

Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions

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API Foreword

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Contents

	Page
API Foreword	iii
Foreword	xi
Introduction	xii
1 Scope	1
2 Normative References	1
3 Terms and Definitions	2
4 Symbols and Abbreviated Terms	10
4.1 Symbols	10
4.2 Abbreviated Terms	10
5 General Requirements and Conditions	11
5.1 Fundamental Requirements	11
5.2 Design Methods	12
5.3 Site-specific Considerations	12
5.4 Construction, Transportation, and Installation	13
5.5 Design Considerations	14
5.6 Environmental Protection	14
5.7 Serviceability Requirements Including Vibrations and Crew Comfort	14
6 Physical Environmental Conditions	14
6.1 General	14
6.2 Daylight Hours	15
6.3 Meteorology	15
6.4 Oceanography	16
6.5 Sea Ice and Icebergs	17
6.6 Seabed Considerations	18
7 Reliability and Limit States Design	19
7.1 Design Philosophy	19
7.2 Limit States Design Method	21
8 Actions and Action Effects	26
8.1 General	26
8.2 Ice Actions	26
8.3 Metocean Related Actions	30
8.4 Seismic Actions	32
9 Foundation Design	33
9.1 General	33
9.2 Site Investigation	34
9.3 Characteristic Material Properties	36
9.4 Design Considerations	36
9.5 Gravity Base Structures (GBS)	40
9.6 Piled Structures	42
9.7 Floating Structures	42
9.8 Scour	44
9.9 Inspection and Performance Monitoring	44
9.10 Seismic Analysis	45

Contents

	Page
10 Man-made Islands	45
10.1 General	45
10.2 Island Types	45
10.3 Design Considerations	46
10.4 Seismic Design	52
10.5 Construction	52
10.6 Monitoring and Maintenance	52
10.7 Decommissioning and Reclamation	53
11 Fixed Steel Structures	54
11.1 General	54
11.2 General Design Requirements	54
11.3 Structural Modeling and Analysis	54
11.4 Strength of Tubular Members and Joints	55
11.5 Strength of Stiffened-plate Panels	55
11.6 Strength of Steel-concrete Composite Walls	55
11.7 Seismic Design	58
11.8 Fatigue	58
11.9 Materials, Testing, and Nondestructive Testing (NDT)	58
11.10 Corrosion and Abrasion Protection	59
11.11 Welding	59
12 Fixed Concrete Structures	59
12.1 General Requirements	59
12.2 Actions and Action Effects	60
12.3 Structural Analysis	60
12.4 Concrete Works	62
12.5 Mechanical Systems	68
12.6 Marine Operations and Construction Afloat	69
12.7 Corrosion Control	69
12.8 Inspection and Condition Monitoring	69
13 Floating Structures	70
13.1 General	70
13.2 General Design Methodology	70
13.3 Environment	72
13.4 Actions	72
13.5 Hull Integrity	74
13.6 Hull Stability	75
13.7 Stationkeeping	76
13.8 Mechanical Systems	78
13.9 Operations	81
14 Subsea Production Systems	83
14.1 General	83
14.2 Ice and Seabed Considerations	84
14.3 Actions on Subsea Production Systems	85
14.4 Seismic Design	87
14.5 Risk Reduction	87

Contents

	Page
15	Topsides 88
15.1	Overall Considerations. 88
15.2	Design and Operational Requirements. 91
15.3	Seismic Design 99
16	Other Ice Engineering Topics 101
16.1	Ice Roads and Supplies over Ice. 101
16.2	Artificial Ice Islands. 103
16.3	Protection Barriers 103
16.4	Measurements of Ice Pressure and Actions 105
16.5	Ice Tank Modeling 107
16.6	Offloading in Ice 108
17	Ice Management 109
17.1	General 109
17.2	Ice Management System 109
17.3	Ice Management System Capabilities. 110
17.4	Ice Management Planning and Operations 111
18	EER 113
18.1	General 113
18.2	EER Philosophy. 113
18.3	EER Strategy 113
18.4	Environment. 113
18.5	Hazard and Risk Analysis 114
18.6	Continuous Assessment 115
18.7	EER System Design 115
18.8	Emergency Response Organization 116
18.9	Competency Assurance 116
18.10	Communications and Alarms 116
18.11	PPE 116
18.12	Man Overboard Recovery. 117
18.13	Escape Design. 117
18.14	Evacuation Design 118
18.15	Rescue Design. 119
Annex A (informative)	Additional Information and Guidance. 120
Annex B (informative)	Regional Information 326
Bibliography	 437
Figures	
A.7-1	Schematic Illustration of ELIE and ALIE, for Rare and Frequent Events 147
A.7-2	Schematic Showing Calculation of Design Values from Representative Action and Characteristic Resistance 149
A.8-1	Flowchart of Overall Approach for Calculating Design Ice Actions 151
A.8-2	Geometric Definitions for Determining Collision Probability 156
A.8-3	Factors Influencing Interaction Scenarios. 158
A.8-4	Failure Modes 161
A.8-5	Ridge Building and Local Ice Failure Processes 163
A.8-6	Ridge Building and Ridge Failure Adjacent to the Structure. 163

Contents

	Page
A.8-7 Ridge Failure Processes	164
A.8-8 Schematic Showing Localization of Action in Compressive Ice-structure Interaction	165
A.8-9 Processes in the Interaction Between a Sloping Structure and Sheet Ice.	171
A.8-10 Ice Rubble Pile-up and Clearing around a Sloping Structure	171
A.8-11 Ice Action Components on a Sloping Structure for a Two-dimensional Condition	172
A.8-12 Idealized Geometry of a First-year Ridge.	179
A.8-13 Ridge Building Action Behind Thick Floe or Ridge	182
A.8-14 Ridge Building Action versus Width (Normalized Using Thickness to the Power 1.25)	182
A.8-15 Schematic of Ice Bustle Formed on Quay Piles	188
A.8-16 Thermal Ice Load versus the Rate of Temperature Increase of the Ice Surface	189
A.8-17 Definition of Loaded Areas for Local Actions	190
A.8-18 Distribution of the Full Thickness Pressure on the Loaded Area.	192
A.8-19 Compilation of Data for Ice Pressures as a Function of the Loaded Area.	194
A.8-20 Method of Combining the Local Pressure with a Pressure Acting on a Larger Area.	196
A.8-21 Modes of Time-varying Action due to Ice Crushing and the Corresponding Dynamic Component of Structure Response	197
A.8-22 Idealized Time Histories of the Ice Action due to Intermittent Crushing	197
A.8-23 Assumed Ice Load History for Frequency Lock-in Conditions	199
A.8-24 Idealized Time History of the Horizontal Action on a Conical Structure	200
A.13-1 Range of Options for Floating Structures in Arctic and Cold Regions	233
A.13-2 Relationship Between the Various Factors for Floater Operations in Ice Environments.	234
A.14-1 Soil Displacements During the Gouging Process.	244
A.14-2 Strategy for Reliability-based Design of Marine Pipelines in Ice Gouged Areas	250
A.16-1 Floating Ice in Bending Under Lateral Load	259
A.16-2 Typical Ice Cover Temperature Profile	259
A.16-3 Typical Ice Cover Failure Pattern	260
A.16-4 Ice Bearing Failure Data—Individual Failed and Safe Ice Loads.	263
A.16-5 Critical Speed for Dynamic Effects	267
A.16-6 Ice Action and Resistance of an Ice Island	270
A.16-7 Cut-away of a Refrigerated Conductor.	275
A.16-8 Potential Arctic and Cold Region Offshore Loading Concepts.	294
A.17-1 Typical Components of an Ice Management System	296
A.17-2 Typical Functions of an Ice Management System.	297
A.17-3 Schematic of Sea Ice Management Techniques	302
A.17-4 Schematic Showing Single-line Hook-up and Towing Configuration.	303
A.17-5 Profile Schematic of Single Towline Configuration	304
A.18-1 EER Taxonomy	307
A.18-2 Schematic of the EER Philosophy for Hydrocarbon Facilities	308
A.18-3 Process to Achieve a Performance-based EER System	311
A.18-4 Illustration of the Continuous Assessment and Improvement Process for EER Systems	316
B.2-1 Map of the Baffin Bay and Davis Strait Region	327
B.3-1 Map of Offshore Labrador	331
B.4-1 Map of Newfoundland and Offshore Regions	334
B.5-1 Map of the Canadian Arctic Archipelago	338
B.5-2 Median Concentration, in Tenths, of Ice in the Sverdrup Basin at the Time of Minimum Extent (3 September), Based on a 30 Year Climatology for 1970 to 1999	340
B.6-1 Map of Greenland	343
B.6-2 Frequency by Month of Wind Speeds Exceeding 5 m/s, 10 m/s, and 15 m/s (from ECMWF)	344
B.6-3 Wind Roses Showing Direction and Speed (Based on ECMWF Data for 1980–1993)	345

Contents

	Page
B.7-1 Map of the Beaufort Sea	351
B.8-1 Borders and Parts of the Chukchi Sea	356
B.8-2 Diagram of the Surface Currents of the Chukchi Sea.	358
B.9-1 Map of the Bering Sea	363
B.10-1 Map of Cook Inlet	369
B.11-1 Map of the Okhotsk Sea	373
B.11-2 Range of Freezing Degree Days for a Number of Stations around the Okhotsk Sea	374
B.12-1 Map of the Tatar Strait (Northern Sea of Japan) Region.	378
B.13-1 Map of the Bohai Sea	382
B.14-1 Map of the Northern Caspian Sea	386
B.14-2 Ice Boundaries for Winters of Different Severities, by Month (I to XII).	387
B.15-1 Map of the Baltic Sea Area.	391
B.15-2 Baltic Sea Ice Cover	393
B.16-1 Boundaries and Regions of the Barents Sea.	397
B.17-1 Boundaries and Parts of the Kara Sea	403
B.18-1 Boundaries and Parts of the Laptev Sea	410
B.19-1 Boundaries and Parts of the East Siberian Sea	417
B.20-1 Map of the Black Sea and the Sea of Azov	424
B.20-2 Parts of the Black Sea	426
B.20-3 The Boundaries of Ice Cover Propagation in Winters of Various Severity	427
B.21-1 Map of the Sea of Azov.	431
B.21-2 Frequency of Occurrence of Ice in Temperate Winter (February).	433

Tables

7-1 Determination of Exposure Level	20
7-2 Companion EL Environmental Actions	24
7-3 Combination Factors for Companion EL Environmental Processes	24
7-4 Exposure levels L1 and L2—ULS and ALS Action Factors and Action Combinations	25
A.6-1 Icing for Environmental Action Checks	130
A.7-1 Reliability Targets for Each Limit State Action Combination.	148
A.8-1 Common Physical Parameters used to Describe Interaction Scenarios	159
A.8-2 Subsection References for Various Interaction Scenarios	160
A.8-3 Ice Strength Coefficient, C_i , as a Function of the Brine Volume	168
A.8-4 Tensile Strength Values	205
A.8-5 Measured Values of Kinetic Friction Coefficient.	207
A.9-1 Summary of the Common Types of SSI Analyses, Along with the Corresponding Common Domain of Analysis and Soil Modeling	215
A.12-1 Minimum Concrete Temperature After Placing	200
A.13-1 Exposure Levels for Major Components of Floating Structures.	235
A.13-2 Overview of Stationkeeping Systems.	237
A.14-1 Summary of Reported Operational Experience with Pipelines in Ice-covered Regions	250
A.16-1 Underwater Spray Ice Strength	271
A.16-2 Overview of Ice Load Measurement Objectives and Requirements	283
A.16-3 Ice Processes and Variables that are Important to Model	287
A.16-4 Scale Relations	289
A.17-1 Downtime and Towing Effectiveness Based on Operational Experience	298
A.17-2 Summary of Potential Ice Detection and Tracking Systems	300
A.18-1 Example of Safety-critical Element Groups—Emergency Response	319
A.18-2 Safety-critical Element Groups—Lifesaving Appliances	320

Contents

	Page
A.18-3 Example of Performance Standard Template	321
A.18-4 Example of Evacuation Method Decision Hierarchy—OIM Evacuation Decision Matrix	323
B.2-1 General Information for Baffin Bay and Davis Strait	327
B.2-2 Baffin Bay and Davis Strait Meteorological Conditions	329
B.2-3 Baffin Bay and Davis Strait Oceanographic Conditions	329
B.2-4 Baffin Bay and Davis Strait Sea Ice Conditions	330
B.3-1 General Information for Labrador	330
B.3-2 Labrador Meteorological Conditions	332
B.3-3 Labrador Oceanographic Conditions	332
B.3-4 Labrador Sea Ice Conditions	333
B.4-1 General Information for Newfoundland	333
B.4-2 Newfoundland Meteorological Conditions	336
B.4-3 Newfoundland Oceanographic Conditions	336
B.4-4 Newfoundland Sea Ice Conditions	337
B.5-1 General Information for Canadian Arctic Archipelago	337
B.5-2 Canadian Arctic Archipelago Meteorological Conditions	339
B.5-3 Canadian Arctic Archipelago Oceanographic Conditions	341
B.5-4 Canadian Arctic Archipelago Sea Ice Conditions	341
B.6-1 General Information for Greenland	342
B.6-2 Greenland Meteorological Conditions	348
B.6-3 Greenland Oceanographic Conditions	349
B.6-4 Greenland Sea Ice Conditions	350
B.7-1 General Information for the Beaufort Sea	350
B.7-2 Beaufort Sea Meteorological Conditions	353
B.7-3 Beaufort Sea Oceanographic Conditions	354
B.7-4 Beaufort Sea Ice Conditions	355
B.8-1 General Information for the Chukchi Sea	356
B.8-2 Chukchi Sea Meteorological Conditions	359
B.8-3 Chukchi Sea Oceanographic Conditions	360
B.8-4 Chukchi Sea Sea Ice Conditions	361
B.9-1 General Information for the Bering Sea	362
B.9-2 Bering Sea Meteorological Conditions	365
B.9-3 Bering Sea Oceanographic Conditions	366
B.9-4 Bering Sea Sea Ice Conditions	367
B.10-1 General Information for Cook Inlet	368
B.10-2 Cook Inlet Meteorological Conditions	370
B.10-3 Cook Inlet Oceanographic Conditions	371
B.10-4 Cook Inlet Sea Ice Conditions	371
B.11-1 General Information for the Okhotsk Sea	372
B.11-2 Okhotsk Sea Meteorological Conditions	375
B.11-3 Okhotsk Sea Oceanographic Conditions	376
B.11-4 Okhotsk Sea Sea Ice Conditions	377
B.12-1 General Information for the Tatar Strait	377
B.12-2 Tatar Strait Meteorological Conditions	379
B.12-3 Tatar Strait Oceanographic Conditions	380
B.12-4 Tatar Strait Sea Ice Conditions	381
B.13-1 General Information for the Bohai Sea	381
B.13-2 Bohai Sea Meteorological Conditions	383
B.13-3 Bohai Sea Oceanographic Conditions	383

Contents

	Page
B.13-4 Bohai Sea Ice Conditions	384
B.14-1 General Information for the North Caspian Sea	384
B.14-2 North Caspian Meteorological Conditions	388
B.14-3 North Caspian Oceanographic Conditions	388
B.14-4 North Caspian Sea Ice Conditions	389
B.15-1 General Information for the Baltic Sea	389
B.15-2 Baltic Sea Meteorological Conditions	394
B.15-3 Baltic Sea Oceanographic Conditions	395
B.15-4 Baltic Sea Sea Ice Conditions	396
B.16-1 General Information for the Barents Sea	397
B.16-2 Barents Sea Meteorological Conditions	400
B.16-3 Barents Sea Oceanographic Conditions	401
B.16-4 Barents Sea Sea Ice Conditions	402
B.17-1 Kara Sea Meteorological Conditions	405
B.17-2 Kara Sea Oceanographic Conditions	407
B.17-3 Kara Sea Sea Ice Conditions	407
B.18-1 Laptev Sea Meteorological Conditions	413
B.18-2 Laptev Sea Oceanographic Conditions	414
B.18-3 Laptev Sea Sea Ice Conditions	415
B.19-1 East Siberian Sea Meteorological Conditions	420
B.19-2 East Siberian Sea Oceanographic Conditions	421
B.19-3 East Siberian Sea Sea Ice Conditions	422
B.20-1 Black Sea Meteorological Conditions	428
B.20-2 Black Sea Oceanographic Conditions	429
B.20-3 Black Sea Sea Ice Conditions	430
B.21-1 Sea of Azov Meteorological Conditions	434
B.21-2 Sea of Azov Oceanographic Conditions	435
B.21-3 Sea of Azov Sea Ice Conditions	435

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 nongovernmental, 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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 19906 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*.

ISO 19906 is one of a series of International Standards for offshore structures. The full series consists of the following International Standards.

- 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*¹
- ISO 19902, *Petroleum and natural gas industries—Fixed steel offshore structures*
- ISO 19903, *Petroleum and natural gas industries—Fixed 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*²
- ISO 19906, *Petroleum and natural gas industries—Arctic offshore structures*

¹ ISO 19901-3, *Topsides structure*, to be published.

² All parts are under preparation.

Introduction

A series of API standards address 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.

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

The series of standards applicable to the various types of offshore structure is 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 standards.

This standard was developed in response to the offshore industry's demand for a coherent and consistent definition of methodologies to design, analyze, and assess arctic and cold region offshore structures of the class described in Section 1.

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 ice loads 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 standard. Where uncertainties still exist, conservative approaches and methods have been recommended.

This standard also addresses issues such as topsides winterization, and escape, evacuation, and rescue that go beyond what is strictly necessary for the design, construction, transportation, installation, and decommissioning of the structure. These issues are essential for offshore operations in arctic and cold region conditions and they are not covered in other standards. When future editions of this and other standards are prepared, efforts will be made to avoid duplication of scope.

Annex A provides background to and guidance on the use of this standard and it is intended that it be read in conjunction with the main body of this standard. The section numbering in Annex A is the same as 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.

To meet certain needs of industry for linking software to specific elements in this standard, a special numbering system has been permitted for figures, tables, equations and bibliographic references.

Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions

1 Scope

This standard specifies requirements and provides recommendations and guidance for the design, construction, transportation, installation, and removal 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 standard is deemed to include both the arctic and other cold regions that are subject to similar sea ice, iceberg, and icing conditions. The objective of this standard is to ensure that offshore structures in arctic and cold regions provide an appropriate level of reliability with respect to personnel safety, environmental protection, and asset value to the owner, to the industry, and to society in general.

This standard does not contain requirements for the operation, maintenance, service-life inspection, or repair of arctic and cold region offshore structures, except where the design strategy imposes specific requirements (e.g. 17.2.2).

While this standard does not apply specifically to mobile offshore drilling units (see ISO 19905-1), the procedures relating to ice actions and ice management contained herein are applicable to the assessment of such units.

This standard 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.

2 Normative References

The following referenced documents are indispensable for the application 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.

API Recommended Practice 2EQ, *Seismic Design Procedures and Criteria for Offshore Structures*

API Recommended Practice 2FPS, *Planning, Designing, and Constructing Floating Production Systems*

API Recommended Practice 2GEO, *Geotechnical and Foundation Design Considerations*

API Recommended Practice 2MOP, *Marine Operations*

API Recommended Practice 2SK, *Design and Analysis of Stationkeeping Systems for Floating Structures*

ISO 19900¹, *Petroleum and natural gas industries—General requirements for offshore structures*

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

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

¹ International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

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

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

3 Terms and Definitions

For the purposes of this document, the terms and definitions given in ISO 19900, ISO 19901-1, API references, and the following apply.

3.1

abrasion

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

3.2

accidental situation

Exceptional condition of use or exposure for the structure.

NOTE Exceptional conditions include fire, explosion, impact, or local failure.

3.3

action

External load applied to the structure (direct action) or an imposed deformation or acceleration (indirect action).

NOTE The word “action” is equivalent to the word “load/imposed displacement/accelerations” in the API references used in “load case combinations” that are prescribed in working stress design (WSD).

3.4

action combination

Design values of the different actions considered simultaneously in the verification of a specific limit state.

3.5

action effect

Effect of actions on the structure or its components.

3.6

adfreeze

Freezing of ice to the surface of a structure.

3.7

alert

Prescribed reaction to specific ice conditions, which in time can become hazardous to the operation of a structure.

NOTE Several different levels associated with the time proximity of the hazard are normally recognized.

3.8

aspect ratio

Ratio of structure diameter or width to ice thickness.

3.9

broken ice

Loose ice consisting of small floes, broken up as a result of natural processes, or active or passive intervention.

3.10**characteristic value**

Value assigned to a basic variable associated with a prescribed probability of being exceeded by unfavorable values during some reference period.

NOTE For actions, the characteristic value is the main representative value. In some design situations, a variable can have two characteristic values, an upper and a lower value.

3.11**companion environmental action**

Environmental action applied simultaneously with the principal environmental action.

3.12**consequence category**

Classification system for identifying the environmental, economic and indirect personnel safety consequences of failure of a platform.

NOTE For offshore structures, three consequence categories are defined; see 7.1.3:

- C1: high consequences;
- C2: medium consequences;
- C3: low consequences.

3.13**consolidated layer**

Portion of an ice ridge keel, rubble pile, rubble field, or stamukha below the waterline formed by the ice consolidation process.

3.14**consolidation**

Process of freezing of pore water in voids within ice rubble, between floes, or between soil particles.

NOTE For soils, this involves drainage of pore fluid as a result of overburden pressures.

3.15**design action**

Action combination resulting from factored representative actions associated with an abnormal level (AL) or EL event.

3.16**design resistance**

Resistance calculated from factored characteristic material properties or from factored resistance based on unfactored characteristic material properties.

3.17**design service life**

Assumed period for which a structure or a structural component will be used for its intended purpose with anticipated maintenance but without substantial repair being necessary.

3.18**design value**

Value derived from the representative value for use in the design verification procedure.

3.19**disconnection**

Planned separation of the risers (and mooring, if applicable) from a floating structure.



3.20**ductility**

Ability of a material to deform and absorb energy beyond its elastic limit or ability of a component to sustain load beyond yield.

NOTE See also **system ductility** (3.79).

3.21**dynamic action**

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

3.22**dynamic positioning****DP**

Technique of automatically maintaining the position of a floating vessel within a specified tolerance by controlling onboard thrusters to counter the wind, wave, current, and ice actions.

3.23**emergency disconnection**

Planned separation of the risers (and mooring, if applicable) from a floating structure, without depressurization of the risers.

3.24**escape**

Act of personnel moving away from a hazardous event to a place on the installation where its effects are reduced or removed.

3.25**evacuation**

Planned precautionary and emergency method of moving personnel from the installation [muster station or temporary refuge (TR)] to a safe distance beyond the immediate or potential hazard zone.

3.26**exposure level**

Classification system used to define the requirements for a structure based on consideration of life-safety and of environmental and economic consequences of failure.

For offshore structures, three exposure-level categories are defined; see 7.1.4:

- L1: highest exposure level;
- L2: intermediate exposure level;
- L3: lowest exposure level.

3.27**first-year ice****FY**

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

3.28**floe**

Relatively flat piece of sea ice greater than 20 m across.

NOTE There are typically subcategories: small (20 m to 100 m across), medium (100 m to 500 m across), big (500 m to 2000 m across), vast (2 km to 10 km across), and giant (greater than 10 km across).

3.29**flowline**

Piping on the seafloor linking one or more subsea wells to the production system.

NOTE Functions may include production, injection, subsea systems control and export of produced fluids.

3.30**freeboard****3.30.1****freeboard**

Vertical distance from the water surface to the top of the ice.

3.30.2**freeboard**

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.

3.31**freeze-thaw**

Possible degrading effect on concrete of repeated temperature changes causing frost cycles at the surface.

3.32**glory hole**

Man-made areal excavation in the seabed used to protect a subsea installation or its components from ice damage.

3.33**ice alert**

Alert related to encroaching hazardous ice features or conditions, generally requiring specific changes to production operations.

3.34**ice concentration**

Proportion of the water surface covered by ice.

NOTE Ice concentration is usually expressed in tenths.

3.35**iceberg**

Glacial or shelf ice (greater than 5 m freeboard) that has broken (calved) away from its source.

NOTE Icebergs can be freely floating or grounded, and they are sometimes defined as tabular, dome, pinnacle, wedge, or block shaped.

3.36**ice detection**

Discrimination of ice features or associated conditions from the surrounding environment.

3.37**ice gouge**

ice scour

Incision made by an ice feature in the seabed, having the form of either an areal incision (i.e. pit) or a linear incision (i.e. furrow).

3.38**ice island**

Large tabular shaped ice feature that has calved from an ice shelf or glacier.

3.39**ice management**

Active processes used to alter the ice environment with the intent of reducing the frequency, severity, or uncertainty of ice actions.

3.40**ice management plan**

Detailed plan outlining the objectives, active procedures involved, and individual responsibilities for the implementation of the ice management system.

3.41**ice management system**

Ice management and associated ice detection and threat evaluation tools used for its implementation.

3.42**ice ridge**

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

NOTE A pressure ice ridge is formed when ice sheets are pushed together and a shear ice ridge is formed when ice sheets slide along a common boundary.

3.43**ice scenario**

Combination of circumstances involving the presence of ice, resulting in actions or action combinations on a structure.

3.44**infill**

Material deposited in an ice gouge, excavation, or trench through natural processes.

3.45**landfast ice**

fast ice

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

3.46**level ice**

sheet ice

Region of ice with relatively uniform thickness.

3.47**life-safety category**

Classification system for identifying the applicable level of life-safety for a platform.

NOTE For offshore structures, three life-safety categories are defined; see 7.1.2:

- S1: manned nonevacuated;
- S2: manned evacuated;
- S3: unmanned.

3.48**local failure**

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

3.49**lowest anticipated service temperature****LAST**

Minimum hourly average extreme-level (EL) air temperature.

NOTE The EL temperature is described in 7.2.2.6.

3.50**mat**

Man-made weighted sheet used for the stabilization of soils or subsea components.

3.51**material factor**

Partial safety factor applied to the characteristic value of a material property.

3.52**multi-year ice****MY**

Sea ice that has survived at least one summer melt season.

NOTE When the term “multi-year ice” is used in conjunction with the term “second-year ice,” the former should be interpreted as ice that has survived at least two summer melt seasons.

3.53**offshore installation manager****OIM**

Person responsible for the installation and all operations on and around a structure.

3.54**owner**

Representative of the company or companies that own, hold a license for or hold a lease for the development.

3.55**pack ice**

Sea ice consisting of discrete floes that is not landfast.

3.56**pack ice driving actions**

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

3.57**permafrost**

Ground (soil or rock) remaining at or below 0 °C for at least two consecutive years.

3.58**place of safety**

Area outside the hazard zone in which personnel safety is no longer at risk due to the installation hazard.

3.59**polynya**

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

3.60**rafted ice**

Ice feature formed from the superposition of two or more ice sheet layers.

3.61**recognized classification society****RCS**

Member of the International Association of Classification Societies (IACS), with recognized and relevant competence and experience, and with established rules and procedures for classification/certification of arctic and cold region structures or ice class vessels used in petroleum and natural gas activities.

3.62**recovery**

Transfer of evacuees to a rescue vessel, helicopter, etc.

3.63**reliability target**

Specified average annual probability associated with failure.

3.64**representative value**

Value assigned to a basic variable for verification of a limit state.

3.65**rescue**

Process by which persons entering the sea or reaching the ice surface, directly or in an evacuation craft, are subsequently retrieved to a place where medical assistance is typically available.

3.66**ridge keel**

Portion of an ice ridge that extends below the waterline.

NOTE A ridge keel can consist of a consolidated layer and an unconsolidated layer.

3.67**ridge sail**

Portion of an ice ridge that extends above the waterline.

3.68**rubble field**

Region of broken ice blocks floating together as a continuous body.

3.69**rubble pile**

Ice feature of areal, rather than linear, extent, composed of blocks of broken ice.

NOTE See also **stamukha** (3.76), the term for a grounded rubble pile.

3.70**safety-critical element****SCE**

Item of equipment, procedure, or structure whose failure can lead to a major accident or whose purpose is to prevent or limit the consequences of a major accident.

3.71**scour**

Soil erosion caused by wave, ice, or current action.

3.72**seabed**

Material below the elevation of the seafloor or ocean floor.

3.73**seafloor**

mudline

Interface between the sea and the seabed and referring to the upper surface of all unconsolidated material.

3.74**seasonal operation**

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

3.75**second-year ice**

Sea ice that has survived one summer's melt season.

NOTE "Second-year ice" is sometimes referred to as "multi-year ice"; see 3.51.

3.76**shelf ice**

Sea ice formed adjacent to a glacier terminating in the ocean.

3.77**stamukha**

Grounded ice feature composed of broken ice pieces or rubble.

3.78**station bill**

Posted list showing the duties and duty stations of designated personnel on the installation with emergency response organization roles and responsibilities.

3.79**strudel scour**

Incision in the seabed caused by a natural water jet draining through holes in the ice.

NOTE Strudel scours are usually found in river deltas when freshwater flows on the surface of sea ice.

3.80**system ductility**

Ability of a structure to deform and dissipate energy, taking into account material ductility, the ability of structural components to maintain inelastic load-carrying capacity and structural redundancy.

3.81**temporary refuge****TR**

Place provided on the installation where personnel can take refuge for a specified period while investigations, emergency response, and evacuation preparations are undertaken.

3.82**unconsolidated layer**

Part of an ice ridge keel or ice rubble found below the consolidated layer that consists of unbonded or very weakly bonded ice blocks.

NOTE The unconsolidated layer is also called the unconsolidated rubble layer.

3.83**upheaval buckling**

Buckling of a conductor or buried pipe due to soil deformations.

NOTE Upheaval buckling is generally induced by changes to the permafrost.

4 Symbols and Abbreviated Terms

4.1 Symbols

For the purposes of this document, the following symbols apply.

A	accidental action
E	environmental action
F	repetitive action
f_c	concrete compressive strength
f_y	characteristic yield strength
G	permanent action
G_1	dead 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

For the purposes of this document, the following abbreviated terms apply.

AL	abnormal level
ALARP	as low as reasonably practicable
ALE	abnormal-level earthquake
ALIE	abnormal-level ice event
ALS	abnormal (accidental) limit state
BWL	ballast waterline
CPT	cone penetration 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
FSO	floating storage and offloading
FY	first-year, with reference to ice
GBS	gravity base structure

HAZID	hazard identification
HPZ	high pressure zone
HSE	health, safety, and environment
HVAC	heating, ventilating, and air conditioning
IMO	International Maritime Organization
LAST	lowest anticipated service temperature
MIZ	marginal ice zone
MY	multi-year, with reference to ice
NA	not applicable
ND	no data
NDT	nondestructive testing
OIM	offshore installation manager
POB	personnel on board
PPE	personal protective equipment
QC	quality control
QRA	quantitative risk analysis
RCS	recognized classification society
SAL	single anchor loading
SALM	single anchor leg mooring
SAR	search and rescue
SCE	safety-critical element
SLIE	serviceability-level ice event
SLS	serviceability limit state
SPM	single point mooring
SSI	soil-structure interaction
STP	submerged turret production
STL	submerged turret loading
TLP	tension leg platform
TR	temporary refuge
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, and decommissioned in accordance with ISO 19900 supplemented by this standard.

Physical environmental parameters shall be determined in accordance with ISO 19901-1 and the further requirements of this standard. Seismic actions shall be determined in accordance with API 2EQ, foundation behavior shall be determined in accordance with API 2GEO, and actions and resistances for steel, concrete, and floating structures shall be determined in accordance with ISO 19902, ISO 19903, and 19904-1, respectively, and according to the further requirements of this standard. Requirements for marine operations, stationkeeping, and topsides in arctic and cold regions are provided to complement the requirements of API

2GEO, API 2SK, and 19901-3, respectively. This standard provides requirements, recommendations, and guidance on ice related parameters, as well as actions for the above structure types and for particular structures such as man-made islands. The above documents should be used jointly to develop appropriate physical environmental parameters, actions, resistances, and designs.

Section 5 provides general requirements and conditions applicable to all types of offshore structures.

5.2 Design Methods

For designs performed in accordance with the design process and equations provided in this standard, levels of safety and performance are established in Section 7.

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

Where possible, data from full-scale measurements of ice actions shall be used to verify new designs. Appropriately scaled physical models and mathematical models may also be used to determine the response of structures to ice actions, in combination with current, wind, and wave actions. Where possible, such models shall be calibrated using data from full-scale measurements.

5.3 Site-specific Considerations

5.3.1 General

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

The structure and all its subsystems shall be operated in an environmentally sound manner. Conditions that can influence the functional and operational requirements shall be identified. Appropriate procedures for matters concerning health, safety, and environment (HSE) shall be established and maintained.

The evaluation of possible hazard scenarios shall include potential occurrences of abnormal-level ice events (ALIE), the local and global consequences of impacts from ice features, and arctic-specific geohazards.

5.3.2 Long-term 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.

5.3.3 Structural Configuration

The configuration of the structure should consider the following:

- protection of risers and conductors;
- concept for oil storage and export;
- wet or dry storage system;
- layout of facilities and separation distances from hazards;
- potential for future expansion under phased development;
- potential for platform removal;

- environmental constraints;
- capability of local construction facilities and materials; and
- available construction season for offshore operations.

Different structural shapes, orientations, and profiles for the structure and the topsides should be considered for resisting sea ice or iceberg actions.

In defining the orientation of the structure at the site, consideration should be given to the ice conditions, prevailing ice drift directions, and ice rubble buildup. The topsides should be arranged with respect to the functional and operational requirements—such as resupply, offloading, flaring, and escape, evacuation, and rescue (EER)—and with respect to wind and ice encroachment.

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

- a) ice management to prevent ice rubble accumulation;
- b) duplication of facilities on opposite sides of the platform; and
- c) large crane booms to reach over accumulated rubble.

5.3.4 Winterization

Winterization measures should be considered to ensure the safe operation of all systems and equipment, thereby ensuring the safety of personnel. Such 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 (PPE). Selected options should not result in adverse environmental consequences.

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 extreme 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 minimal 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 API 2MOP.

5.5 Design Considerations

The combinations of actions and partial factors for determining action effects applicable to the different limit states shall be in accordance with the provisions of Section 7.

5.6 Environmental Protection

Arctic and cold region environments can be more sensitive and vulnerable to pollution than other environments. A structure intended for such environments shall be designed to minimize the potential for polluting the environment as far as is reasonably practicable. 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.

Fluids and materials that, if released, can pollute the environment shall be contained in tanks having double barriers. A careful strategy should be followed as far as practically possible 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.

5.7 Serviceability Requirements Including Vibrations and Crew Comfort

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 vibrations do not cause crew discomfort during normal operations.

6 Physical Environmental Conditions

6.1 General

6.1.1 Physical Environment Requirements

The owner shall be responsible for selecting appropriate physical environmental design parameters and operating conditions. The owner shall take regulatory requirements into account, where they exist. These requirements can include a minimum duration of site-specific data (according to country regulations), the type of data, and a definition of extreme design parameters.

General guidelines on metocean information are given in ISO 19900 and specific requirements in ISO 19901-1.

A realistic assessment of the physical environmental parameters affecting the proposed offshore structure shall be made. All relevant environmental data, as well as applicable physical, statistical, mathematical, and numerical models, shall be used to develop the appropriate information.

The following information shall be determined:

- a) normal environmental conditions that are required to carry out checks for serviceability limit states (SLS), 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 define design situations and to perform design checks for the FLS, 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 that are required to develop extreme and abnormal environmental actions and/or action effects, which are used to define design situations and to perform design checks for ultimate limit states (ULS) and abnormal limit states (ALS);
- d) regional environmental oscillations, cycles, and long-term trends associated with the parameters in Items a) through c).

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

To obtain reliable and appropriate physical environmental parameters, experts in the field of metocean and ice technology shall be involved with the analysis of data and its interpretation for developing appropriate design situations and design criteria.

6.1.2 Physical Environmental Data Monitoring Programs

Appropriate physical environmental parameters shall be monitored and forecast during the design service life of the structure to ensure safe operational procedures.

6.1.3 Relationship with Remainder of this Standard

Physical environmental parameters described in 6.2 through 6.6 shall be obtained for use in the calculation of global and local action values, as described in the appropriate subsections of this standard.

Data shall be analyzed in a format appropriate for use in the determination of relevant environmental actions (e.g. 8.2 for ice actions).

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 should be incorporated in operational planning.

6.3 Meteorology

6.3.1 Air Temperature

Estimates shall be made of the probability distributions of air temperatures that a structure is likely to encounter during its design service life. The lowest anticipated service temperature (LAST) shall be defined in accordance with 3.48.

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 behavior and human capability shall be considered as part of the design and operation of the structure.

The air temperature affects ice properties and ice conditions. Air temperature changes, combined with wind and snow depth, control thermal expansion and associated actions in landfast ice. Low air temperatures, combined with winds, waves, and sea spray, can also lead to marine icing events.

6.3.2 Wind

Wind related parameters shall be determined in accordance with ISO 19901-1.

6.3.3 Wind Chill

The combined effect of air temperature and wind shall be used to calculate wind chill. The effect of wind chill upon human capability, machinery heat loss, and topsides winterization shall be considered.

The importance of PPE, heated shelters, appropriate work procedures, and other actions should be considered when workers are exposed to outdoor conditions.

6.3.4 Precipitation and Snow

Estimates shall be made of the probability distributions of precipitation and snowfall that a structure is likely to encounter during its design service life. The extent to which snow can accumulate, and its possible effect on the structure and machinery, shall be considered. The effect of snow cover should be considered when evaluating ice properties, e.g. friction and ice strength, in determining ice actions and assessing vessel operations.

As snow accumulation can affect platform operations, considerations for snow removal should be made at the design stage.

6.3.5 Ice Accretion

The extent of ice accretion from sea spray, freezing rain or drizzle, freezing fog, or cloud droplets shall be considered in the design and operability of the structure. Ice accretion can increase the diameter of structural components and can lead to a substantial increase of actions caused by wind and self-weight, particularly for long slender structures such as flare towers. Ice accretion also affects operations and personnel safety.

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

Polar lows can affect the subarctic and arctic. Due to their small size and the lack of an extensive ground observation system in these regions, polar lows are difficult to observe and forecast. The waves and winds associated with these features are generally not in the extreme range, but can affect operations. When activities take place, the use of satellite remote sensing to seek out these features should be considered as part of the normal meteorological forecast service.

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 are due to astronomical tide, storm surges caused by wind and atmospheric pressure, long-term variations, seafloor subsidence, and tsunamis. 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 ‰ (parts per thousand), water freezes at -1.9°C . This shall be considered as the coldest water temperature that can be found in regions affected by sea ice.

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 design service life.

Data can be obtained from direct observations at a location, interpretation of satellite imagery, or historical information at the geographic region of the installation. 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 modeling may be used to extend these data sets, with due account for uncertainties. Long-term trends shall be taken into account. Interrelationships between the various parameters listed in 6.5.2, 6.5.3, 6.5.4, and 6.5.5 shall 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. Statistics, such as probability distributions and parameters thereof, shall reflect the occurrence and concentration of all relevant ice types.

Interannual 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 and historical data from nearby sites. Statistics, such as probability distributions and parameters thereof, and appropriate ice feature frequency, dimensions, as well as ridge and stamukha consolidated layer thickness, sail height, and keel depth 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 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.

Interannual and seasonal variations in ice morphology shall be considered.

6.5.4 Ice Movement

Wind, waves, current, and thermal expansion affect ice movement and pack ice pressure. Statistics, such as probability distributions, means and extremes, of movement rates for pack ice, ice floes and discrete features such as icebergs and ice islands, shall be determined on the basis of field data. Ice movement rates affect the number of ice features encountered, ice actions, and operations. Ice pressure can affect vessel traffic, ice management, and evacuation procedures.

If field data do not exist for these parameters, numerical modeling 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 modeling procedures.

Interannual and seasonal variations in ice presence, polynyas, and physical parameters shall be considered.

6.5.5 Ice Properties

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

6.5.6 Ice Monitoring

Ice conditions shall be considered as part of the physical environmental data monitoring program. Real-time information on ice conditions should be used, for example, to operate ice management systems, and EER procedures for the installation. Coupled with a management plan for shutdown and possible removal during the operational phase of the structure, ice monitoring can help to reduce the ice criteria used for structural design of both floating and bottom-founded mobile structures.

6.6 Seabed Considerations

6.6.1 Earthquake

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 API 2EQ. Acceleration levels taken from the maps provided in API 2EQ 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 analyses shall be carried out (see 9.10).

6.6.2 Permafrost

An investigation into the extent of permafrost from the shore and the presence of permafrost at platform locations shall be performed. 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 (refer to Section 9). The potential effects of thaw consolidation of ice-rich permafrost as a result of producing warm hydrocarbons should be considered in the design of all structure foundations.

6.6.3 Ice Gouge

Seabed gouging occurs due to the interaction of ridges, icebergs, and stamukhi with the seabed. Data on ice-induced gouging shall be obtained to determine the frequency of gouge occurrence and its depth, width, length, and direction. Gouge statistics shall be used in regions of seabed utilization for the design and burial of flowlines and umbilicals, subsea facilities, and platform tie-ins. See 9.2 for survey requirements and 14.2.2 for effects on subsea structures.

6.6.4 Strudel Scours

Strudel scouring shall be investigated for structures in regions near the mouths of rivers. See 9.2 for survey requirements, and 14.2.3 and 14.3.5 for effects on subsea structures.

7 Reliability and Limit States Design

7.1 Design Philosophy

7.1.1 Governing Principles

The structure and its components shall be designed so that they function with adequate reliability for all physical environmental, accidental, and operational actions and conditions to which the structure can be subjected during all phases of the design service life, including construction, transportation, installation, and removal. The required reliability depends on the exposure level, which is determined by the life-safety category and the environmental and economic consequence category of the 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 factored action combinations shall not exceed factored resistances. Resistances and their relevant partial factors shall be determined in accordance with this standard and its referenced documents. Actions shall include, but not be limited to, ice, seismic, oceanographic, meteorological, permanent, and variable actions. Partial factors for action combinations associated with ULS and ALS shall be in accordance with 7.2.4.

7.1.2 Life-safety Categories

The life-safety category of a structure and its components is a ranking of its exposure in relation to the safety of personnel on the platform and the likelihood of successful evacuation before a design environmental event occurs during its design service life, and it shall conform to the life-safety categories defined in ISO 19902, ISO 19903, and API 2FPS as relevant for the type of structure. Since the life-safety category of a structure can change during its design service life, the structure shall be designed to meet the applicable life-safety category during each phase of its design service life or shall meet the most stringent category occurring during the design service life.

For offshore structures, three life-safety categories are defined:

- S1: manned nonevacuated;
- S2: manned evacuated;
- S3: unmanned.

7.1.3 Consequence Categories

The consequence category of a structure and its components is a ranking of its hazard potential with respect to the safety of personnel brought in to react to any incident, the potential risk of damage to the environment,

and the potential risk of economic losses, and it shall conform to the consequence categories defined in ISO 19902, ISO 19903, and API 2FPS.

For offshore structures, three consequence categories are defined:

- C1: high consequences;
- C2: medium consequences;
- C3: low consequences.

7.1.4 Exposure Levels

Exposure level depends on the life-safety and consequence categories in accordance with Table 7-1. All manned, nonevacuated structures (S1) and high consequence structures (C1) are designated L1; unmanned (S3), low consequence (C3) structures are designated L3; and other structures are designated L2.

Table 7-1—Determination of Exposure Level

Life-safety Category		Consequence Category		
		C1 High Consequence	C2 Medium Consequence	C3 Low Consequence
S1	Manned nonevacuated	L1	L1	L1
S2	Manned evacuated	L1	L2	L2
S3	Unmanned	L1	L2	L3

The exposure level applicable to a structure or a component shall be determined by the owner prior to the design of a new structure or the assessment of an existing structure and be agreed by the regulator where applicable. Where more than one exposure level can apply to a structure or component, the most stringent exposure level matching the specification is applicable. Some components or substructures can be categorized differently from each other and from the overall structure, in which case their exposure level can be different.

Categorization may be revised over the design service life of the structure as a result of changes in factors affecting life-safety or consequence category.

7.1.5 Limit States

For the limit states design method, the reliability relevant to the exposure level is achieved with respect to ULS and ALS. These limit states are critical because their violation can directly result in loss of human life, environmental damage, or asset loss.

FLS shall be satisfied.

SLS are only assigned quantitative reliability targets under specific circumstances in this standard. Such limit states shall be satisfied as appropriate.

7.1.6 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 state design approach as set out in 7.2.

7.2 Limit States Design Method

7.2.1 Limit States

7.2.1.1 Categories of Limit States

Limit states are divided into the following four categories:

- a) ULS that generally correspond to resistance to extreme applied actions;
- b) SLS that correspond to criteria governing normal functional use;
- c) FLS that correspond to the accumulated effect of repetitive actions;
- d) ALS that correspond to accidental events and abnormal environmental events.

The structure shall be designed for ULS for strength and stiffness, for ALS so it has adequate reserve capacity and energy dissipation capability, for FLS so it has adequate endurance under dynamic action effects, and for SLS so it performs adequately under normal use.

7.2.1.2 ULS

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. The ULS design condition for ice shall be the extreme-level ice event (ELIE). Both local and global actions shall be considered.

7.2.1.3 SLS

Exceedance of SLS results in the loss of capability of a structure to perform adequately under normal use. The specification of actions for SLS is generally the owner's responsibility, except for considerations that can lead to long-term structural degradation, such as corrosion of reinforcement in concrete.

7.2.1.4 FLS

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.

7.2.1.5 ALS

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. Some structural damage can be allowed for ALS. The ALS design condition for ice shall be the ALIE. Both local and global actions shall be considered.

7.2.2 Actions

7.2.2.1 General

Permanent actions (G), variable actions (Q), environmental actions (E), repetitive actions (F) 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 API 2FPS.

For structures in arctic and cold regions, the design shall be based on both EL and abnormal-level (AL) events, which include ice actions arising from ELIE and ALIE.

Representative values shall be assigned to each action. The main representative value is the characteristic value, which is a value associated with a prescribed probability of being exceeded by unfavorable 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 Events (SLIE)

For SLS, the structure should satisfy the requirements of this standard when structural members are subjected to localized ice damage. Examples include: concrete cracking and shrinkage, for which action factors are provided in ISO 19903; loss of concrete cover due to ice abrasion, removal of paint, and removal of corroded steel from ice abrasion; and localized damage as a consequence of vibrations induced by ice and other physical environmental factors. The structure shall also satisfy serviceability limits for vibrations and deflections.

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

7.2.2.3 ELIE

For ULS, the design procedures shall be based primarily on linear elastic methods of structural analysis. Some localized inelastic behavior is acceptable, for example, as permitted in Section 11 for fixed steel structures.

The representative value for actions arising from ELIE shall be determined based on an annual probability of exceedance not greater than 10^{-2} . The ELIE is not applicable for discrete events with an annual probability of occurrence of less than 10^{-2} .

7.2.2.4 Abnormal-level Ice Events

For ALS, nonlinear methods of analysis may be used. Structural components are allowed to behave plastically, and foundation piles are allowed to reach axial capacity or develop plastic behavior. The design is based on a combination of static reserve strength, ductility, and energy dissipation to resist the ALIE conditions.

7.2.2.5 Dynamic Ice Actions

If relevant, dynamic ice actions and ice-induced vibration shall be characterized with respect to the FLS and with respect to other effects on structures and foundations including potential for soil liquefaction.

7.2.2.6 Other Environmental Actions

Characteristic values for all other environmental actions shall be determined at the EL, with an annual probability of exceedance not greater than 10^{-2} , and at the AL, with 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 AL events for L3 structures. For seismic actions, the extreme-level earthquake (ELE) and abnormal-level earthquake (ALE) event probabilities shall be as specified in API 2EQ.

It is not necessary to consider actions from environmental events other than ice if the action arising has an annual probability of exceedance less than 10^{-4} .

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

Accidental situations shall be addressed in accordance with ISO 19902, ISO 19903, and API 2FPS depending on the structure type. For man-made islands, the provisions of ISO 19902 shall be applied.

7.2.3 Principal and Companion Environmental Actions

Action combinations for each environmental action shall be derived by considering each EL and AL representative value of the action, in turn, as the principal action. These values shall be accompanied by companion environmental actions.

Potential combinations of principal and companion environmental actions are given in Table 7-2.

The effect of water level changes shall be considered in the specification of companion actions. Storm surges 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 where the principal action depends on tidal currents.

Where data are available, the joint probability distribution of the principal and relevant companion actions should be used to determine the magnitude of combined EL or AL environmental action. In the absence of specific consideration of joint probabilities, the combination factors provided for companion EL actions in Table 7-3 shall be used. In this case, the representative EL value of each relevant companion action shall be multiplied by the relevant factor from Table 7-3 and added to the value of the EL or AL principal action. The values specified in Table 7-3 are conservative to account for a wide variety of possibilities. Consequently, site-specific data should be used and joint probabilities calculated whenever possible.

The principal and companion EL actions for ice are ELIE. The principal AL action for ice is the ALIE.

7.2.4 Combinations of Actions and Partial Action Factors

The action combinations specified in Table 7-4 shall be used in design. For each action combination, the representative value of an action or combined environmental action shall be multiplied by a partial action factor not less than that specified in Table 7-4, except that, alternatively, action factors for permanent and variable actions may be taken from ISO 19902, ISO 19903, or API 2FPS for the respective structure types. These 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.

Action factors and action combinations for SLS and FLS shall be in accordance with ISO 19902, ISO 19903, or API 2FPS as relevant to the structure type.

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

The partial action factors for environmental actions other than earthquakes specified in Table 7-4 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 within the scope of this standard of exposure levels L1 and L2, the reliability targets given in Table A.7-1 are deemed to be achieved.

As an alternative to Table 7-4, the partial action factors may be derived from a calibration analysis using a full probabilistic description of actions if this analysis demonstrates that the reliability targets of A.7.2.4 are achieved.

Table 7-2—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 isolated ice features	Wind, wind-driven current, tidal and background current	Waves ^b , swell ^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 It can be necessary to assess the swell-driven motion of large icebergs.

Table 7-3—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

7.2.5 ULS and ALS Design

For the ULS, the characteristic resistances shall be divided by resistance factors to obtain the design resistances. Alternatively, the characteristic material properties shall be divided by material factors to obtain the design material properties. The safety for each ULS shall be verified by ensuring that the effect of factored actions does not exceed the factored resistance.

For the ALS, the resistances shall be derived such that failure or collapse does not occur, and therefore structure and foundation resistance or safety factors may be reduced from their ULS values, or set to unity, as permitted by this standard and its referenced documents. However, components may be allowed to behave inelastically (i.e. design resistance may be exceeded) if there is sufficient ductility and if the overall structural design is adequately robust and provides alternative load-paths to distribute and resist the action effects and dissipate the energy.

Table 7-4—Exposure levels L1 and L2—ULS and ALS Action Factors and Action Combinations

Action Combination		Limit State Action Factors						Accidental Action A
		Permanent Action G		Variable Action Q		Environmental Action E		
		Dead G_1	Deformation G_2	Long Duration Q_1	Short Duration Q_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	—	—
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, and for variable Q_1 actions when there is a reversal of variable action effects.								
^c The representative value of the environmental action to which the action factor applies shall be calculated as described in 7.2.3.								
^d The limit state partial action factor for the extreme-level seismic action (ELE) shall be as defined in ISO 19902 for steel structures and shall be as defined in ISO 19903 for concrete structures. The partial action factor for the ELE shall be 1.0 for all other structures.								
^e For L2 exposure level, all 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 API 2FPS.								

8 Actions and Action Effects

8.1 General

The actions and action effects necessary to consider for design depend on the physical environment into which the structure will be placed, as well as the reliability expected of the structure. Guidance on actions and action effects is found in ISO 19900, ISO 19901-1, API 2EQ, ISO 19902, ISO 19903, and API 2FPS.

Wave actions, wind actions, current actions, ice actions, and seismicity are considered in ISO 19901-1, API 2EQ, ISO 19902, ISO 19903, and API 2FPS. Provisions for the treatment of ice actions and their combination with other types of actions are given in 7.2.4 with the further requirements of Section 8.

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

The actions used for design shall consider all phases of the design service life, including construction, transportation, installation and removal. Allowance for possible weight increase and shift in the center of gravity 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.

Structures or components subjected to ice interaction events with an annual probability exceeding the value specified in 7.2.2.4 appropriate to the exposure level shall be designed for ice actions. 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 realistic interaction scenarios with potentially adverse consequences should be considered in this respect. Reference should also be made to 8.3.1.4 for wave-induced ice motion.

8.2 Ice Actions

8.2.1 General Principles for Calculating Ice Actions

Direct ice actions and actions arising from the interaction between the ice and the structure shall be considered for both global and local scales. 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, liquefaction, and personnel discomfort; and
- c) spatial actions such as rubbing, pile-up, ride-up, and similar ice behavior that can hinder operations.

The magnitude of global ice actions and their point of action shall be determined in accordance with 8.2.4 so that the required 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 design ice actions on offshore structures, with due account of their applicability, and for 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, and strength parameters. 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 also be used to complement the full-scale data, with due account for uncertainties in their application.

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

8.2.2 Representative Values of Ice Actions

The design shall be carried out for ELIE and ALIE, as defined in 7.2.2.3 and 7.2.2.4.

Representative values for ice actions shall be calculated using probabilistic methods or deterministic methods for ELIE and ALIE.

8.2.3 Ice Action Scenarios

Design ice actions 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 ice management, maneuvering of the structure, and disconnection, with reference to the provisions of 8.2.7.

The ELIE and ALIE shall be determined for each relevant ice loading scenario. When several ice and operational scenarios are relevant for a particular structure, those resulting in the largest ice actions for each limit state shall be considered in the design.

Where applicable, 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) MY ice features (level ice, floes, ridges, rubble, or hummock fields);
- c) icebergs; and
- d) ice islands (ice shelf fragments).

The basis for determining the scenarios is given in Annex B, which outlines the various ice regimes present in offshore waters. The relative importance of potential scenarios shall be determined based on the structural configuration.

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, 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 MY), where inertial action effects within the structure can be neglected;
- b) dynamic actions due to level ice (FY, rafted, or MY), 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 MY 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 mechanisms shall be considered.

- Limit stress, which is the mechanism 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 include direct ice failure against the structure, ice failure within rubble lodged against the structure, floe buckling, or floe splitting.
- Limit energy, which is the mechanism that occurs when the interaction is limited by the kinetic energy of the ice feature and is generally characterized by the absence of surrounding ice. Such actions are likely to arise due to impacts of icebergs, refloated stamukhi, MY floes, or ice islands.
- Limit force, which is the mechanism 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 failure mechanisms. Where relevant for the scenario, ice conditions, and limiting mechanisms, 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;
- 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 buildup, and implications for 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;
- dynamic and hydrodynamic effects;
- degree of contact between the ice and the structure;
- friction between the ice and the structure;
- thermal effects in the ice;
- environmental actions of wind, current, and pack ice pressure available to drive the ice and their persistence;
- surface morphology and the presence of snow on the ice; and
- influence of shoals and other barriers.

8.2.5 Local Ice Actions

Local ice actions shall be based on relevant full-scale measurements or established theoretical methods. Due account shall be taken of geographical differences and water level changes in their specification.

Local ice actions shall be considered for all parts of the structure contributing to its overall integrity and stability or that, if damaged, can lead to progressive failure as required in 7.2.2.3 and 7.2.2.4. For steel structures, local actions shall apply to the design of sheet piling, plates, stiffeners, frames, and bulkheads. For concrete structures, local actions shall be considered for wall thickness, steel reinforcement, and abrasion (see Section 12). Regardless of structural material, local actions shall be applied to corners, structural discontinuities, and appendages where these contribute to overall structural integrity.

Design contact areas shall be considered based on the local structural configuration, including frame spacing, plate thickness, and appendage dimensions. The size and placement of the local contact areas shall be selected to ensure that the most critical cases are addressed.

Local ice actions shall be considered in the context of background actions on adjacent panels or areas of the structure.

8.2.6 Dynamic Ice Actions

The time-varying nature of ice actions and the corresponding ice-induced vibrations shall be considered in the design. The potential for dynamic amplification of the action effects due to lock-in of ice failure and natural frequencies shall be assessed. Particular attention shall be given to dynamic actions on narrow structures, flexible structures, and structures with vertical faces exposed to ice action.

Structural fatigue and foundation failure as a consequence of dynamic ice actions shall be considered.

8.2.7 Operational Procedures to Reduce Ice Actions

Operational procedures may be used to mitigate ice actions on fixed, floating, and subsea structures provided that it can be shown that, in combination with structural resistance, the intended level of reliability is achieved. Operational procedures include ice management, disconnection and removal, clearing of snow and ice accumulations, rubble and spray ice barriers, and seasonal operation. Ice management can be used to alter the ice regime, through decreases in floe size and the destruction or removal of potentially hazardous ice features, and through local reduction in ice coverage.

Ice action calculations for managed ice shall be performed when appropriate.

Reduction in design actions for ELIE and ALIE shall be demonstrated through changes to the magnitude and frequency of ice actions for all applicable scenarios. The effectiveness of operational procedures shall be founded on documented experience, where applicable, and the approach shall reflect the uncertainty inherent in the input data and modeling techniques.

8.2.8 Physical and Mechanical Properties of Ice

Appropriate physical and mechanical properties of ice shall be used in the calculation of ice actions. The following provisions apply.

- Ice properties shall be appropriate to the geographical location and season under consideration.
- Appropriate full-scale test data shall be used, when available, with due account of their applicability.
- Ice property tests should follow accepted practice (see A.8.2.8).
- When reliable methods exist to predict the mechanical properties from physical properties, these may be used.
- Small-scale field and laboratory test data should be used with caution.

The following parameters may be used in adjusting and interpreting full-scale ice load data for the calculation of ice actions:

- a) compressive and shear strength;
- b) flexural strength;
- c) tensile strength;
- d) fracture toughness;
- e) friction;
- f) adfreeze strength;
- g) internal cohesion and friction of fragmented ice;
- h) elastic modulus; and
- i) density.

8.3 Metocean Related Actions

8.3.1 Metocean Actions on Structures

8.3.1.1 General

Metocean actions on structures are discussed in ISO 19901-1. Additional requirements are provided in 8.3 for structures located in arctic and cold regions. These requirements fall in three categories:

- a) effects of ice accumulation on the structure, its members and decks above the waterline;
- b) particular forms of structures employed in such environments;
- c) wave-induced local ice loading.

8.3.1.2 Ice Accumulation on the Structure

8.3.1.2.1 General

The expected effects of icing shall be accounted for in the ELIE and ALIE analyses of the structure. Icing of structures or structural members can result from fog, freezing rain, green water trapped on decks, wind- and wave-driven seawater spray, or tidal variation. Icing modifies the aerodynamic and hydrodynamic properties, static stability, and dynamic responses of the structure. Icing can also modify the buoyancy and stability of floating structures.

Icing can be measured in terms of the thickness, volume or mass of ice adhering to the structure. Such estimates may be obtained from observations of icing on similar existing structures in the same area or from available theoretical models. When theoretical models are used, they should be suitably calibrated against observations.

8.3.1.2.2 Wave and Current Actions

The effect of icing on wave and current actions shall be determined. Icing can significantly raise the levels of wave and current actions on a structure due to changes in projected area, volume, and surface roughness.

Accumulation of ice on a structure can cause large increases of projected area and volume around and above the mean waterline. It can also make circular cylinders effectively rough. Where these effects are present in the design situation, they should be accounted for in the areas, volumes and drag coefficients used in the calculation of environmental actions. Any of these effects can cause large action increases on a member above that in the absence of ice. Advice on the selection of drag coefficients for the Morison equation is given in ISO 19902. Advice on the use of diffraction analysis for large volume structures is given in ISO 19903, API 2FPS, and ISO 19902. Where computational fluid dynamics are used, the method should be verified against good quality model tests.

8.3.1.2.3 Wind Actions

Wind actions shall reflect the presence of icing. The effect of icing on drag actions due to wind shall be analyzed in the same way as Morison drag actions due to waves and currents are treated in 8.3.1.2.2.

8.3.1.2.4 Dynamic and Static Responses

Icing can affect the dynamic and static responses of structural members, appurtenances, and complete structural systems and, consequently, the following factors shall be considered.

- a) Actions exciting dynamic responses shall be modified as described in 8.3.1.2.1 and 8.3.1.2.3.
- b) Strouhal numbers for the assessment of vortex-induced vibrations of members shall be similarly modified.
- c) Masses of members and systems and any added masses shall be adjusted and moved in accordance with the icing. Consequences for additional vertical actions, stability, static position, reductions of structure freeboard, and righting moments of floaters shall also be considered.

8.3.1.3 Particular Considerations for Large Volume Structures

The nonlinear effects that control water surface elevation beneath a structure standing on large columns are not easily treated theoretically. In the case of fixed arctic offshore structures, wave focusing due to the presence of large caissons and/or earth mounds can further complicate the wave-structure interaction. Model testing should be carried out to assess the required air gap under the deck of a platform.

Wave actions shall be assessed for ice resisting structures with sloping faces and conical forms.

8.3.1.4 Freeboard and Deck Elevation

Deck elevations, structure freeboard, and bow wall or ice deflector height shall account for the wave-induced vertical motion of the water surface and incident ice features. Account shall be taken of ice accumulations on

the structure, the underside of the topsides deck or the substructure. The routing of all risers, caissons, J-tubes, and other appurtenances shall minimize the risk of impact by such ice features. Further guidance is provided in 15.1.1.3.

Nonlinear wave-structure interaction tends to increase water surface elevations around the structure. Consequently, ice can impact the structure at levels higher than most numerical schemes predict. The area of ice strengthening shall take this into account.

8.3.2 Wave-induced Velocity of Ice Features

The incident wave and current determine the velocities of ice features impacting a structure and shall be considered. Methods to estimate the velocities depend on the ratio of the wavelength of the incident wave to the dimensions of the ice and the structure.

Pieces of ice with maximum dimension less than $1/15$ of the incident wavelength can be conservatively assumed to follow the water particle velocity. For larger ice pieces, velocities can be obtained by solving their equation of motion accounting for wind, wave and current actions. For ice with horizontal dimensions less than $1/5$ of the incident wavelength, actions may be derived from the relative velocity formulation of the Morison equation. For larger pieces, diffraction analysis can be used to calculate wave actions. Computational fluid dynamics or model testing may also be applied to estimate actions and velocities induced.

Slopes and changes in water depth can focus and steepen incident waves through refraction. If the tops of underwater mounds or caissons are less than half a wavelength below the free surface, the possibility of their influence shall be considered.

NOTE 1 Where the dimensions of the ice or the structure are $1/15$ of the wavelength of the incident wave or greater, the approach described above becomes less accurate and generally overestimates the velocity of the ice induced by the incident wave field.

NOTE 2 Small ice features can impact structures with an accelerated velocity due to breaking or near-breaking waves. Such situations can also arise in cases of shallow water near shore due to shoaling waves. In addition, these situations can arise for gently sloping structures such as man-made islands and extended berms.

8.4 Seismic Actions

8.4.1 General

Offshore structures in arctic and cold regions shall be designed for ELE and ALE in accordance with the provisions of API 2EQ. In addition, steel structures shall comply with ISO 19902 and concrete structures shall comply with ISO 19903.

This standard contains specific provisions for seismic actions and effects for foundations in 9.4.4, for man-made islands in 10.4, for steel structures in 11.7, for concrete structures in 12.3.6, for subsea structures in 14.4, and for topsides in 15.3.

Ice and seismic events may be considered as stochastically independent. The combination of ice and seismic events should be made through an assessment of their joint probability, in which the duration of events is reflected.

8.4.2 Companion Seismic Actions

Probabilities associated with the simultaneous occurrence of EL and AL ice actions of short duration and seismic actions can be very low. In such cases, it is not necessary to consider companion seismic actions for ELIE and ALIE.

8.4.3 Companion Ice Actions

When offshore structures in arctic and cold regions are designed for ELE and ALE, appropriate companion ice actions shall be included.

There is a very low probability for the simultaneous occurrence of EL or AL seismic events and ice events of short duration. Accordingly, the specification of companion ice actions is likely to involve ice conditions of long duration only. The companion actions provided in Table 7-2 may be disregarded when the joint probability of seismic and ice events has been established.

8.4.4 Factors Influencing Seismic Actions and Effects

The relative speed of the structure and the ice shall be considered in the specification of companion ice actions.

Ice accretion and landfast ice or grounded ice rubble adhering to the structure shall be considered when calculating the mass of the structure used for seismic analyses. The local restraint can result in changes to the natural modes of the system, and potentially induce large local and global actions.

The presence of a surrounding ice sheet shall be considered in the calculation of hydrodynamic added mass.

8.4.5 Seismic Isolation and Damping Systems

Seismic isolation and damping systems may be used for arctic offshore structures to meet the requirements of this standard, provided they are designed to operate reliably under the expected environmental conditions. Further requirements for seismic isolation and damping systems are provided in 15.3.5.

9 Foundation Design

9.1 General

Foundations for structures in arctic and cold regions require consideration of several factors beyond usual offshore geotechnical practice that can influence the reliability of foundations. The ice loading environment can be such that high horizontal actions can occur. Depending on the shape of the structure, these high actions can be eccentric and cyclic with magnitudes, frequencies, and durations of loading that are different from those caused by other environmental conditions such as waves and earthquakes. These same ice action conditions and resulting action combinations can result in structural forms different from those that are designed for temperate waters, so that the experience base for overall performance of arctic offshore structure foundations can be limited.

Climate (past and present) has resulted in occurrence of widespread permafrost even in deep water in some arctic and cold regions. Identification and characterization of permafrost becomes a particular task of the soils investigation and can require specific sampling procedures and expertise. Stability of frozen soils through the design service life of the structure shall be considered. Hydrocarbon exploration and production activities, as well as structures, can result in permanent or cyclic thermal changes to permafrost. Lower ground temperatures also increase the probability of the presence of frozen gas hydrates at relatively shallow depths in cold climates.

Furthermore, soils in arctic and cold regions are likely to have been affected by glacial episodes in recent geological history. There can, therefore, be a greater likelihood of the occurrence of boulders and gravels in certain geological environments. Current geological processes such as gouging of the seabed by moving ice keels can change seafloor topography and can affect the properties of soils and loading for buried structural components and flowlines.

Quick clays, or highly sensitive clays, can be encountered in certain nearshore arctic locations. A characteristic of quick clays is a natural moisture content that is considerably in excess of the liquid limit, as a result of which the soil possesses negligible remolded shear strength.

9.2 Site Investigation

9.2.1 Purpose and Scope of the Investigations

9.2.1.1 Site Investigations—General

Site investigations shall be performed for all offshore structures in arctic and cold regions. The purpose of the investigation shall be to provide relevant bathymetric, geophysical and geotechnical data necessary to characterize the site conditions and for the determination of characteristic material properties.

Site investigations shall take the following into consideration:

- type of structure and foundation actions;
- size of structure;
- nature of the seafloor;
- types of seabed materials;
- near-field and far-field conditions;
- data available from previous investigations in the area;
- available performance data from existing structures in the area;
- liquefaction susceptibility.

The investigation shall be performed utilizing the skills of professional personnel in the fields of geology, geophysics, ice engineering, seismology, and geotechnics, and it should include an evaluation of all relevant existing data.

Potential geohazards such as ice gouges, sand waves, boulder beds, submarine slope instability, faults, shallow gas, subsidence, mud volcanoes, gas hydrates, permafrost, and overpressurized geological strata shall be considered and investigated as necessary.

Soil studies in arctic and cold regions require additional data gathering to ensure that the structure foundation can be adequately designed, especially in terms of dynamic soil properties. This includes special geophysical as well as geotechnical studies with guidance as provided in A.9.2.4.

Investigations shall consider both far-field and near-field seabed conditions.

9.2.1.2 Site Investigations—Far-field

The far-field investigations shall determine the impact of the following on the design of the structure:

- bathymetry;
- surficial geology;
- bedrock geology;
- risk of seismic events;
- slope stability and the potential for mass movements;
- presence of ice gouges;
- present sedimentary environment and erosional processes.

9.2.1.3 Site Investigations—Near-field

The near-field investigations shall address the local issues related to

- a detailed seafloor bathymetry;
- a detailed soil/rock seabed stratigraphy;
- the foundation stability and displacement;
- the local slope stability;
- sediment movements adjacent to the structure;
- the presence and influence of ice gouges, boulders, permafrost, and gas hydrates and shallow faults.

The near-field conditions shall be evaluated to provide detailed quantitative and qualitative data on relevant bathymetric and geomorphological features, geological processes, and geotechnical parameters that can affect the design of the structure. The lateral and vertical extent of the near-field investigation shall be consistent with the size, zones of influence, and placement tolerances of the intended structure and with the complexity of the site conditions.

The near-field investigation shall include as a minimum

- a) a bathymetry survey;
- b) a geophysical survey, including ice gouge delineation where applicable;
- c) a geotechnical investigation.

9.2.2 Bathymetry Survey

Bathymetric data shall be obtained to provide information about the relief and elevations of the seafloor, and can assist in determining the likely draught of ice features reaching the structure.

Bathymetry shall be determined by methods that account for vessel heave, tidal fluctuations, and other factors that can influence the establishment of local and relative datums. The precision of the methods and accuracy of the survey shall be compatible with the design requirements of the structure.

The areal extent, spacing, and orientation of the survey lines shall be compatible with the purpose of the investigation and the type (near-field or far-field) and shall adequately define bathymetry and morphology.

9.2.3 Geophysical Survey

Geophysical data shall be obtained to assist in the identification and delineation of relevant geological features as set out in 9.2.1. The geophysical data shall be interpreted in conjunction with available bathymetric and geotechnical data to permit cross-checking and verification.

High-resolution geophysical survey methods and equipment shall be chosen with due consideration for site conditions and the intended purpose. The capabilities of the equipment with regard to the depth of penetration and resolution shall also be considered.

The areal extent, spacing, and orientation of the geophysical survey lines shall be compatible with the purpose and the type (near-field or far-field) of the investigation, and with the nature of the seafloor and seabed features.

Additional features pertinent to arctic and cold regions include the depth, frequency, and distribution of ice gouges and the presence or otherwise of shallow permafrost and gas hydrates. In areas of shallow permafrost, consideration shall be given to the use of special geophysical investigation techniques such as the incorporation of shorter receiver arrays or the application of resistivity methods.

9.2.4 Geotechnical Investigation

The geotechnical investigation program shall be established on the basis of the geological and geophysical data. The investigation should include borehole drilling and sampling, *in situ* testing, and laboratory testing.

The investigation shall cover the area and the soil/rock layers of significance to the structure. Particular attention shall be given to determining the disposition and properties of shallow soils/rocks, as relatively thin layers of weak soils/rocks near the seabed can have a significant influence on foundation stability of gravity structures. It shall also cover the zone of expected thermal disturbance for locations where permafrost is present. Special attention shall be given to minimizing both thermal and mechanical sample disturbance when sampling permafrost.

9.3 Characteristic Material Properties

Characteristic strength and deformation parameters shall be determined for all relevant soil layers, and for the relevant temperature ranges and stress ranges, taking due account of stress history, anisotropy, and soil disturbance effects.

In these evaluations, caution should be exercised in the utilization of a strength value that depends on the dilatancy of the foundation soils and hence foundation movement.

NOTE Dilatancy is the tendency of a soil to increase its volume with change in shear stress.

Similarly, post-peak strength reduction and the possibility of progressive failure shall be considered.

The selected characteristic material properties shall be appropriate to the particular issues/situations to which they are applied. Limitations of the validity of the parameters, or conditions for their application, shall be clearly stated.

The effect of cyclic stresses on soil strength and stiffness induced by hydrodynamic and ice actions on the structure and applied to the foundation soils shall be determined when such effect is of relevance to the particular issues under consideration.

The effect of stress paths and load periods on soil characteristic properties shall be accounted for in the design.

The effects of thermal conditions prior to and during the operation of the structure shall be considered.

9.4 Design Considerations

9.4.1 General

The following additional factors shall be taken into consideration in the design of foundations for offshore structures in arctic and cold regions:

- potential for permafrost or gas hydrates in the seabed;
- potential variation in seafloor relief and soil properties due to ice gouging;
- potential for grounding of ice in shallow water;
- potential for gouging around structures due to stamukhi or movement of grounded ice.

The design shall consider the limit equilibrium between driving and resisting actions using the method of partial factors. Both the material factor and the resistance factor approaches for calculation of the resisting actions are acceptable within this standard as appropriate to the safety format and methodology contained within the particular referenced code relating to each foundation type.

Geotechnical foundation engineering depends on the extent and reliability of the basic soils data, their interpretation, method of analysis, type of structure, type of loading, and monitoring and maintenance. All of these considerations influence the choice of action, resistance, material factors, and combinations of actions.

The transfer of actions between the structure and the adjacent soil shall be analyzed with respect to all limit states and all phases in the design service life of the structure, including the removal of the structure, when required.

The sensitivity of the calculated results should be analyzed making due allowance for reasonable variations of the assumptions made in the computation models and variations in material properties and static and cyclic actions and effects.

In the analysis of the interaction between soil and structure, consideration shall be given as to whether the stiffness of the structure should be taken into account. The analysis should be based on appropriately selected characteristic deformation properties of the soil.

All significant effects of ice and companion environmental actions shall be considered, including the stability of adjacent seabed slopes. Possible interaction effects between structures should be considered.

Representative drainage conditions shall be determined for the designs under consideration.

Where permafrost or gas hydrates are anticipated or proven to exist, the design of the foundation shall make appropriate allowance for these conditions. Locations where soil deposits include gas hydrates that can affect the integrity of the structure should be avoided. The effects of thawing of permafrost and gas hydrates on soil strength and foundation stability shall be considered.

In areas with subsea permafrost or where development can induce freezing of soils, the design process shall involve analysis to evaluate the influence of the structure, its storage, and wells on the soil. Such analyses can include: evaluation of thawing and freezing; deformation analyses of the creep characteristics of permafrost; and deformation analysis to evaluate the extent and time dependence of foundation settlements and the ramifications of the time-dependent reduction in foundation shear strength as a result of thawing.

The potential for the development of grounded ice rubble around the structures that can impose ice actions, influence the path of the actions, and create seabed gouges shall be considered.

The design shall consider the potential influence of ice gouging on the variability in seafloor relief and the requirement for site preparation. Ice gouging can also affect the strength and compressibility of near-surface sediments.

Physical testing complemented by numerical modeling should be considered where there is uncertainty in the mode of resistance of new foundation solutions and/or the ground conditions differ from those where there is precedent for a particular foundation type.

9.4.2 Action Factors

Action effect combinations that give the most unfavorable result shall be selected in each of the stability mechanisms and deformation analyses performed.

In order to demonstrate that the design resistance is equal to or greater than the design action effect and that large cyclic and permanent displacements cannot occur due to the cyclic action effects, the ULS shall be analyzed with the appropriate cyclic action effect history.

9.4.3 Material and Resistance Factors

Either the material factor or the resistance factor approach may be used. Designers are encouraged to use sound engineering judgment, precedent cases and their own experience, as well as relevant industry experience and due diligence, to investigate which method is more suitable to a particular application. Wherever feasible, designers are encouraged to investigate the applicability of both methods to determine which approach best meets the geotechnical design requirements.

While the material factor or resistance factor should not generally be lower than 1.25, it may be modified with regard to the consequences of failure, the failure mechanism, and the way in which the characteristic strength of the soil material is determined and expressed. Recognized practice should be considered in the selection of the computation procedures and stability mechanisms.

Consideration should be given to increasing the material factor or resistance factor for new types of structures and foundations and/or soil conditions with which no experience has been gained. An increased factor should also be considered when site variability is greater than usually encountered.

In the serviceability, fatigue and progressive collapse limit states, the material and resistance factors shall be 1.0.

9.4.4 Dynamic Action Effect Analysis

In cases where the structure is subjected to cyclic actions due to waves, seismic or ice, the effects of cycling and dynamic amplification shall be considered. For dynamic studies, the soil-structure interaction (SSI) behavior shall take into account the dynamic response of the foundation, unless it can be shown that the frequency is such that the foundation can be treated in a quasi-static manner.

Dynamic analysis should be considered for certain types of structures where the action frequency is such that foundation design cannot be treated in a quasi-static manner under wave or ice action. It should be noted that the results can be sensitive to variations of 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 analysis.

Soil parameters and calculation methods shall be selected in accordance with the action history included in the analysis of the structure and the stress and strain levels resulting from the calculations.

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 design events and subsequent consolidation over a period of time should be considered.

Earthquake response shall be calculated on the basis of dynamic properties of all soil layers likely to influence the response of the structure. The effect of interaction between soil and structure shall be taken into consideration.

Offshore structures in arctic and cold regions shall be designed for cyclic loading from ice in addition to cyclic loading from waves. Ice failure against the structure can generate cyclic loading at multiple frequencies, depending on the stiffness of the structure and its foundation.

9.4.5 ULS

It shall be demonstrated that the design resistance of the soil under and around the foundation is sufficient to resist the design action effects. The development of the design resistance over a period of time shall be assessed.

Displacements of the foundation due to design action effects should be considered when checking the ULS of the structure or vital equipment, such as conductors, casings, and risers.