformations of the structure from environmental actions and the relatively small difference in mass densities. High and low operational interface levels should take this possibility into account. Diffusers providing a maximum crude and ballast water exit/inlet velocity of 0,1 m/s have been used successfully.

The piping design pressures and ballast water tank volume of crude oil and permanent ballast water systems should be checked for the "breathing" effect of the structure (e.g. variations of storage volumes due to deformation of the structure under wave action).

Where one storage compartment is composed of several intercommunicating cells, the openings providing the intercommunication shall cover the full range of the interface level and shall be sized to limit the interface level difference between two cells to an acceptable value when the compartment is filled or emptied at full rate. Partial blockage of such openings from wax build-up or sludge shall be considered in the sizing.

10.2.3 Other storage systems

The structure may provide compartments for the storage of auxiliary fluids, such as brine, drill water, fresh water, diesel oil, methanol and glycol. Except for diesel oil, these systems are normally of the dry storage type. Vapour space can be air filled for non-flammable fluids. Design considerations are generally the same as for crude oil storage.

10.2.4 Refrigerated gas storage systems

Concrete offshore structures can be used to house or support storage facilities for refrigerated liquefied gases, such as LNG. The storage facility and the mechanical systems to operate it are normally a separate package and are not covered by this document. All interfaces and loading scenarios from the operations and possible accidental events shall be considered in the design of the structure.

For the design and construction of concrete structures that house refrigerated liquefied gas storage, reference can be made to EN 14620, and for direct containment by concrete structures to ACI 376 and EEMUA 207. For floating concrete structures, reference can be made to the ISO 20257-1¹⁾.

10.2.5 Permanent ballast water system

A permanent ballast water system is designed to keep the wet storage compartments of the structure filled with liquid using sea water and can be designed, if required, to cater for the differing requirements of several interfacing systems, such as the following:

- the ballast water associated with the wet crude oil storage system and the ballast water for any other wet storage compartments;
- the ballast water for wet shafts or other compartments, which are designed to be dewatered during the operational life of the platform.

The ballast water system shall be designed so that the sea water can be sufficiently frequently renewed or treated to avoid the build-up of excessive H₂S concentrations in stagnant sea water.

H₂S formation in dead spaces can be mitigated by the following:

- renewal of the ballast water by natural convection (in the drill and riser shafts, top and bottom openings to the sea usually provide sufficient sea water circulation), where renewal to cold shafts (or cold compartments) may be provided by openings just above sea level so that waves bring new sea water in at regular intervals, circulation through the shaft being achieved via openings near the base of the shafts;
- forced circulation;
- injection of air or biocide (e.g. hypochlorite-dosed sea water).

NOTE 1 H₂S can be formed by the action of anaerobic bacteria feeding on organics, sulphates, sulphites, etc., in sea water, in solid ballast materials and in hydrocarbons. H₂S can also come from the stored crude oil itself. H₂S build-up in the ballast water associated with the crude oil storage can generally be limited to acceptable levels [e.g. mass fraction < (10 × 10⁻⁶)] by ensuring regular displacement of ballast water from all compartments, followed by renewal with fresh sea water.

The ballast water system associated with the wet storage system shall be designed to limit the amount of hydrocarbons returning to sea.

NOTE 2 Owner specifications and local regulations might specify requirements for the hydrocarbon content in the ballast water returning to sea.

NOTE 3 North Sea experience with fixed concrete offshore structures has shown that ballast water associated with crude oil storage with no treatment during operational design situations can reach an oil content of less than 10 mg/kg.

1) Under preparation. Stage at the time of publication: ISO/DIS 20257-1:2018.

The ballast water tank or the buffer cell (the cell used for storage systems kept in balance with sea water pressure) should be provided with facilities to allow any oil accumulated above the ballast water level to be removed.

10.2.6 Sea water systems

Sea water systems include sea water circulation (for cooling of shafts) and utility systems associated with topsides (sea water lift, service water, fire water, sea water return from topsides to the sea, etc.).

Permanent systems handling sea water should generally be made of materials with excellent anti-fouling and corrosion-resistant properties, such as titanium, duplex stainless steel, 6 % molybdenum (Mo) austenitic stainless steel and GRP. Special circumstances, such as piping embedded in concrete or piping with a short design life, could justify the choice of carbon steel.

Piping for sea water systems crossing the caisson below sea water level is generally medium-to-large diameter, such that rupture within a dry compartment (e.g. utility shaft) would cause rapid flooding. For such piping, a remotely operated and highly reliable isolating valve should be located at a minimum distance from the wall of the dry compartment.

NOTE It could be desirable to leave sufficient length of piping between the isolating valve and the wall to allow use of a freeze-plug for maintenance.

For large-diameter piping, inlets and outlets to the sea should be fitted with removable screens of the same material to avoid the entry of fish, ropes, umbilicals, hoses, etc. They should also be capable of being closed by doors or blind flanges operated by divers or remotely operated vehicles (ROVs). Suitable structures around these inlets or outlets should be included to provide protection against snagging by ropes, chains, etc., and to provide assistance to divers or ROVs.

All systems that could, through leakage, result in flooding the utility shaft or another dry compartment, shall be analyzed. In consideration of flooding scenarios, emphasis should be placed on the design to minimize the likelihood of such an event by selection of materials, dropped object protection, rapid detection and alerting of such an event, etc.

Sea water discharge lines originating below sea level within the utility shaft can be grouped together into a common line and routed to sea via an inverted U-loop (with siphon breaker as necessary) located above sea water level, to decrease the risk of flooding.

10.2.7 Drains, sumps and bilge

Drainage systems shall be provided, as required, to safely handle the draining of equipment and piping for operational and maintenance considerations, and to collect and dispose of water or other liquids released into the open, such as wash-down or fire water release.

A closed drainage system shall be designed to prevent the escape of flammable or harmful liquids, vapours and gases. The vapour space within tanks containing flammable vapours or gases shall be kept free of air, using a closed vent system with inert gas purge. Provision shall be made to safely handle the overflow of such tanks in the event that the pump-out facilities are unable to meet the demands.

10.2.8 Vents

Vents from tanks (sump, ballast, compartments, etc.) within the concrete structure which lead into vent piping on topsides could lead to topsides' vapours and gases back-flowing into the piping of the structure. The design shall ensure that this does not create the possibility of flammable gas entering piping within the structure, by means of an inert gas purge within the structure or separation of the vent piping.

10.2.9 Safety systems

Safety systems for the protection of personnel and equipment in the concrete structure shall generally be similar to those included in topsides within hazardous and non-hazardous areas; for fire explosions,

see ISO 13702. For the structure and, in particular, the shafts, special consideration shall be given to the consequences of

- lack of natural ventilation, and
- the “mine shaft” nature of the structure’s shafts.

NOTE Safety systems commonly utilized in concrete structures include fire, gas and smoke detection, CCTV (closed-circuit television), active (water spray, deluge, foam, hose reels, CO₂) and passive fire protection, resistance to blast, personnel protection devices (clothing, breathing apparatus), fire extinguishers and blankets, and safety shower and eye wash.

10.2.10 Decks

Where plated decks are used in dry shafts, either fully gas-tight or with limited free drainage, they shall be provided with sufficient open, piped drainage to handle the greatest operational influx rate of liquid onto the deck (e.g. release of deluge fire water system). Failure panels or hatches may be utilized for abnormal flow rates (e.g. flooding event) to allow liquid to cascade from one deck to another without causing structural failure. The safety of personnel shall be considered in the selection of such devices. Grated decks may also be considered where gas tightness is not required.

10.2.11 Elevators

If elevators are provided, the following shall be considered:

- escape facilities in the case of breakdown;
- optical sensors [to prevent door closure] shall be avoided unless provided with a manual local override.

10.2.12 Lifting devices

Hoists, trolleys, runway beams, lifting lugs, drop-out areas, access hatches, etc., provided for maintenance activities shall be included, as necessary, to allow maintenance to be performed in a safe manner.

10.2.13 Risers and J-tubes

The routing of risers and J-tubes shall be based on an overall platform safety study and evaluation of risk. The following issues shall be considered:

- location outside, inside or embedded within the concrete structure;
- type of fluid within riser (stabilized crude, sea water, gas);
- type of fluid within flowline pulled into J-tube (well stream, sea water, gas, etc.); J-tubes may also be used for umbilicals to control subsea completions;
- pressure and temperature of the fluid;
- diameter, length, pipe schedule and inventory of riser or flowline;
- location of emergency shutdown valves (subsea external to the structure, within the structure, within the topsides);
- piping within the structure: all-welded or with flanges;
- consequences of fire (pool fire, jet fire) and explosion resulting from leakage or riser rupture.

For multishaft structures, drill shafts are normally located at the “process end” of topsides, while the utility shaft is located at the living quarters end. In such configurations, risers and J-tubes containing

flammable fluids are located within the drill shafts and the riser shaft. If the riser shaft is also located at the living quarters end, it should generally not be used for high-pressure gas and well fluids.

Where risers and/or J-tubes are routed on the outside of the caisson and/or shafts, special consideration shall be given to dropped objects protection and boat collision. For J-tubes, consideration shall be given to the consequences of flowline failure within the J-tube.

10.2.14 Conductors and shale chutes

Metal sleeves located in the base of the concrete structure, used to guide the penetration of the conductors through the base, shall generally extend to a height above the base sufficient to allow each conductor to be raised and the cutting units of an under-reamer to be deployed beneath the conductor in order to drill out the temporary concrete plug.

The design of the structure shall consider the need to cut conductors below the base of the structure in the event that removal of the structure is a project requirement.

The location of shale chute discharges shall be based on a consideration of the need to prevent their effluent entering sea water intakes and forming mounds on parts of the caisson, subsea pipelines, etc., not designed for such actions or requiring visual inspection.

10.2.15 Access

Access ways for personnel shall meet the requirements of the project work specification. At least two access/escape routes shall be provided from each deck. An elevator, if present, shall not be considered as an escape route.

Vertical escape access ways (stairs and ladders) shall be enclosed in areas containing hydrocarbons in flanged piping or equipment, unless otherwise specified by the project work specification. In other areas, the need to provide one or more enclosed vertical escape routes shall be evaluated based on an evaluation of the risk, and possible severity, of fire and release of smoke or toxic gases. Smoke ingress into enclosures of escape ways shall be prevented, even if one door is left open, by suitable pressures and flows and/or intermediate doors. Stairs, and possibly elevators, shall be sized to allow evacuation of injured personnel by stretcher.

External valves, if any, should be provided with ROV access docking ports if appropriate.

10.2.16 HVAC

HVAC with supply and extract shall be required for all enclosed areas in which personnel are expected to work. The system design shall provide sufficient air changes per hour to meet project requirements and area classification for electrical equipment. Flow patterns within the enclosed areas shall consider both lighter- and heavier-than-air gases and vapours.

Passive fireproofing of ductwork, fire dampers, etc., shall be provided as required by the project work specification.

10.2.17 Structure and foundation condition monitoring

System requirements are given in [Clause 14](#).

Cabling from the instrumentation needed for the structure and foundation condition monitoring system shall withstand the sea water hydrostatic pressure. Where cabling passes through a watertight concrete member, watertight penetrations shall be used.

Cabling running in areas open to personnel shall conform with requirements for flammability and release of smoke and toxic gases when subject to fire.

Penetrations for casings through watertight concrete members for such items as pore water pressure measurement, horizontal displacement or settlement of the structure, etc., shall be designed to the same criteria as for other penetrations (e.g. conductors).

10.2.18 External markings

Level markings below and above the still waterline shall be included in accordance with the project work specification. Markings shall be of a type recognizable when lit by submerged light (e.g. reflective). In a marine environment a non-fouling surface shall be provided. Markings on horizontal surfaces below water should be designed to remain visible (e.g. being elevated) during the deposition of solids (e.g. sand).

NOTE Markings attached to the structure in a similar manner to embedment plates have proven effective in the past.

10.2.19 Other

Other systems, such as those for pore water pressure reduction (anti-liquefaction) for removal of the structure, shall be designed to meet the project work specification.

10.3 Temporary mechanical systems

10.3.1 General

Systems frequently needed for temporary use include the following:

- air cushion systems;
- construction and temporary ballast water systems including ballast control room;
- skirt evacuation systems;
- grouting systems;
- systems for monitoring under-keel clearance (e.g. echo sounders), skirt penetration and seabed pressure on the base.

HAZOPs shall be carried out for all temporary systems which can affect the safety of the structure and shall cover all relevant design situations of the afloat construction, tows and installation phases. Potential damage caused by dropped objects shall also be considered.

10.3.2 Air cushion system

Where an air cushion system is specified to reduce the draught for float-out from the dry dock, and possibly during a period at the deep water construction site, the grout system piping or the skirt evacuation system piping can generally be used. Differences in operating and design pressures shall then be considered in the design of the piping.

The air cushion system shall be sized with sufficient margin for the lift-off operation of the structure in the dry dock to be achieved within the time stated in the project work specification. The possibility of air leakage through mal-operation, cracks in concrete, etc., shall be considered.

The air/water interface level can be established by differential pressure measurement, and the design should provide for level measurement of each separate compartment.

System design shall ensure that all air is vented from compartments at completion of use of the air cushion to avoid reduction of the structure's floating stability that would otherwise result.

10.3.3 Temporary ballasting/de-ballasting water system

The structure shall have a ballasting system while afloat and during tow to the offshore site. Ballasting with sea water is required to control inclination and draught. The ballasting system can also be used for pumping out water that enters the structure by means of snow, rain, construction activities, leakage, etc.

The sizing of the temporary ballasting water system shall meet the project work specification with respect to marine operations, such as lift-off in the dry dock, deck mating, installation at the offshore site, construction requirements and accidental leakage rates.

It is generally found necessary to design and install more than one system to cover the changing situation during construction when floating construction stage(s) is/are used. The system first utilized can be extended and modified to meet changing needs during construction. The following issues shall be considered in the design:

- During construction, water within the structure will be dirty and abrasive. Blockage or partial blockage of pump suction piping can occur. The inlets of pump suction piping should not be at low points; thus, a certain volume of water will remain under all conditions.
- Piping taking suction from one compartment and running through other compartments creates a potential hazard if leakage occurs. Protection against pipe damage shall be considered and shall be provided to the extent necessary to reduce this risk to an acceptable level.
- Piping that can be exposed to dropped objects or other mechanical damage should be fabricated from ductile materials, such as carbon steel, which will deform rather than fracture when subjected to impact actions. While carbon steel will corrode in water and sea water, this aspect is generally not a problem for the relatively short period of use, provided adequate wall thickness is specified.
- Simple systems with portable pumps placed directly in compartments, and with all water added by a pumped system, require greater attention from operators, but are inherently safe. Their use, particularly during any initial stages of afloat construction, should be carefully considered.

More complex systems with remote, centralized pumps and controls reduce operational demands, but can create greater possibilities of mal-operation leading to uncontrolled tilt or submergence of the structure. Such systems shall be provided with the necessary safeguards, alarms, interlocks, status indication, etc., to provide the high level of reliability and safety required. A minimum of two fail-safe actuated valves in series shall be included in any piping directly routed to sea (i.e. sea water inlet/outlet) which could result in flooding of the structure.

The most critical operations are

- transfer by differential head from one or more compartments to one or more other compartments via piping manifold, and
- introduction of sea water into one or more compartments by the differential head of the draught of the structure and ballast water level in the compartments.

In establishing the requirements for system safeguards and reliability, the consequences of mal-operation shall be considered. Single compartment damage stability and the structural ability of walls to withstand hydrostatic differential ballast water levels shall be considered in the design. The ballasted areas shall be divided into compartments such that flow of ballast water will not cause uncontrolled tilting.

Depending on the consequences of failure, the design of instrumentation associated with temporary ballasting operations should take into account the need for redundancy provided by readily accessible local indicators (water level tubes, gauges, etc.). The effects of structure tilt on levels shall be considered.

Particularly for large-diameter piping, water hammer resulting from rapidly closing valves shall be considered as well as the possibility of vibrations caused by control valves, orifices, etc.

The design of temporary systems shall take into account the need to fill the temporary piping running from the utility shaft with grout after the temporary use is completed, to prevent the possibility of leakage of liquid from one compartment to another resulting from corrosion of the piping.

The design of temporary ballast water systems shall take into account the possibility of components, such as motors, instrumentation, controls, junction boxes and cables being sprayed or inundated by water.

10.3.4 Grouting and skirt evacuation systems

10.3.4.1 Grouting system

Where required to meet foundation and/or structure design requirements, a grouting system shall be designed to fill void spaces between the sea floor and the base of the structure. The system design shall consider the need to displace sea water with grout from the void, without incurring unacceptable dilution from this displacement operation.

NOTE The void space beneath drill shafts is generally left ungrouted.

The number of grout lines and their sizing shall take into account the need to achieve full or partial completion of the grouting operation when this is necessary for the structure in order to resist the environmental actions that could develop during the grouting period.

A means to monitor the grout filling operation shall be provided so that verification of void space filling is obtained. Measurement of injected quantities, differential and/or absolute pressure measurements, facilities to permit visual checks, etc., may be used.

Grouting piping design shall include flushing facilities to allow displacement of grout in cases where grout injection is halted for unexpected reasons, such as adverse weather preventing transfer from a grout vessel, mechanical failure, etc. The flushing facilities shall be designed to overcome the resistance of grout that has gelled within the piping.

10.3.4.2 Skirt evacuation system

The skirt evacuation system is used for

- evacuation of sea water trapped within skirts as they penetrate the seabed during installation of the structure at the offshore site, and
- evacuation of the sea water displaced by grout during the grouting operation.

NOTE The system can also be used as part of an air cushion system.

Sizing of the skirt evacuation piping system shall take into account the need to prevent piping action below the skirt tips during penetration by limiting the pressure drop through this piping system. The design shall be based on the maximum rate of penetration, considering the possibility of uneven penetration resulting from seabed characteristics, bathymetry and tilt of the structure.

The skirt evacuation system may be designed to create an underpressure below the base of the structure to provide an additional driving force for skirt penetration. Such designs shall take into account the possibility of reverse piping action below the skirt tips.

10.3.4.3 Grouting and skirt evacuation piping

Grouting and skirt evacuation piping systems design shall consider the risks of plugging of, or obstruction to, piping outlets and inlets resulting from the structure's installation. Seabed disturbance can result from skidding of the skirts across the seabed and from soil heave during penetration. The possibility of unplanned flow from one void space to another (around a skirt) shall be considered.

Special care shall be taken with the design of piping as it cannot usually be flanged/plugged below the structure's base and is thus pressurized with sea water during afloat phases of construction. As one or

both of these systems will enter the utility shaft, the piping within the utility shaft up to the first block valve will be under pressure. If jumper hoses are used below sea level within the utility shaft, non-return valves should be included in the design unless it is demonstrated that a rupture of a hose can be handled without flooding.

Where this piping is of small diameter, it can frequently be embedded in structural concrete members as protection, until it exits into, for example, the utility shaft. If this is not the case and the piping is run in the open inside the structure, then special precautions shall be taken to provide protection from dropped objects.

Where run inside concrete members, the design of those members shall consider the design pressure of the piping and the possibility of leakage.

Where grout and/or skirt evacuation piping is brought inside the utility or other dry shaft, it should be fitted with double valving located as close as possible to the entry point (e.g. within 1 m). Dropped object protection shall also be considered.

While grout piping is generally routed to a dry area within the structure, skirt evacuation piping may be run to the same location, or to the outside of the structure. The location of skirt evacuation outlets on the outside of the structure shall consider the need to prevent sea water intakes, external risers, J-tubes, etc., being exposed to grout during offshore installation of the structure.

10.3.5 Instrumentation for construction, tow and installation of the structure

At installation, under-keel clearance assumes particular significance. It is also possible that bottom clearance can be of concern along certain parts of the tow route to the offshore site.

Suitable instrumentation for measuring under-keel clearance includes echo sounders mounted at the base of the structure, either beneath it or along the perimeter. Consideration should be given to provision of three or four units. This number of units will also provide some redundancy in case of failure while the structure is under construction.

Side scan sonar for use during tow to the offshore site, mounted at the base of the structure, can also be useful.

Echo sounders do not always provide sufficiently accurate measurements of under-keel clearance for the final stages of touchdown (less than 2 m clearance). Bottom contact instrumentation utilizing a lever arm with contact pad can be considered. Earth pressure transducers can also provide confirmation of touchdown.

Instrumentation shall be installed to measure penetration depth and inclination in order to ensure that the installation criteria are met.

Special care shall be taken with all such instrumentation, together with its cabling, to ensure operation after submergence in sea water. Meticulous functional testing, mechanical completion and protection against subsequent damage are essential.

10.3.6 Other systems

Other systems, such as caisson pressurization (for deep submergence) and the structure docking template, shall be designed to meet the project requirements and relevant clauses of this document.

10.4 Attachments and penetrations

10.4.1 Attachments

Attachments to the concrete structure can generally be fixed to embedment plates cast into the concrete. The transfer of actions from the embedment plate into the concrete shall be considered in the design of