



BSI Standards Publication

Petroleum and natural gas industries — Arctic offshore structures

National foreword

This British Standard is the UK implementation of EN ISO 19906:2019. It is identical to ISO 19906:2019. It supersedes BS EN ISO 19906:2010, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/525/12, Design of offshore structures.

A list of organizations represented on this committee can be obtained on request to its secretary.

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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

This document (EN ISO 19906:2019) has been prepared by Technical Committee ISO/TC 67 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries" in collaboration with Technical Committee CEN/TC 12 "Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries" the secretariat of which is held by NEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2020, and conflicting national standards shall be withdrawn at the latest by February 2020.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

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Endorsement notice

The text of ISO 19906:2019 has been approved by CEN as EN ISO 19906:2019 without any modification.

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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 cancels and replaces the first edition (ISO 19906:2010), which has been technically revised. The main changes compared to the previous edition are as follows:

- revisions to definitions and provisions to reflect updates in the general requirements standard ISO 19900 since the publication of the first edition of ISO 19906;
- significant revisions to provisions related to operational and emergency response measures, see 5.5, 8.2.7, clauses 13, 17, and 18;
- significant changes throughout the document to reflect user input on the first edition of the standard, notably with respect to ice actions in A.8.2;
- reference to the new data requirements standard ISO 35106 and corresponding revisions to Clauses 6 and 14, including significant deletion of now redundant content in Clause 14;
- reference to the new ice management (IM) standard ISO 35104 and corresponding revisions to Clause 17, including significant deletion of now redundant content;
- reference to the new EER standard ISO 35102 and corresponding revisions to Clause 18, including significant deletion of now redundant content.

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

ISO 19906 is one of the International Standards on offshore structures prepared by TC 67/SC 7 (i.e. ISO 19900, the ISO 19901 series, ISO 19902, ISO 19903, ISO 19904-1, the ISO 19905 series and ISO 19906).

NOTE These are sometimes referred to as the ISO 19900 series on offshore structures.

The International Standards on offshore structures prepared by TC 67/SC 7 addresses design requirements and assessments for 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, regardless of the type of structure and the nature or combination of the materials used.

The International Standards on offshore structures prepared by TC 67/SC 7 consist of the following documents:

- ISO 19900, *Petroleum and natural gas industries — General requirements for offshore structures*
- ISO 19901 (all parts), *Petroleum and natural gas industries — Specific requirements for offshore structures*
- ISO 19902, *Petroleum and natural gas industries — Fixed steel offshore structures*
- ISO 19903, *Petroleum and natural gas industries — Concrete offshore structures*
- ISO 19904-1, *Petroleum and natural gas industries — Floating offshore structures — Part 1: Monohulls, semi-submersibles and spars*
- ISO 19905 (all parts), *Petroleum and natural gas industries — Site-specific assessment of mobile offshore units*
- ISO 19906, *Petroleum and natural gas industries — Arctic offshore structures*

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

These documents applicable to the various types of offshore structure are intended to provide wide latitude in the choice of structural configurations, materials and techniques without hindering innovation. Sound engineering judgment is, therefore, necessary in the use of these documents.

This document was developed in response to the offshore industry's demand for a coherent and consistent definition of methodologies to design, analyse and assess arctic and cold region offshore structures within the Scope.

Structures capable of resisting ice have been in use in temperate regions for well over a century. These include bridge piers and navigation aids in ice-covered rivers and estuaries. In fact, bridge codes in cold

countries have included methods for addressing ice actions dating back many decades. In more severe arctic and cold regions, ice-resistant structures are more recent. But much experience has been gained commencing in the 1960s, and this knowledge is incorporated into this document. Where uncertainties still exist, conservative approaches and methods have been recommended.

Annex A provides background to and guidance on the use of this document and it is intended that it be read in conjunction with the main body of this document. The clause numbering in Annex A follows the numbering in the normative text to facilitate cross-referencing.

Annex B provides regional information on the physical environment of specific offshore areas in arctic and cold regions.

Some symbols in this document are not in accordance with the system of quantities on which the International System of Units is based, due to the need to conform with current ice literature. This might change in future editions of this document.

To meet certain needs of industry for linking software to specific elements in this document, a special clause-based numbering system has been permitted for figures, tables and formulae.

Petroleum and natural gas industries — Arctic offshore structures

1 Scope

This document specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation and decommissioning of offshore structures related to the activities of the petroleum and natural gas industries in arctic and cold regions. Reference to arctic and cold regions in this document is deemed to include both the Arctic and other locations characterized by low ambient temperatures and the presence or possibility of sea ice, icebergs, icing conditions, persistent snow cover, and/or permafrost.

The objective of this document is to ensure that complete structures, including substructures, topsides structures, floating production vessel hulls, foundations and mooring systems, in arctic and cold regions provide an appropriate level of reliability with respect to personnel safety, environmental protection and asset value. Value includes value to the owner, to the industry and to society in general.

This document does not contain requirements for the operation, maintenance, service-life inspection or repair of arctic and cold region offshore structures, unless the design strategy imposes specific requirements such as ice management (IM) to reduce ice actions.

Provisions for the operation, maintenance, service-life inspection and repair of mobile units are given in ISO 19905-1 and ISO 19905-3, supplemented by the provisions relating to ice actions and IM in this document.

This document does not apply to mechanical, process and electrical equipment or any specialized process equipment associated with arctic and cold region offshore operations except in so far as it is necessary for the structure to sustain safely the actions imposed by the installation, housing and operation of such equipment. This document applies to equipment used for the positioning and disconnection of floating structures (see Clause 13).

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 17776, *Petroleum and natural gas industries — Offshore production installations — Major accident hazard management during the design of new installations*

ISO 19900:2013, *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 19901-6, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 6: Marine operations*

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

ISO 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 19903, *Petroleum and natural gas industries — Concrete offshore structures*

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

ISO 35101, *Petroleum and natural gas industries — Arctic operations — Working environment*

ISO 35102, *Petroleum and natural gas industries — Arctic operations — Escape, evacuation and rescue from offshore installations¹*

ISO 35104, *Petroleum and natural gas industries — Arctic operations — Ice management*

ISO/TS 35105, *Petroleum and natural gas industries — Arctic operations — Material requirements for Arctic operations*

ISO 35106, *Petroleum and natural gas industries — Arctic operations — Metocean, ice, and seabed data*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19900, ISO 19901-1, ISO 19901-2, ISO 19901-4, ISO 35102, ISO 35104, ISO 35106 and the following apply. ISO and IEC maintain terminological databases for use in standardization at the following addresses:

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

3.1

abrasion

effect of ice grinding against the surface of a structure thus removing paint, surface protrusions and coatings, oxidized material, or concrete particles and aggregate

¹ Under preparation. Stage at the time of publication: ISO/DIS 35102:2019.

3.2**action combination**

expression in which values of individual simultaneous actions for a design situation are summed to obtain the total *design action* (3.10) for design verification of a structure for a specific limit state

3.3**action effect**

effect of actions on structural components

EXAMPLE Internal force, moment, stress or strain.

3.4**adfreeze**

freezing of ice or soil onto the surface of a structure

3.5**aspect ratio**

ratio of structure diameter or width to ice thickness

3.6**broken ice**

ice pieces of varying size, broken up as a result of natural processes, or active or passive intervention

Note 1 to entry: Active intervention includes IM resulting in managed ice; passive intervention includes the channel, or wake, caused by a stationary structure in moving ice cover.

3.7**companion environmental action**

environmental action applied simultaneously with the principal environmental action

3.8**consolidation**

process of freezing of pore water in voids within ice rubble or between floes

Note 1 to entry: For soils, consolidation involves drainage of pore fluid as a result of overburden pressures.

3.9**consolidated layer**

portion of an *ice ridge* (3.35) keel, *rubble pile* (3.58), *rubble field* (3.57) or *stamukha* (3.66) below the waterline formed by the ice freezing process

3.10**design action**

sum of design values of individual simultaneous actions for an *action combination* (3.2)

3.11**design resistance**

resistance limit calculated from factored representative values of basic variables, or from factored expressions based on unfactored representative values of basic variables

Note 1 to entry: Material properties are examples of basic variables relevant to resistance.

3.12

disconnection

planned separation of the risers (and mooring, if applicable) for a floating system

3.13

ductility

ability of a material to deform and absorb energy beyond its elastic limit or ability of a component to sustain *action effects* (3.3) beyond yield

Note 1 to entry: See also *system ductility* (3.69).

3.14

dynamic action

action that induces acceleration of a structure or a structural component of a magnitude sufficient to require specific consideration

3.15

dynamic positioning

stationkeeping technique consisting primarily of a system of automatically controlled on-board thrusters, which generate appropriate thrust vectors to counter the mean and slowly varying *dynamic actions* (3.14)

[SOURCE: ISO 19901-7:2013, 3.9]

3.16

emergency disconnection

procedure involving separation of the risers (and mooring, if applicable) for a floating system, without depressurization of the risers

3.17

first-year ice

FY ice

sea ice formed during the current or prior winter that has not survived one summer melt season

3.18

floe

relatively flat piece of sea ice greater than 20 m across

Note 1 to entry: There are typically sub-categories of floe: small (20 m to 100 m across), medium (100 m to 500 m across), big (500 m to 2 000 m across), vast (2 km to 10 km across) and giant (greater than 10 km across).

3.19

flowline

pipework on the *sea floor* (3.61) linking one or more subsea wells to the production system

Note 1 to entry: Flowline functions can include production, injection, subsea systems control and export of produced fluids.

3.20 Freeboard

3.20.1

freeboard

<ice> vertical distance from the water surface to the top of the ice

3.20.2**freeboard**

<floating structure> vertical distance from the mean water surface at a given draught to the deck level, measured at the lowest point where water can enter the structure or ship

3.20.3**freeboard**

<platform or island> vertical distance from the water surface to the surface of a platform or man-made island measured at the perimeter

3.21**freeze-thaw**

possible degradation effect of repeated freezing temperature cycles on the properties of concrete, soil, and porous materials with water-absorbing properties

3.22**ice alert**

prescribed reaction to a forecast hazardous *ice event* (3.28)

Note 1 to entry: Several different levels associated with the time proximity of the hazard are normally recognized.

Note 2 to entry: Focus in this document is on alerts related to ice hazards. Ice alerts are linked with other constraints on operating protocols, including those due to metocean, equipment or production considerations, see for example ISO 19905-3.

3.23**ice belt**

strengthened hull region around the waterline, as specified in ice class requirements

3.24**iceberg**

glacial or *shelf ice* (3.65) of greater than 5 m freeboard that has broken (calved) away from its source

Note 1 to entry: Icebergs can be freely floating or grounded, and are sometimes defined as tabular, dome, pinnacle, wedge or block-shaped.

3.25**ice concentration**

proportion of the water surface covered by ice

Note 1 to entry: The proportion of surface coverage is usually expressed in tenths.

3.26**ice detection**

identification of ice features or associated conditions within the surrounding environment

3.27**ice encroachment**

movement of sea ice onto the surface of a platform or man-made island

Note 1 to entry: Ice encroachment can result from ice ride-up, pile-up, and ride-down processes.

Note 2 to entry: The extent of ice encroachment is typically included in operational or design criteria.

3.28

ice event

occurrence of ice-structure interaction for which ice actions can be calculated

Note 1 to entry: Ice events can be occurrences of interactions with discrete ice features such as icebergs, ice islands, ice ridges, stamukhi and ice floes, or can be occurrences of peaks within a specified length or duration of the interaction process.

3.29

ice gouge

ice scour

incision in the *seabed* (3.62) or removal of seabed soils by an ice feature

Note 1 to entry: Incisions can have the form of either an areal incision (pit) or a linear incision (furrow).

3.30

ice island

large tabular-shaped ice feature that has calved from an ice shelf or glacier

3.31

ice management

IM

processes and activities whose objective is to reduce or avoid ice actions

Note 1 to entry: IM includes, but is not limited to, detection, tracking, ice forecasting, threat evaluation, alerting and physical management.

3.32

ice management plan

IM plan

plan detailing the objectives, measures involved and individual responsibilities for the implementation of an IM system

3.33

ice management system

IM system

IM and the tools used for its implementation

3.34

ice model test

scaled physical testing of a structure or a component under controlled conditions

Note 1 to entry: The structure, ice properties and test parameters are normally scaled according to some similitude principles (scaled model tests).

Note 2 to entry: Ice model tests are often carried out in special laboratories which are called ice tanks or ice basins.

3.35

ice ridge

linear feature formed of ice blocks created by the relative motion between ice sheets

Note 1 to entry: Ice pressure ridges are formed when ice sheets are pushed together, and a shear ice ridge is formed when ice sheets slide along a common boundary.

3.36**ice scenario**

combination of conditions involving the presence of ice, resulting in *ice events* (3.28)

3.37**infill**

material deposited in an *ice gouge* (3.29), excavation or trench through natural processes

3.38**landfast ice**

fast ice

ice that remains attached to a shoreline, island or grounded ice feature

3.39**level ice**

sheet ice

region of ice with relatively uniform thickness

3.40**local failure**

localized damage to the structure with the potential for escalating to partial or complete failure

3.41**lowest anticipated service temperature****LAST**

reference temperature for determining test temperatures of structural materials

Note 1 to entry: LAST is used for structural steels but can also be used for other structural materials.

Note 2 to entry: For the purposes of this document, the concept of LAST presented in ISO 19902 for in air and in water is extended to include enclosed and/or heated zones.

3.42**lowest operational service temperature****LOST**

reference temperature for winterization

Note 1 to entry: LOST is a reference temperature used as a criterion for winterization of non-structural, non-critical systems, equipment, and materials and can vary by zone and position.

3.43**mat**

man-made weighted sheet structure used for the stabilization of soils or subsea components

3.44**material factor**

partial factor applied to the characteristic value of a material property

3.45**mudline cellar**

man-made areal excavation in the seabed used to protect subsea structures or equipment from damage due to ice actions

3.46

multi-year ice

MY ice

sea ice that has survived at least two summer melt seasons

3.47

old ice

sea ice that has survived at least one summer melt season

Note 1 to entry: Old ice includes both *second-year ice* (3.64) and *multi-year ice* (3.46).

3.48

pack ice

sea ice consisting of discrete *floes* (3.18) that is not landfast

3.49

pack ice driving actions

actions exerted by the surrounding sea ice on the structure or to an ice feature in contact with it

3.50

permafrost

ground (soil or rock) remaining at or below 0 °C for a duration of two years or more

3.51

polynya

area of open water surrounded by sea ice, caused by persistent winds, currents or upwelling of warm water

3.52

rafted ice

ice feature formed from the superposition of two or more ice layers of ice

3.53

recognized classification society

RCS

member of the International Association of Classification Societies (IACS), with recognized and relevant competence and experience relating to arctic and cold region structures or ice class vessels used in petroleum and natural gas activities

3.54

reliability target

specified average annual reliability to be achieved for structural components or structures

3.55

ridge keel

portion of an *ice ridge* (3.35) that extends below the waterline

Note 1 to entry: A ridge keel can consist of a *consolidated layer* (3.9) and an *unconsolidated layer* (3.70).

3.56

ridge sail

portion of an *ice ridge* (3.35) that extends above the waterline

3.57**rubble field**

region of ice blocks floating together as a continuous body, generally frozen together

3.58**rubble pile**

ice feature of areal, rather than linear, extent, composed of blocks of ice generally frozen together

Note 1 to entry: See also *stamukha* (3.66), the term for a grounded rubble pile.

3.59**safety-critical element**

equipment and other systems determined to be essential in preventing the occurrence of or mitigating the consequences of a major accident

3.60**scour**

removal of *seabed* (3.62) soils by currents and waves

3.61**sea floor**

interface between the sea and the *seabed* (3.62)

3.62**seabed**

material below the elevation of the *sea floor* (3.61) or ocean floor

3.63**seasonal operation**

operation of a structure during a selected period during the course of the year, generally to avoid particular ice conditions

3.64**second-year ice**

sea ice that has survived one summer melt season

3.65**shelf ice**

sea ice formed adjacent to a glacier terminating in the ocean

3.66**stamukha**

grounded ice feature composed of *broken ice* (3.6) or rubble

Note 1 to entry: The plural form of *stamukha* is *stamukhi*.

3.67**stationary floating system**

floating unit kept in position by moorings or *dynamic positioning* (3.15)

EXAMPLES: Ship-shaped vessels, spar, buoy-shaped platforms.

3.68

strudel scour

incision in the *seabed* (3.62) caused by a natural water jet draining through hole(s) in the ice

Note 1 to entry: Strudel scours are usually found in river deltas when freshwater flows on the surface of sea ice.

3.69

system ductility

ability of a structure to deform and dissipate energy which takes into account material *ductility* (3.13), the ability of structural components to maintain inelastic load-carrying capacity, and structural redundancy

3.70

unconsolidated layer

unconsolidated rubble layer

part of an *ice ridge* (3.35) keel or ice rubble found below the *consolidated layer* (3.9) that consists of unbonded or very weakly bonded ice blocks

4 Symbols and abbreviated terms

4.1 Symbols

A	accidental action
E	environmental action
f_c	concrete compressive strength
f_y	representative yield strength
G	permanent action
G_1	gravity and hydrostatic permanent action
G_2	deformation permanent action
Q	variable action
Q_1	long-duration variable action
Q_2	short-duration variable action
γ_s	steel resistance factor
γ_c	concrete resistance factor
η	concrete efficiency factor

4.2 Abbreviated terms

AL	abnormal-level
ALE	abnormal-level earthquake
ALIE	abnormal-level ice event
ALS	abnormal (accidental) limit state
CPT	cone penetrometer test

DP	dynamic positioning
EER	escape, evacuation and rescue
EL	extreme-level
ELE	extreme-level earthquake
ELIE	extreme-level ice event
FE	finite element
FLS	fatigue limit state
FPSO	floating production, storage and offloading facility
FY	first-year, with reference to ice
GBS	gravity-based structure
HPZ	high pressure zone
HSE	health, safety and environment
HVAC	heating, ventilating and air conditioning
IM	ice management
IMO	International Maritime Organization
L1, L2, L3	exposure levels of structures
LAST	lowest anticipated service temperature
LOST	lowest operational service temperature
MY	multi-year, with reference to ice
MIZ	marginal ice zone
NA	not applicable
ND	no data
NDT	non-destructive testing
QC	quality control
RCS	recognized classification society
SAL	single anchor loading
SALM	single anchor leg mooring
SLS	serviceability limit state
SPM	single point mooring
SSI	soil-structure interaction
TLP	tension leg platform
ULS	ultimate limit state
WMO	World Meteorological Organization

5 General requirements and conditions

5.1 Fundamental requirements

Offshore structures for use in arctic and cold regions shall be planned, designed, constructed, transported, installed, assessed in service and decommissioned in accordance with ISO 19900 supplemented by this document.

Physical environmental parameters shall be determined in accordance with ISO 19901-1, ISO 35106 and the further requirements of this document. Seismic events shall be characterized in accordance with ISO 19901-2. Marine soil investigations for characterization of the seabed soil conditions and for geohazard evaluation shall be performed in accordance with ISO 19901-4 and ISO 19901-8.

Actions, action effects and resistances for steel, concrete and floating systems shall be determined in accordance with ISO 19902, ISO 19903 and ISO 19904-1 respectively, and according to the further requirements of this document. Foundation behaviour shall be determined in accordance with ISO 19901-4. Requirements for marine operations, stationkeeping and topsides in arctic and cold regions are provided to complement the requirements of ISO 19901-6, ISO 19901-7 and ISO 19901-3 respectively. Seismic actions shall be determined in accordance with ISO 19901-2.

This document provides requirements, recommendations and guidance on ice-related parameters and ice actions for steel, concrete and floating systems, and for man-made islands. The above documents should be used jointly with this document to develop appropriate physical environmental parameters, actions, resistances and designs for structures in arctic and cold regions.

The structure and all its subsystems shall be designed to allow for operation in a safe and environmentally sound manner. Conditions associated with arctic and cold regions that can influence the functional and operational requirements shall be identified and addressed in the design. Design aspects influencing the health and safety of personnel and the state of the environment throughout the design service life shall be identified and addressed appropriately.

5.2 Design methods

For designs performed in accordance with the design process and limit states design verification procedure provided in this document, levels of safety and performance are established in Clause 7.

An alternative rational design method based on theory, analysis, and recognized engineering practice may be used in lieu of the design process and formulae provided in this document, provided that levels of safety and performance are at least equal to those established in Clause 7.

Where possible, data from full-scale measurements of ice actions shall be used to verify new designs. Physical models and mathematical models may also be used to determine the response of structures to ice actions, in combination with ocean current, wind and wave actions. If ice model tests are used in the design process, the designer is advised to seek independent verification of the results obtained as well as seek expert guidance regarding the most appropriate physical ice modelling techniques.

5.3 Site-specific considerations

5.3.1 Hazards

All hazards that can be reasonably foreseen during all phases of the design service life shall be identified and evaluated, see ISO 19900:2013, 5.6.

Identification, investigation and determination of site-specific conditions for sea ice and icebergs shall be made in accordance with ISO 35106, with due consideration to the phenomena and effects described in 6.5 and 8.2.

Hazards can also include low ambient temperature, icing conditions, snow and ice accumulation, ice encroachment and permafrost.

5.3.2 Climate change

Changes in storm frequency and magnitude, ice conditions, ocean circulation, air temperatures, permafrost, wave heights and water levels can occur during the design service life of the structure. Consideration for such changes should be included in the design.

For interpreting climate change effects on historical ice and metocean data, see ISO 35106.

5.3.3 Structural configuration

In addition to functionality, the configuration of the structure should consider the following:

- a) robustness in abnormal and accidental design situations;
- b) protection of risers and conductors;
- c) arrangement, protection and operation of the stationkeeping system;
- d) concept for oil storage and export;
- e) wet or dry storage system;
- f) layout of facilities and separation distances from hazards;
- g) potential for future expansion under phased development;
- h) potential for platform removal;
- i) environmental constraints;
- j) capability of local construction facilities and materials;
- k) available construction season for offshore operations;
- l) marine access, e.g. re-supply, offloading and, escape, evacuation and rescue (EER);
- m) arrangement of topsides with respect to icing and snow accretion.

Consideration should be given to choices for structural configuration (e.g. plan shape, profile) and orientation, with due account for ice conditions, prevailing wind and ice drift directions, and the potential for ice rubble build-up. The topsides should be arranged with respect to the functional and operational requirements, such as re-supply, offloading, flaring and EER, and with respect to wind and ice encroachment.

Operational measures can be used for reducing the frequency and/or severity of ice events and for mitigating ice action effects, see 5.5.

The reliability of EER, platform supply, and offloading systems can potentially be improved through:

- IM;
- methods to reduce ice rubble accumulation;
- use of large crane booms to reach over accumulated rubble; and
- duplication of facilities on opposite sides of the platform.

5.3.4 Winterization

5.3.4.1 Objective

Winterization is the process of ensuring that a structure is suitably prepared for and capable of operation in low-temperature conditions. The objective is to provide a safe working environment for personnel, and appropriate conditions for performance of materials and for functionality of systems and equipment.

The effects of temperature shall be accounted for in the selection of structural materials, machinery lubrication, sealants and topsides winterization. The effects of thermal changes on structural behaviour and human capability shall be considered as part of the design and operation of the structure.

Different low temperatures can apply for different positions in or on the structure. At each position there can be a temperature in each of three categories, see 5.3.4.2. The low temperature for each position shall be the lowest of those applicable for the transportation, installation, operation, and decommissioning phases of the life of the structure.

5.3.4.2 Low temperature categories

Low temperatures are specified in three categories of application as follows:

- a) extreme-level (EL) minimum temperatures; these temperatures apply for safety-critical equipment. EL is described in 7.2.2.6;
- b) lowest anticipated service temperature (LAST); these temperatures apply for structural materials, in particular for determining test temperatures for steel, see 11.9. In arctic and cold regions, LAST for each position shall be determined as the EL minimum temperature, except that LAST shall not be taken as warmer than -10°C for positions in air or exposed to sea ice.
- c) lowest operational service temperature (LOST); these temperatures are specified by the owner for winterization of non-structural, non-critical systems, equipment, and materials.

5.3.4.3 Low temperature zones

Low temperatures for each of the three low temperature categories can be considered at individual positions within three zones.

- a) In air (exposed). The low temperatures shall be determined from the ambient atmospheric air temperature at the location of the structure, see 6.3.1. The same value normally applies for the entire zone, but it can be specified to vary with height above sea level.
- b) In water and below the seabed. The low temperatures shall be determined from the ambient water temperature profile, see 6.4.4.4, and from shallow geotechnical investigation. Temperatures lower than the water temperature should be considered for positions near the water surface and exposed to sea ice. The possibility of permafrost below the seabed should be considered.
- c) Enclosed. The low temperatures for enclosed or internal structures which are permanently heated may be higher than for the in-air zone if risk assessment of heating systems and consequences of failure periods demonstrates adequate reliability of continued safe operation or standby. Localised cryogenic storage or other cooling conditions shall be taken into account.

Within each zone, the specified low temperatures at different positions can be different. If one single temperature value is intended to be used for a zone or an area within a zone with expected spatial temperature variations, the low temperature from the position with the lowest temperature shall be used for the entire zone or area.

5.3.4.4 Winterization measures

Winterization measures for topsides are provided in Clause 15.

Winterization measures should be considered to ensure the safe operation of all systems and equipment, thereby ensuring the safety of personnel. Winterization measures shall also ensure that personnel can conduct the required tasks in an ergonomically sound way, with respect to temperature, wind, visibility and restrictions imposed by personal protective equipment. Further guidance on winterization principles can be found in documents such as DNVGL-OS-A201^[36]. Further guidance on the working environment for personnel is provided in ISO 35101.

Selected options should not result in adverse environmental consequences, see 5.1.

Safety-critical equipment shall be documented to function as intended down to EL minimum temperature.

5.4 Construction, transportation and installation

5.4.1 General

The construction, transportation and installation of offshore structures shall be planned to minimize the risks to personnel and equipment due to adverse environmental conditions associated with cold regions.

5.4.2 Construction planning

The planning of construction activities shall include adequate consideration for periods of low ambient temperatures. Materials and equipment shall be adequately protected by the provision of heating or insulation.

5.4.3 Transportation and installation

Evaluation of draft limitations shall be performed for all regions through which the structure can be transported in order to reach its final destination.

Consideration shall be given to the specification of all marine spread equipment and the ability of personnel to safely perform the required transportation and installation activities during periods of low ambient temperature, low visibility and other relevant environmental conditions. Limiting environmental conditions shall be specified for all critical offshore activities, and the associated weather windows shall be included in the planning and execution of such work. Contingency planning for all critical offshore activities shall be included to ensure safe transportation and installation.

Marine operations associated with the transportation and installation of the structure shall be in accordance with ISO 19901-6.

5.5 Operational measures

If operational measures such as IM and, for floating systems, disconnection are planned with respect to prevailing or anticipated ice conditions and hazards, ice actions can be mitigated or the frequency of ice events can be reduced, see 8.2.7.

The implementation of an ice alert system, see 17.1.2, and emergency response plans for ice hazards, see 18.1, should be considered because of the uncertainties in ice events and actions, and especially if either or both of the following applies:

- a) operational procedures related to ice conditions and hazards are planned;
- b) very unlikely, high consequence ice events are reasonably foreseeable.

Very unlikely events have a lower probability than events for which a design situation is specified, see 7.1.5. Actions are calculated only if a design situation is specified, see 7.2.2.

5.6 Environmental protection

The environment in arctic and cold regions can be more sensitive and vulnerable to pollution than other environments. Structures intended for such environments shall be designed to minimize the potential for polluting the environment as far as is reasonably practicable.

A structure should be designed to contain spills that can result in release of contaminants to the environment. Structural systems requiring active operations to avoid pollution should be kept to a minimum. Harmful environmental impacts should also be minimized in the construction, transportation, installation and decommissioning phases.

Special attention should be given to containing fluids and materials used for commissioning in order to avoid potential harmful releases to the environment.

Fluids and materials that, if released, can pollute the environment shall be contained in tanks having double barriers. The structure shall be designed to facilitate environmental monitoring, which is addressed in ISO 35103. A protocol should be established for inspection, maintenance and repair of any tanks containing fluids or materials that possibly can pollute.

Means for the containment and clean-up of polluting fluids shall be available at the site and be proven to operate under the expected physical environmental conditions.

In the case of permafrost or freezing conditions, provision should be made to ensure the integrity of ballast tanks, and to avoid upheaval buckling of conductors and buried flowlines.

5.7 Serviceability requirements including vibration

In addition to normal serviceability requirements for structural design such as those described in 7.2.2.2, measures should be taken to ensure that structural vibration during normal operations does not cause crew discomfort.

5.8 Decommissioning and reclamation

The structure shall be planned, designed, constructed and maintained so that future decommissioning and/or reclamation can be completed safely and with adequate protection of the environment.

6 Physical environmental conditions

6.1 General

6.1.1 Physical environment requirements

General guidelines on metocean information are given in ISO 19900 and specific requirements in ISO 19901-1. Clause 6 of the present document outlines the physical environmental parameters necessary for arctic offshore structure design. ISO 35106 specifies requirements and provides recommendations and guidance for the collection, analysis and presentation of relevant physical environmental data for arctic activities, including design and operations. Operations include planning and execution.

All operating conditions and physical environmental design parameters of relevance for the design of offshore structures shall be identified and assessed. Data and analysis methods shall comply with the requirements of ISO 19901-1 and ISO 35106. These requirements can include a minimum duration of site-specific data, the type of data and a definition of extreme design parameters.

All relevant environmental data, as well as applicable physical, statistical, mathematical and numerical models, shall be applied as the basis for design. When considering these parameters, potential allowance should be made for a changing climate, see 5.3.2.

The following information shall be determined:

- a) normal environmental conditions that are required to carry out checks for serviceability limit states, to develop actions and action effects to determine when particular operations can safely take place, and to plan construction activities (fabrication, transportation and installation) or field operations (e.g. drilling, production, offloading, underwater activities);
- b) long-term distributions of physical environmental parameters, in the form of cumulative conditional or cumulative marginal statistics that are used to perform design checks for fatigue limit states or to

make evaluations of downtime/workability/operability during a certain period of time for the structure or for associated items of equipment;

- c) extreme and abnormal physical environmental parameters which are used to define design situations and which are required for developing extreme-level (EL) and abnormal-level (AL) environmental actions;
- d) joint probability distributions of relevant physical environmental parameters, for accurate specification of ice events and for determining action combinations;
- e) regional environmental oscillations, cycles, and long-term trends associated with the parameters in a) to c).

The relevant physical environmental parameters can be dependent on the chosen structural form.

Experts in the field of metocean and ice technology shall be involved with the analysis of data and its interpretation in order to ensure that reliable and appropriate physical environmental parameters are obtained. This includes parameters for identifying hazards and hazardous events for developing appropriate design situations, and for determining design values of principal and companion actions.

6.1.2 Physical environmental data monitoring programmes

Appropriate physical environmental parameters shall be monitored and forecast during the design service life of the structure to ensure safe operational procedures. For specific requirements, see ISO 35106.

6.2 Daylight hours

The varying amount of daylight hours in arctic regions is a consideration for initial data collection and for the operations of offshore facilities. Due consideration of the effect of this parameter shall be incorporated in operational planning.

6.3 Meteorology

6.3.1 Air temperature

Atmospheric air temperatures will vary both as a function of elevation above sea level and as a function of averaging interval. When considering effects of low atmospheric air temperatures, relevant elevation and averaging interval for the application in consideration shall be used.

Air temperatures for enclosed zones should be estimated based on atmospheric air temperature and the effect of enclosure and heating, with due consideration of risk of heating failure, heat flux and cool-down times before restart of heating.

Probability distributions of low air temperatures should be determined for zones and positions as needed for quantifying EL minimum air temperatures and other low temperatures for winterization, see 5.3.4. For estimation of EL minimum temperatures and LAST in exposed or enclosed areas, temperatures averaged over 3 hours shall be used as a basis.

6.3.2 Wind

Wind-related parameters shall be determined in accordance with ISO 19901-1. When calculating wind actions on structural elements, increase in dimensions, weight and change in the shape and surface roughness of the structure due to snow or ice accumulations shall be taken into account.

6.3.3 Wind chill

An appropriate measure of wind chill shall be calculated, reflecting the combined effects of air temperature, wind and potentially humidity. The effect of wind chill upon human capability, machinery heat loss and topsides winterization shall be considered.

For wind chill, the effects on working environment shall be determined according to ISO 35101 and data collection requirements shall be carried out according to ISO 35106.

6.3.4 Snow

Snow accretion shall be assessed in relation to action effects on offshore structures and in relation to safety-critical systems such as EER craft, escape and evacuation routes, ventilation and communication systems.

Estimates of snow accumulation can be obtained from observations on similar existing structures in the same area or from available theoretical models. When theoretical models are used, they shall be suitably calibrated against observations. Snow actions shall be determined based on local conditions (temperature, wind, structure, precipitation). In relation to safety-critical systems, any impact on performance thereof shall be assessed.

The joint effect of snow and ice accretion shall be considered.

General information and further requirements related to actions from snow are given in ISO 35106.

6.3.5 Ice accretion

The extent of ice accretion from sea spray (sea spray icing), freezing rain/sleet/snow or drizzle, freezing fog or cloud droplets (atmospheric icing) shall be considered in the design and operability of the structure.

Ice accretion shall be assessed in relation to action effects on structures and in relation to safety-critical systems such as EER craft, escape and evacuation routes, ventilation and communication systems.

In relation to safety-critical systems, any impact on performance thereof shall be assessed. Further requirements and general information related to actions from sea spray and atmospheric icing are given in ISO 35106.

6.3.6 Visibility

Information on factors affecting visibility (e.g. fog, blowing snow, daylight hours) particular to the site of the offshore structure shall be obtained. Its effect upon operations and physical environmental monitoring shall be considered.

6.3.7 Polar lows

When considering statistics from waves and winds, the effects of polar lows shall be taken into account. Data sources for winds and waves (recorded or hindcast) do not typically include the effects of polar lows.

When considering the frequency and occurrence of polar lows, allowance should be made for a changing climate, see 5.3.2.

6.4 Oceanography

6.4.1 Water depth

The water depth at the site, including its variation, shall be determined. The range of water levels and its effect on ice action location shall be used to determine the most adverse effect on the foundation or structural component under consideration. For shallower water depths, ice can ground around a structure and cause changes in ice design scenarios for the structure and transportation systems, create operational problems and affect EER procedures.

For the purpose of design or assessment, water depth can be considered to consist of a more or less stationary component relative to a reference datum (e.g. lowest astronomical tide or mean sea level) and a variable component being the variations in time relative to this level. The variations can be due to astronomical tide, storm surges caused by wind and atmospheric pressure, sea floor subsidence, tsunamis and climatic changes. The design implications of positive and negative storm surges should be considered in the specification of actions on the structure, in the operation of the structure and for vessel operations planning.

6.4.2 Waves

Wave parameters for open water shall be determined in accordance with ISO 19901-1.

Ice coverage on the sea surface affects wave growth, propagation and decay. The effect of ice cover should be considered when determining extreme and operational wave parameters, especially when numerical models are employed to determine these parameters.

The effect of increased speed and elevation of ice features due to waves shall be taken into account in determining the combined wave-ice actions upon the structure.

6.4.3 Ocean currents

Parameters related to currents, including tidal effects, shall be determined in accordance with ISO 19901-1.

6.4.4 Other oceanographic factors

6.4.4.1 Marine growth

Marine growth shall be determined in accordance with ISO 19901-1.

When calculating the effect of marine growth in ice covered regions, consideration should be given to local conditions and their effect on the periodic cleaning of marine growth on the parts of the structure exposed to ice. Increased marine growth near areas of warm water discharge should be considered.

6.4.4.2 Tsunamis

The design implications of tsunamis shall be determined in accordance with ISO 19901-1.

Consideration should be given to the effect of ice cover on tsunami wave parameters.

6.4.4.3 Dissolved oxygen

Higher dissolved oxygen content can be encountered in cold water regions. Since higher oxygen levels can enhance corrosion, local data should be collected to assess this hazard when relevant for the structural materials used.

6.4.4.4 Water temperature and salinity

The temperature at which water freezes is a function of water salinity. At normal ocean water salinity, considered to be 35 g/kg, water freezes at $-1,9^{\circ}\text{C}$. This shall be considered as the coldest water temperature that can be found in regions affected by sea ice. Water temperature profiles should be established from the water surface to the seabed.

Probability distributions of low water temperature profiles should be determined for positions as needed for quantifying EL minimum water temperatures and other low temperatures for winterization, see 5.3.4. EL minimum temperatures and LAST in water can be selected as the coldest monthly mean temperature minus 3.5 times the monthly temperature standard deviation.

6.5 Sea ice and icebergs

6.5.1 General

Information required to characterize site-specific ice criteria shall be determined for the location of the structure under consideration. This information should consider all phases of the structure's life, including transportation to and from the site.

Data should be obtained from direct observations at a location, interpretation of satellite imagery, or historical information at the geographic region of the structure, platform or facility. Where local ice data are unavailable or are not representative of relevant severe ice conditions, or where ice incursions are infrequent, data from nearby sites or geographical regions with similar ice environments may be used. Numerical or statistical modelling may be used to extend these data sets, with due account for

uncertainties. Long-term trends and provisions for a changing climate, see 5.3.2, shall be taken into account.

Interrelationships between the parameters listed in 6.5.2 to 6.5.5 and other physical environmental parameters should be considered, where relevant for the development of design criteria.

6.5.2 Ice types

The types of ice expected, i.e. first-year (FY), second-year, multi-year (MY), shelf or glacial, shall be determined. If a distinction cannot be made between second-year and MY ice, old ice can be specified. Statistics, such as probability distributions and parameters thereof, shall reflect the occurrence, concentration, dimensions, physical properties and mechanical properties of all relevant ice types.

Inter-annual and seasonal variations in the presence of ice types shall be considered.

6.5.3 Ice morphology

The occurrence and geometry of specific ice features, such as icebergs, ice islands, rafted ice, rubble fields, leads or polynya, pressure and shear ridges, stamukhi, landfast ice, pack ice, shelf ice and glacial ice, shall be determined on the basis of field measurements at the site or representative data from nearby sites. Statistics, such as probability distributions and parameters thereof, and appropriate ice feature frequency and dimensions shall be determined.

The occurrence of grounded ice features, such as grounded rubble piles and beach pile-ups, shall be determined to obtain appropriate ice feature frequency, extent, size, potential ice gouge depth and stability. This information shall be used in the determination of ice actions, design of flowlines and their burial depth, access to facilities, logistics, and evacuation systems.

The consolidated layer thickness of ridges, rubble fields and stamukhi shall be determined directly from regional data or estimated from data for other regions with suitable correction to local conditions.

Inter-annual and seasonal variations in ice morphology shall be considered.

6.5.4 Ice movement

Statistics of movement rates for pack ice, ice floes, floating ridges, rubble fields, icebergs, ice islands and landfast ice, where relevant, shall be determined on the basis of field data. The statistics can include probability distributions, means and extremes. If field data do not exist for these parameters, numerical modelling or analysis of the interaction of winds, waves, ocean currents and ice may be performed to obtain this information, with due account for uncertainties in the data and modelling procedures.

Inter-annual and seasonal variations in ice presence, polynyas and physical parameters shall be considered.

The areal density of ice features and the probability distribution of ice drift velocities should be estimated on a consistent basis with respect to the inclusion or exclusion of grounded ice features. Grounded features should be included for both areal density and ice drift or for neither of these parameters.

6.5.5 Ice properties

Appropriate mechanical and physical properties of ice shall be used for design and operational measures. The considerations of 8.2.8 shall apply.

6.5.6 Ice monitoring

Real-time information on ice conditions shall be included in the physical environmental data monitoring programme, for example, to operate IM systems and EER procedures for the platform or facility. See ISO 35106.

6.6 Seabed considerations

6.6.1 Earthquakes

The complexity of a seismic action evaluation and the associated design procedure for an arctic offshore structure depends on the structure's seismic risk category as determined in accordance with ISO 19901-2. Acceleration levels taken from the maps provided in ISO 19901-2 define the seismic zones, which can be used to determine the appropriate seismic design procedure. The selection of the procedure depends on the structure's exposure level as well as the severity of ground motion.

Where seismic events are a design concern, appropriate site-specific dynamic seabed-structure interaction analyses shall be carried out (see 9.10).

6.6.2 Permafrost

An investigation into the presence of permafrost shall be performed at platform locations and at any sites where structures make contact with the sea floor. Offshore structures founded on permafrost require special studies in order to understand the performance of the soil under time-varying actions induced by earthquakes, waves or sea ice. The potential effects of thaw consolidation of ice-rich permafrost as a result of production of warm hydrocarbons should be considered in the design of all structural foundations.

6.6.3 Ice gouge

Ice gouges occur due to the interaction of ice features such as ridges, icebergs, and stamukhi with the seabed. Data on ice gouges shall be obtained to determine the frequency of ice gouge occurrence as well as depth, width, length, and direction information of individual features. Ice gouge statistics shall be used for design in regions where the seabed is used for the laying and burial of flowlines and umbilicals, subsea facilities and platform tie-ins.

6.6.4 Strudel scours

Strudel scouring shall be investigated for structures and other facilities in regions near the mouths of rivers.

7 Reliability and limit states design

7.1 Design philosophy

7.1.1 Governing principles

The complete structure and its components including foundations shall be designed so that they function with adequate reliability for all physical environmental, accidental and operational actions and design situations to which the structure can be subjected during all phases of the life of the structure. These phases include construction, transportation, installation, service in place and decommissioning. The required reliability depends on the exposure level, see 7.1.4, which is determined by the life-safety category and the environmental and economic consequence category of the complete structure or component.

Design shall be in accordance with the limit states approach as specified in 7.2. This requires that action effects arising from design actions shall not cause the structure or its components including foundations to exceed the limits specified for the relevant limit state. Resistances and their relevant partial factors shall be determined in accordance with this document and its referenced documents. Actions shall include, but not be limited to, ice, seismic, oceanographic, meteorological, permanent and variable actions.

Hazardous events shall be defined and evaluated for the hazards identified in accordance with 5.3.1. Extreme and abnormal environmental events, see ISO 19900:2013, 7.1.6, shall each be considered as separate hazardous events. When considering a specific hazardous event, design situations shall be defined as described in ISO 19900:2013, 5.6. A typical design situation is generally dominated by one type of hazardous event with associated companion environmental conditions, and the design is verified for the relevant limit state. Partial factors for the action combination associated with ultimate limit states (ULS) and abnormal limit states (ALS) shall be in accordance with 7.2.4.

7.1.2 Life-safety categories

Life-safety category shall be determined in accordance with ISO 19900:2013, 6.2.

The life-safety category addresses the safety of personnel on the platform and the likelihood of successful evacuation before a design environmental event occurs.

7.1.3 Consequence categories

Consequence category shall be determined in accordance with ISO 19900:2013, 6.3.

The consequence category should also consider the potential risk to life of personnel brought in to respond to any incident, the potential risk of environmental damage and the potential risk of economic losses.

7.1.4 Exposure levels

Exposure level depends on the life-safety and consequence categories. Exposure levels shall be determined in accordance with the process set out in ISO 19900:2013, 6.4.

All manned, non-evacuated platforms and high-consequence platforms or structures are designated L1; unmanned, low-consequence platforms or structures are designated L3; other platforms or structures are designated L2.

NOTE Platform is defined in ISO 19900:2013.

Structural components of arctic and cold regions platforms or structures may be categorized differently from each other and from the overall platform or structure, if different life-safety and consequence categories are demonstrated, in which case their exposure level can be different.

7.1.5 Safety and reliability

Safety and reliability is addressed by design verification, supplemented by operational measures.

Design verification by the limit states design method is addressed in 7.2. Operational measures, see 5.5, can be a requirement of the design, reducing the EL and AL ice actions, and can mitigate risks arising from very unlikely events.

A design situation shall be defined for each EL ice action and AL ice action, and the structural design shall be verified. For very unlikely events, see 5.5, operational measures can be used to further mitigate life safety and other risks in accordance with the owner's risk management policy.

When deciding on which events require verification of the structural design, and which can be managed by operational measures alone, the uncertainties associated with low probability events shall be taken into account.

7.1.6 Limit states

Limit states are divided into four categories as described in this document, see 7.2.1.1, and in ISO 19900:2013, 7.1.

Due to the significance of AL ice actions in arctic and cold regions, this document places emphasis on the abnormal aspect of the ALS.

7.1.7 Alternative design methods

Alternative design methods may be used if the reliability of the structure and its components is shown to be equivalent to or better than that of the limit states design approach as set out in 7.2 and Table A.7-1.

7.2 Limit states design method

7.2.1 Limit states

7.2.1.1 Categories of limit states

The limit states are divided into the following four categories:

- a) ultimate limit states (ULS) — for strength and resistance to extreme-level actions, as described in 7.2.2.1;
- b) serviceability limit states (SLS) — for stiffness and adequate performance under normal functional use;
- c) fatigue limit states (FLS) — for adequate endurance for the accumulated effect of repetitive or cyclic action effects;
- d) abnormal (accidental) limit states (ALS) — for adequate reserve capacity and energy dissipation capability in situations of abnormal environmental and accidental events.

For the limit states design method, the reliability relevant to the exposure level is achieved through design verification to ultimate limit states (ULS) and abnormal limit states (ALS).

7.2.1.2 Ultimate limit states

The ULS requirement ensures that no significant structural damage occurs for actions with an acceptably low probability of being exceeded during the design service life of the structure. Significant damage is associated with impairment of structure function.

ULS design situations shall be based on environmental events which result in extreme-level environmental actions. For ice, both local and global actions shall be considered.

Representative resistances shall be factored by resistance factors to obtain the design resistances. Alternatively, the representative material properties shall be factored by material factors to obtain the design material properties.

Design procedures shall be based primarily on linear elastic methods of structural analysis. Some localized inelastic behaviour of the structure and its components is acceptable, for example, as permitted in Clause 11 for fixed steel structures and Clause 12 for fixed concrete structures. Structure interaction with foundation soils may be modelled non-linearly, considering non-linear elastic or plastic behaviour of the soil. Procedures and further provisions for floating systems are described in 13.4 and 13.5.

The safety for each ultimate limit state shall be verified by ensuring that the effect of combined factored actions does not exceed the factored resistance.

7.2.1.3 Serviceability limit states

Exceedance of SLS can result in the loss of capability of a structure to perform adequately under normal functional use. The structure shall satisfy serviceability limits for vibration and deflection, including limits for habitability and crew comfort.

The specification of actions and limits for SLS is generally the owner's responsibility. SLS shall also include considerations that can lead to long-term structural degradation, such as corrosion of reinforcement in concrete.

For SLS, the structure should satisfy the requirements of this document when structural members are subjected to localized ice damage. Examples include: concrete cracking and shrinkage, for which partial action factors are provided in ISO 19903; loss of concrete cover due to ice abrasion; removal of paint and removal of corroded steel due to ice abrasion; and localized damage due to vibration induced by ice and other physical environmental factors.

7.2.1.4 Fatigue limit states

Exceedance of FLS for offshore structures results from cumulative damage due to repeated actions. All actions over the design service life shall be considered, including the transportation phase to the site. For ice actions, cyclic variations are generally associated with compressive and flexural ice failure.

Fatigue analysis shall be based on a cumulative damage assessment in accordance with the relevant ISO document to ensure that the cumulative damage does not exceed the defined FLS.

7.2.1.5 Abnormal (accidental) limit states

The ALS requirement is intended to ensure that the structure and foundation have sufficient reserve strength, displacement or energy dissipation capacity to sustain large actions and other action effects in the inelastic region without complete loss of integrity.

ISO 19900:2013, 7.1.6 identifies two types of hazardous event related to ALS, namely accidental events and abnormal environmental events. Accidental events and accidental situations are described in ISO 19900. For abnormal environmental events, ALS design situations shall be based on events which result in abnormal-level environmental actions. For ice, both local and global actions shall be considered.

Partial factors for structure and foundation resistance, or overall safety factors, may be reduced from their ULS values or set to unity, as permitted by this document and its referenced documents.

The safety for each abnormal and accidental limit state shall be verified by ensuring that the effect of combined actions does not cause global failure or collapse of the structure or any of its vital parts.

7.2.2 Actions

7.2.2.1 General

Permanent actions (G), variable actions (Q), environmental actions (E), repetitive actions leading to fatigue, and accidental actions (A) are defined in ISO 19900. Further details on their specification are found in ISO 19902, ISO 19903 and ISO 19904-1.

For structures in arctic and cold regions, the design shall be based on EL and AL environmental actions for hazardous events arising from the relevant design situations. The environmental action shall comprise a principal action combined with relevant companion actions as described in 7.2.3.

Representative values shall be assigned to each EL and AL action. The main representative value is the characteristic value, which is a value associated with a prescribed probability of being exceeded by unfavourable values during a reference period, which is generally one year.

In arctic and cold regions, there can be additional accidental events that should be evaluated, such as ice-driven ship impacts on a structure.

7.2.2.2 Serviceability-level ice actions

Unless the owner has specified otherwise, the representative value of the serviceability-level ice action used for SLS shall be determined based on an annual probability of exceedance not greater than 10^{-1} .

7.2.2.3 Extreme-level ice actions

The representative value for the EL ice action shall be determined for each ULS design situation based on an annual probability of exceedance not greater than 10^{-2} .

The EL ice action is not applicable for hazardous events with an annual probability of occurrence of less than 10^{-2} .

Ice events associated with the EL ice action are termed extreme-level ice events (ELIE), see 8.2.3.

7.2.2.4 Abnormal-level ice actions

The representative value for the AL ice action shall be determined for each ALS design situation based on an annual probability of exceedance related to the exposure level. For L1 structures, this shall be determined based on an annual probability of exceedance not greater than 10^{-4} .

For L2 structures, the annual probability shall be not greater than 10^{-3} . AL ice actions need not be considered for L3 structures.

The AL ice action is not applicable for hazardous events with an annual probability of occurrence of less than 10^{-4} for L1 structures (10^{-3} for L2 structures). Further guidance is provided in A.7.2.2.

Ice events associated with the AL ice action are termed abnormal-level ice events (ALIE), see 8.2.3.

7.2.2.5 Dynamic ice actions

Dynamic amplification of ice actions shall be considered with respect to the structure and foundations, and the potential to cause soil liquefaction, see 8.2.1. If relevant, dynamic ice actions and ice-induced vibration shall be characterized with respect to design actions for the ULS and the ALS, and for action effects for the SLS and the FLS.

7.2.2.6 Other environmental actions

Representative values of actions for all other environmental events shall be determined at the extreme-level (EL), based on an annual probability of exceedance not greater than 10^{-2} , and at the abnormal-level (AL), based on an annual probability of exceedance not greater than 10^{-4} for L1 structures and 10^{-3} for L2 structures. It is not necessary to consider abnormal-level events for L3 structures. For seismic actions, the extreme-level earthquake (ELE) and abnormal-level earthquake (ALE) event probabilities shall be as specified in ISO 19901-2.

Effects due to temperature differences within the structure or component are to be considered in all relevant limit states.

7.2.2.7 Accidental actions

Actions arising from accidental situations shall be addressed in accordance with ISO 19902, ISO 19903 and ISO 19904-1 depending on the structure type. Accidental situations are defined in ISO 19900.

7.2.3 Principal and companion environmental actions

Environmental action combinations for each environmental design situation shall consist of the principal action accompanied by companion environmental actions. The principal action is the action arising from the hazardous event that defines the design situation, such as the EL ice action or AL ice action for ice events. Alternatively, the joint probability of environmental actions may be used, see below.

Potential combinations of principal and companion environmental actions are given in Table 7-1. Companion environmental actions additional to those listed should be considered based on site-specific conditions.

The effect of varying water levels, see 6.4.1, shall be considered in the calculation of principal actions and in the specification of companion actions. The wind-driven component of storm surge should be considered as stochastically dependent on the wind if the principal action depends on the wind. Tidal elevations should be considered as stochastically dependent on the current where the principal action depends on tidal currents.

Where site-specific data are available, the joint probability distribution of the principal and relevant companion actions should be used to determine the magnitude of the combined EL or AL environmental action.

Table 7-1 — Companion EL environmental actions

Principal action (EL or AL)	Companion EL environmental action		
	Stochastically dependent	Stochastically independent	Mutually exclusive
Waves	Wind, wind-driven current	Tidal and background current	Sea ice (for ice concentration $\geq 8/10$)
Waves	Wind, wind-driven current, ice (for ice concentration $< 4/10$)	Sea ice (for ice concentration $< 8/10$)	—
Swell	—	Waves, wind, wind-driven current, tidal and background current, sea ice (for ice concentration $< 8/10$)	Sea ice (for ice concentration $\geq 8/10$)
Tsunami	—	Waves, wind, wind-driven current, tidal and background current, sea ice	—
Wind	Waves, wind-driven current, sea ice	Swell, tidal and background current	—
Wind	Wind-driven current, sea ice	Tidal and background current	Waves, swell (for ice concentration $\geq 8/10$)
Current (tidal and background)	Sea ice	Waves, swell, wind, wind- driven current	Waves, swell (for ice concentration $\geq 8/10$)
Current (wind-driven)	Sea ice, waves, wind	Swell, tidal and background current	Waves, swell (for ice concentration $\geq 8/10$)
Sea ice	Wind, wind-driven current, tidal current	—	Waves, swell (for ice concentration $\geq 8/10$)
Sea ice	Wind, wind-driven current, tidal current, waves (for $< 4/10$ sea ice concentration)	Waves, swell (for ice concentration $< 8/10$)	—
Earthquake ^a	—	Waves, swell, wind, wind- driven current, tidal and background current, persistent ice cover	—
Large icebergs or other large ice features	Wind, wind-driven current, tidal and background current	Waves ^b , swell ^c	—
Isolated ice features (e.g. ice floes, ridge fragments, stamukhi, bergy bits, small icebergs)	Wind, wind-driven current, tidal and background current, waves ^b	Waves ^b	—
Snow	—	Wind, waves, current, sea ice, icebergs ^c	—
Ice accumulation (including icing and ice accretion)	Wind, waves ^c	Wind, waves, current, sea ice ^c	—

^a For the AL earthquake, it is normally sufficient to consider only ice likely to be present when an earthquake occurs.

^b The principal action from small icebergs or ice floes and the companion wave actions can be stochastically dependent.

^c Categorisation of companion actions for snow and icing should be assessed for site-specific conditions.

In the absence of specific consideration of joint probability distributions, other applicable statistical techniques may be used to estimate combination factors that capture site-specific correlations between the principal and the companion actions.

In the absence of site-specific data and in the absence of statistical modelling and analysis, the combination factors provided for companion environmental actions in Table 7-2 may be used. In this approach, the representative EL value of each relevant companion action shall be multiplied by the relevant factor from Table 7-2 and added to the EL or AL value of the principal action as determined by the design situation. The values specified in Table 7-2 are conservative to account for significant correlations between companion and principal actions.

Further considerations for floating systems are provided in 13.4.

Table 7-2 — Combination factors for companion EL environmental processes

Principal action	Factor for representative EL companion environmental action	
	Companion action is stochastically dependent on the principal action	Companion action is stochastically independent of the principal action
EL action	0,9	0,6
AL action	0,5	0,4

7.2.4 Combinations of actions and partial action factors

The limit states action combinations specified in Table 7-3 shall be used in design. For each action combination, the design action shall be calculated as follows:

- the representative value of a combined environmental action, E , or accidental action, A , shall be multiplied by a partial action factor not less than that specified in Table 7-3;
- representative values of permanent and variable actions shall be multiplied by partial action factors which either shall be not less than specified in Table 7-3 or shall be taken from ISO 19902, ISO 19903 or ISO 19904-1 for the respective structure types.

These partial action factors apply to both local and global actions. ISO 19900 provides further information on the classification of types of action.

The combination of actions and the partial action factors for earthquakes shall be in accordance with ISO 19902 for fixed steel structures and in accordance with ISO 19903 for fixed concrete structures. Further guidance is provided in 8.4.

Partial action factors and action combinations for SLS and FLS shall be in accordance with ISO 19902, ISO 19903 or ISO 19904-1 as relevant to the structure type.

Action combination 1 shall include checks for design situations both with and without environmental action, E .

For design situations where an EL action is the principal action, the action effects shall be checked for ULS (action combinations 1 and 2 in Table 7-3), except that in the damaged condition they shall be checked for action combination 3 only.

For design situations where an AL environmental action or accidental action is the principal action, the action effects shall be checked for ALS only (action combinations 4 and 5 in Table 7-3).

The partial action factors for environmental actions other than earthquakes specified in Table 7-3 have been calibrated to the reliability targets given in Table A.7-1. When these partial action factors are applied to ULS and ALS action combinations for arctic offshore structures and their components, including foundations within the scope of this document of exposure levels L1 and L2, the reliability targets given in Table A.7-1 are deemed to be achieved. Further considerations for floating systems are provided in 13.4.4.

As an alternative to Table 7-3, partial action factors may be derived using a calibration procedure, such as the one described in A.7.2.4, involving a full probabilistic description of actions and resistance, and a demonstration that the reliability targets of Table A.7-1 are met.

Table 7-3 — ULS and ALS partial action factors and action combinations

Action combination		Limit states partial action factors						Accidental action <i>A</i>
		Permanent action <i>G</i>		Variable action <i>Q</i>		Environmental action <i>E</i>		
		Gravity and hydrostatic (Dead) <i>G</i> ₁	Deformation <i>G</i> ₂	Long duration <i>Q</i> ₁	Short duration <i>Q</i> ₂	EL	AL	
Ultimate limit states								
1	Gravity and deformation — long and short duration	1,30 ^a or 0,90 ^b	1,00	1,50 ^a	1,50 ^a	0,70 ^c or 0 ^b	—	—
2	Extreme environmental	1,10 or 0,90 ^b	1,00	1,10 or 0,80 ^b	—	1,35 (L1) ^{c,d} 1,10 (L2) ^{c,d,e}	—	—
3	Damaged condition ^f	1,10 or 0,90 ^b	1,00	1,10 or 0,80 ^b	—	1,00	—	—
Abnormal (accidental) limit states								
4	Abnormal environmental	1,00	1,00	1,00	—	—	1,00 ^c	—
5	Accidental	1,00	1,00	1,00	—	—	—	1,00

^a For the gravity and deformation action combination, a partial action factor of 1,20 may be used for permanent hydrostatic pressure and for physically limited variable actions.

^b The lower partial action factor applies for permanent *G*₁ actions when the permanent action resists overturning or uplift, for variable *Q*₁ actions when there is a reversal of variable action effects, and for environmental actions *E* if this produces a more unfavourable total design action effect.

^c The representative value of the environmental action to which the partial action factor applies shall be calculated as the combination of a principal action and appropriate companion actions, as described in 7.2.3.

^d The limit states partial action factor for actions arising from the ELE shall be as defined in ISO 19902 for steel structures and in ISO 19903 for concrete structures, and 1,0 for all other structures.

^e For L2 exposure level, all partial action factors for all action combinations are as for L1 except for the EL factor in the extreme environmental action combination.

^f Damaged condition or progressive collapse limit states are defined generally for structures in ISO 19900 and for particular types of structures in ISO 19902, ISO 19903 and ISO 19904-1.

8 Events and actions

8.1 General

The events and actions used for design shall consider all phases of the life of the structure, including construction (fabrication, transportation, and installation), service in place, and decommissioning. Specific consideration shall be given to the local physical environment for structures in arctic and cold regions.

Actions can be classified as described in ISO 19900:2013, 8.2.1. The classification includes:

- permanent actions;
- variable actions;
- environmental actions;
- accidental actions;
- repetitive actions.

Hazards shall be taken into account in accordance with 7.1.1 and ISO 19900:2013, 5.6. Hazardous events can include extreme environmental events, accidental events and abnormal environmental events.

Metoccean events such as wave events, wind events and ocean current events are considered in ISO 19901-1. Seismic events and actions are considered in ISO 19901-2. Actions arising from these events are considered in ISO 19902, ISO 19903 and ISO 19904-1. Provisions for the treatment of ice actions and their combination with other types of actions are given in 7.2.3 with the further requirements of Clause 8.

The design of arctic offshore structures shall include consideration of global ice actions relating to the overall integrity of the complete structure and its components, including, if relevant, foundation and stationkeeping system, and local ice actions for specific components or portions of the structure.

Allowance for possible weight increase and changes in the centre of gravity of a platform due to ice accretion during fitting out (if performed in arctic or cold regions) and transportation shall be considered. The allowance shall reflect the time of year and geographical area.

Differential strains or lock-in stresses due to temperature changes between construction and permanent locations shall be considered in the design.

8.2 Ice events and actions

8.2.1 General principles for calculating ice actions

Structures or components subjected to ice events shall be designed for ice actions with annual probabilities as specified in 7.2.2, appropriate to the limit state and exposure level. In the absence of data to quantify the potential for ice events, ice actions shall be assessed if there is a reasonable probability of interaction. All reasonably foreseeable interaction scenarios with potentially adverse consequences should be considered in this respect. Reference should also be made to 8.3.2 for wave-induced ice motion.

Direct ice actions and actions arising from the interaction between the ice and the structure shall be considered for both global and local actions. Such actions can include:

- a) static, quasi-static, cyclic and dynamic actions (EL and AL);
- b) cyclic and dynamic actions that can cause structural fatigue, soil liquefaction and personnel discomfort; and
- c) spatial events such as ice rubbing, pile-up, ride-up and other ice mechanisms that can hinder operations.

Global ice actions and their point of action shall be determined in accordance with 8.2.4 so that the integrity of the structure can be assessed. This includes resistance to sliding and overturning, capacity of the foundation, fatigue and foundation liquefaction. Local actions shall be considered in accordance with 8.2.5.

Methods based on full-scale action and response data from measurements on instrumented structures shall be used for the determination of representative ice actions on offshore structures, with due account of their applicability, and of the uncertainties in the data and the methods used in their interpretation. Where no data are available at the location of interest, measurements from other regions may be extrapolated using knowledge of the ice regimes, metocean aspects, climate, brine volume, ice strength and other relevant physical properties of ice. Small-scale ice strength data obtained locally, preferably in situ, can be of assistance in the extrapolation. Physically-based models and scale model tests may be used to complement the full-scale data, with due account of uncertainties in their application.

Further requirements relating to ice actions are found in 10.3 for man-made islands, in 13.4 for floating systems and in 14.3 for subsea structures.

8.2.2 Representative values of ice actions

The design shall be carried out for EL ice actions and AL ice actions, as specified in 7.2.2.3 and 7.2.2.4.

Representative values of ice actions shall be calculated using probabilistic methods or deterministic methods for the ice parameters relevant to the event.

8.2.3 Ice events and design situations

Ice events shall reflect:

- the relevant ice scenario, limiting mechanisms and ice failure modes for the geographical location of the structure, with reference to the provisions of 8.2.4, 8.2.5, 8.2.6 and 8.2.8; and
- the structural configuration and the relevant operational scenarios, including seasonal operation, ice detection, physical IM, manoeuvring of the structure and disconnection, with reference to the provisions of 8.2.7.

Ice actions are estimated for all ice events, from which the EL and AL ice actions are identified, when required by 7.2.2.3 and 7.2.2.4. The events associated with the EL and AL ice actions are termed ELIE and ALIE, which can involve the conditions listed above and the associated parameters. ELIE and ALIE can be used to conduct quality checks for calculated EL and AL ice actions if probabilistic methods are used, or

to directly estimate EL and AL ice actions if deterministic methods are used. When several ice and operational scenarios are relevant for a particular structure, those resulting in the largest ice actions for each design situation shall be considered in the design.

Where applicable, ice scenarios for consideration shall include structures interacting with:

- a) FY ice features (level ice, rafted ice, landfast ice, floes, ridges, rubble fields, refloated stamukhi);
- b) old ice features, including second-year and MY ice features (level ice, floes, ridges, rubble or hummock fields);
- c) icebergs; and
- d) ice islands (ice shelf fragments).

Metocean and ice information provided in Annex B can be used to assist with the development of ice scenarios. The relative importance of potential ice scenarios and ice events shall be determined based on the structural configuration and relevant operational scenarios.

Other types of event can occur with companion actions as described in 7.2.3. Subsidiary conditions that can act in combination with the ice features or can influence the nature of the interaction include:

- seasonality;
- ocean currents, including tidal effects;
- wind;
- waves;
- water depth.

8.2.4 Global ice actions

The determination of global ice actions shall be based on methods that incorporate relevant full-scale measurements, model experiments if they can be scaled reliably (see also 16.5), or theoretical methods (analytical or numerical) that have been calibrated using experiments or full-scale measurements. Each of the following conditions shall be considered, and the governing ones shall be used to determine ice actions:

- a) quasi-static actions due to level ice (FY, rafted, or old ice), where inertial action effects within the structure can be neglected;
- b) dynamic actions due to level ice (FY, rafted, or old ice), where inertial action effects within the structure are influential and a dynamic analysis is required;
- c) quasi-static actions due to ice rubble and ridges, where inertial action effects within the structure can be neglected;
- d) impacts from discrete features such as icebergs, ice islands and large old ice or FY ice features;

- e) quasi-static actions from features lodged against the structure, driven by the surrounding ice or directly by metocean actions;
- f) adfreeze action effects, including the frozen-in condition; and
- g) thermal action effects;

The following limiting processes shall be considered.

- 1) Limit stress, which is the process that occurs when there is sufficient energy or driving force to envelop the structure and generate ice actions across its total width. Limit stress actions are governed by local ice failure against the structure, accounting for the presence of any ice rubble.
- 2) Limit energy, which is the process that occurs when the interaction is limited by the kinetic energy of the ice feature. Such actions are likely to arise due to impacts of icebergs, refloated stamukhi, thick ice floes or ice islands. Such features can either occur in open water or be surrounded by pack ice.
- 3) Limit force, which is the process that occurs when the interacting feature is driven against the structure by metocean actions, and the actions are insufficient for the ice to fail locally and envelop the structure. Such actions are likely to arise where large ice features interact with a structure under the action of wind, current or pack ice pressures, or a combination of these actions.

Ice crushing, shear, flexure, splitting and buckling failure modes should be considered in the calculation of global actions for each of the above limiting processes. Where relevant for the scenario, ice conditions and limiting processes, the following factors shall be considered in determining ice actions:

- event frequency;
- geometry of the ice or ice features;
- geometry of the structure;
- mass and added mass of the ice feature and structure;
- mechanical properties of the ice or ice feature;
- adfreeze bond between ice and the structure;
- inertial effects (and added inertia) for both the ice and the structure;
- velocity and direction of movement of the ice features;
- pressured ice conditions;
- ice rubble build-up, and implications for ice encroachment, structure freeboard requirements and actions transmitted to the structure;
- clearing of ice around the structure;
- ice jamming between the members of a multi-leg structure;
- compliance and damping of the structure and stationkeeping system;