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Petroleum and natural gas industries — Fixed steel offshore structures

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National foreword

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

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

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

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

This document was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 7, *Offshore structures*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 12, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

This second edition cancels and replaces the first edition (ISO 19902:2007), which has been technically revised. It also incorporates the Amendment ISO 19902:2007/Amd.1:2013. The main changes compared to the previous edition are as follows:

— duplication of symbols has largely been eliminated (see Clause 4);

— use of metocean versus environmental has been rationalized. Metocean now refers to wind, wave and current actions only while environmental encompasses metocean, ice and seismic;

— high strength steel: applicable specified minimum yield strength increased to 800 MPa but only with respect to non-material requirements;

— hazards and designing for hazards moved from 10.1.1 and 10.1.2, respectively, to 6.2.2 and 6.2.3, respectively;

— deck elevation (6.3.3.2) expanded to include air gap plus need to consider crest levels 15 % higher than calculated values;

— exposure levels (6.6) are addressed in ISO 19900 so text modified accordingly;

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— damage tolerance now more appropriately addressed in 7.10.2 rather than 10.1.6.1;

— reserve strength ratio (7.11.1): detailed procedure introduced because of general lack of adequate, appropriate documentation;

— structural reliability analysis (7.13): text reordered and supplemented by text from completely rewritten A.9.9.3.3;

— onshore lifting (8.3): because offshore lifting is now addressed in ISO 19901-6, the text and tabulated information on DAFs have been modified accordingly;

— multi-crane lifts (8.3.4): for consistency with ISO 19901-6, now considered in place of dual lifts;

— gravity load partial action factors for extreme conditions reduced from 1.1 to 1.0 (Table 9.10-1 and Table 8.2-1);

— clarified that for abnormal design situations, verification is required even if wave-in-deck events do not occur to ensure that the appropriate robustness requirement is realized;

— ELE structural and foundation modelling: new first paragraph added in response to questions to Seismic Panel (responsible for ISO 19901-2) regarding the appropriate weight of personnel to consider during an event;

— tubular member diameter to thickness ratio non-dimensionalized (13.1);

— shear and torsion now included in all tubular member strength formulae including those addressing hydrostatic pressure;

— tubular member strength formulae for combined axial and bending loading now of cosine interaction form instead of previously adopted linear interaction;

— formulae (13.6-2) and (13.6-3) relating to conical transitions corrected;

— tubular joint strength formulae nearly all changed through adoption of the API RP 2A-WSD 21st Edition Supplement 2 (October 2005) tubular joint formulae supplemented by some limited non-linear FEA;

— grouted connections: pile outer diameter limited (15.1.5.2);

— use of HSS in fatigue applications: warning re possible hydrogen embrittlement when yield strength exceeds 700 MPa (16.11.2);

— fatigue damage design factors: effect of considering life cycle (16.12.2);

— Clause 17: detailed pile design requirements moved to ISO 19901-4 so no longer addressed;

— Clause 19: expanded to include more detailed requirements for Design class approach;

— Clause 20: expanded to include more detailed requirements for Design class approach;

— Clause 21: some requirements for Design class approach added to Tables 21.2-1 and 21.4-1 (previously 21.7-1);

— particular standards identified for NDT personnel qualification (21.3.3);

— Clause 21: existing 21.4 to 21.6 moved to ISO 19901-6;

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— Clause 22: reference to ISO 19901-6 added where appropriate. Requirements for flotation (22.3.2.4) and crane barges (22.3.2.5) combined (22.3.3.4);

— Clauses 23 to 25 (and A.23 to A.25) deleted because ISO 19901-9 *Structural integrity management* approved;

— Annex A modified to accommodate above changes to normative text as appropriate;

— Table C.1: extra strength groups for chord cans and padeyes;

— Table C.4 enlarged considerably;

— Annex D completely rewritten;

— E.3: 100 % CVI now required for all welding;

— Annex F: substantially rewritten and expanded. Now important to consider whether LAST is $\geq -10°C$ or $< -10°C$;

— new Table F.5 and Figure F.1 similar to existing requirements in Table D.3 and Figure D.1, now deleted from Annex D;

— new Table F.6 addressing subsea structures whereas Table F.5 only concerns jacket structures;

— minimum RSR requirement added for North West Europe (H.2.3.1);

— H.3.3.2 Canadian welding references revised;

— US Customary units have been deleted;

— a number of figures have been corrected.

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

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Introduction

The International Standards on offshore structures prepared by TC 67/SC 7 (i.e. ISO 19900, the ISO 19901 series, ISO 19902, ISO 19903, ISO 19904-1, the ISO 19905 series, ISO 19906) constitute a common basis covering those aspects that address design requirements and assessments of all offshore structures used by the petroleum and natural gas industries worldwide. Through their application, the intention is to achieve reliability levels appropriate for manned and unmanned offshore structures, whatever the type of structure and 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.

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

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

Materials, welding and weld inspection requirements can be based either on a “material category” or on a “design class” approach, as discussed in Clauses 19 and 20. If the material category approach is used, see the corresponding provisions of Annexes C and E; if the design class approach is used, see the corresponding provisions of Annexes D and F.

Annex G gives requirements on fabrication tolerances.

Regional information on the application of the document to certain specific offshore areas is provided in Annex H.

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

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Petroleum and natural gas industries — Fixed steel offshore structures

1 Scope

This document specifies requirements and provides recommendations applicable to the following types of fixed steel offshore structures for the petroleum and natural gas industries:

— caissons, free-standing and braced;

— jackets;

— monotowers;

— towers.

In addition, it is applicable to compliant bottom founded structures, steel gravity structures, jack-ups, other bottom founded structures and other structures related to offshore structures (such as underwater oil storage tanks, bridges and connecting structures).

This document contains requirements for planning and engineering of the design, fabrication, transportation and installation of new structures as well as, if relevant, their future removal.

NOTE 1 Specific requirements for the design of fixed steel offshore structures in arctic environments are presented in ISO 19906.

NOTE 2 Requirements for topsides structures are presented in ISO 19901-3; for marine operations in, ISO 19901-6; for structural integrity management, in ISO 19901-9 and for the site-specific assessment of jack-ups, in ISO 19905-1.

2 Normative references

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

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 10414-1, *Petroleum and natural gas industries — Field testing of drilling fluids — Part 1: Water-based fluids*

ISO 12135, *Metallic materials — Unified method of test for the determination of quasistatic fracture toughness*

ISO 15653, *Metallic materials — Method of test for the determination of quasistatic fracture toughness of welds*

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

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

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

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

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

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

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

ISO 19901-9, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 9: Structural integrity management*

ISO 19905-1, *Petroleum and natural gas industries — Site-specific assessment of mobile offshore units — Part 1: Jack-ups*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19901-1, ISO 19901-2, ISO 19901-4, ISO 19901-9 and the following apply.

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

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

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

3.1
abnormal environmental event
environmental hazardous event having a probability of occurrence typically between 10^{-3} and 10^{-4} per annum (i.e. return periods between 1 000 years and 10 000 years)

[SOURCE: ISO 19900:2019, 3.1, modified]

3.2
accidental event
non-environmental hazardous event having a probability of occurrence typically of 10^{-4} per annum (i.e. return period of 10 000 years)

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

[SOURCE: ISO 19900:2019, 3.2, modified]

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

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

[SOURCE: ISO 19900:2019, 3.3]

3.4
action effect
effect of actions on a structure or on structural components

EXAMPLE Internal force, moment, stress or strain.

[SOURCE: ISO 19900:2019, 3.4, modified]

3.5
air gap
clearance between the highest water surface or ice surface that occurs during abnormal metocean or ice events and the lowest exposed part not designed to withstand wave or ice impingement

3.6
analysis type
method including governing equations for deriving action effects

EXAMPLE Static analysis, transient dynamic analysis, non-linear analysis (see Clause 12).

3.7
basic variable
one of a specified set of parameters representing physical quantities which characterize actions, environmental influences, geometrical quantities, or material properties including soil properties

[SOURCE: ISO 19900:2019, 3.7, modified]

3.8
braced caisson
monotower where the lower part of the centre column is supported laterally by one or more inclined braces between the column and one or more foundation piles

3.9
bucket foundation
foundation consisting of a cylindrical shell open on one end and installed by suction

3.10
compliant bottom founded structure
structure which is supported at its base by foundation piles or by another non-superficial foundation system and which is sufficiently flexible that applied lateral dynamic actions are substantially balanced by inertial reactions

Note 1 to entry: Although this document is applicable to fixed steel offshore structures and is not intended to form a complete document for compliant bottom founded structures, some of its requirements and guidance can be applied to compliant bottom founded structures. Parts of its requirements can also apply to other bottom founded structures (e.g. some forms of minimal structure), as considered appropriate and as agreed upon by parties concerned on a case by case basis.

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3.11
consequence category
classification system for identifying the environmental, economic and indirect personnel safety consequences of structural failure of a platform used to determine exposure level

3.12
critical component
structural component, failure of which would cause failure of the whole structure, or a significant part of it

Note 1 to entry: A critical component is part of the primary structure.

3.13
deformation capacity
ability of a structure or structural component to deform without significant loss of resistance, or the extent to which it can do so

3.14
design service life
planned period for which a structure is used for its intended purpose with anticipated maintenance, but without substantial repair being necessary

[SOURCE: ISO 19900:2019, 3.13]

3.15
design situation
set of actions and combination of actions representing real conditions during a certain time interval, for which the design demonstrates that relevant limit states are not exceeded

3.16
design value
value of an action or strength variable derived from its representative value for use in the design verification procedure

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

Note 2 to entry: For yield strength, the design value is equal to the representative yield strength (see 3.42).

3.17
ductility
ability of material, structural component or structural system to deform and dissipate energy without fracturing or tearing

[SOURCE: ISO 19900:2019, 3.55, 3.56 and 3.57, modified]

3.18
dynamic amplification factor
DAF
ratio of a dynamic action effect to the corresponding static action effect

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

3.19
environmental action
effect of wind, wave, current, ice and seismic phenomena on a structure

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3.20
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 structural failure

Note 1 to entry: See 6.6.

[SOURCE: ISO 19900:2019, 3.20, modified]

3.21
extreme environmental event
environmental hazardous event having a probability of occurrence typically of 10^{-2} per annum (i.e. return period of 100 years)

[SOURCE: ISO 19900:2019, 3.21, modified]

3.22
fitness-for-service assessment
demonstration that continued service of a structure does not cause unacceptable risk to life-safety or the environment

3.23
fixed structure
structure that is bottom founded and transfers most of the actions on it to the seabed

[SOURCE: ISO 19900:2019, 3.24]

Note 1 to entry: Typical bottom founded fixed steel piled structures include jackets (see 6.1.2) and towers (see 6.1.3). Non-piled fixed structures include steel gravity structures and fixed concrete structures (see ISO 19903).

3.24
free-standing caisson
monotower consisting of a single vertical column that continues into the seabed as the foundation pile

3.25
hazard
situation or event with the potential for human injury, damage to the environment, damage to property, or a combination of these

Note 1 to entry: See 6.2.2.

3.26
high strength steel
HSS
steel with specified minimum yield strength greater than 460 MPa and up to 800 MPa

Note 1 to entry: There is no consistent definition of HSS. The lower value given here coincides with that adopted for HSS in EN 1993 [9].

3.27
life-safety category
classification system for identifying the applicable level of life-safety for a platform used to determine exposure level

Note 1 to entry: See 3.20 for definition of exposure level.

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3.28
lowest anticipated service temperature
LAST
reference temperature for determining test temperatures of structural materials

Note 1 to entry: In this document, the value corresponding to the extreme environmental event applies.

3.29
maintenance
set of activities performed during the working life of the structure to enable it to fulfil the requirements for reliability

Note 1 to entry: Activities to restore the structure after an abnormal, accidental or seismic event are outside the scope of maintenance.

3.30
metocean action
effect of wind, wave and current on a structure

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

3.31
monotower
fixed structure in which the whole structure, or at least the upper part of the structure, consists of a single vertical column (tubular or framed) that carries the topsides

Note 1 to entry: Where only the upper part of the structure is a single vertical column, the lower part of the structure consists of tubular members or frames that connect the vertical column to the foundation piles or to another non-superficial foundation system that supports the monotower at its base, such as bucket foundations.

3.32
nominal stress
stress calculated in a sectional area, including the stress raising effects of the macro-geometrical shape of the component of which the section forms a part, but disregarding the local stress raising effects from the section shape and any weldment or other fixing detail

Note 1 to entry: Overall elastic behaviour is assumed when calculating nominal stresses.

3.33
nominal value
value assigned to a basic variable, action or strength model determined on a non-statistical basis, typically from acquired experience or physical conditions

EXAMPLE Value published in a recognized code or standard, such as yield strength.

[SOURCE: ISO 19900:2019, 3.33, modified]

3.34
owner
representative of the companies which own a development

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

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3.35
post-damage design situation
design situation for which the condition of the structure reflects damage due to an accidental or abnormal event and for which metocean or ice events are defined for use in verification

Note 1 to entry: Metocean or ice event return periods appropriate for post-damage verification are discussed in 7.10.2.

3.36
primary structure
all main structural components that provide the structure's main strength and stiffness

3.37
quasi-static analysis
static analysis of a structure subjected to actions that vary slowly in relation to the structure's fundamental natural period such that the influence of structural accelerations can be either safely neglected or approximated by using an equivalent quasi-static action

3.38
redundancy
ability of the structure to find alternative load paths following structural failure of one or more components, thus limiting the consequences of such failures

Note 1 to entry: Statically determinate structures, contrary to statically indeterminate structures, do not generally exhibit redundancy.

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

Note 1 to entry: The term “regulator” can encompass more than one agency in any particular territorial waters.

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

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

3.40
repair
activities performed to preserve or restore the function of a structure (usually following damage) that fall outside the scope of maintenance

3.41
representative value
value assigned to a basic variable for verification of a limit state

Note 1 to entry: The representative value is generally a characteristic value.

Note 2 to entry: The representative value of yield strength is a nominal value.

[SOURCE: ISO 19900:2019. 3.40, modified]

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3.42
representative yield strength
specified minimum yield strength

Note 1 to entry: See 3.55.

3.43
reserve strength
capacity of a structural system to withstand overload

3.44
reserve strength ratio
RSR
measure of reserve strength with respect to metocean actions

Note 1 to entry: See 7.11.1; alternative measures are available (see A.7.11.1.2).

Note 2 to entry: The concept of a reserve strength ratio can be applied to all types of actions (metocean, ice, seismic), but RSR as described in 7.11.1 applies to metocean actions only.

3.45
robustness
ability of a structure to withstand events with a reasonable likelihood of occurring without being damaged to an extent disproportionate to the cause

[SOURCE: ISO 19900:2019, 3.44, modified]

3.46
secondary structure
structural components that, when removed, do not significantly alter the overall strength and stiffness of the structure

3.47
steel gravity structure
fixed structure that is held in place against environmental actions by the weight of the structure and any contained ballast together with foundation resistance resulting from its weight and lateral resistance from any skirts

Note 1 to entry: Although this document is not intended to apply to all aspects of steel gravity structures, some of the requirements and guidance can be applied to these structures.

3.48
strength
mechanical property of a material indicating its ability to resist actions, usually given in units of stress

3.49
stress concentration factor
SCF
factor relating a local stress to the nominal stress at a detail

Note 1 to entry: SCFs are very important for and especially used in determining fatigue damage (see 16.10.2).

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3.50
structural analysis
process or algorithm for determining action effects from a given set of actions

Note 1 to entry: Structural analyses are performed at three levels (global analysis of an entire structure, local analysis of a structural component, local analysis of a section of a structural component) using different structural models.

3.51
structural component
physically distinguishable part of a structure

Note 1 to entry: The main structural components of a fixed steel structure are tubular members (see Clause 13), tubular joints (see Clause 14), mechanical connectors and clamps (see Clause 15), foundation piles and bucket foundations (see Clause 17 and ISO 19901-4).

[SOURCE: ISO 19900:2019, 3.49, modified]

3.52
structural system
load-bearing components of a structure and the way in which these components function together

3.53
topsides
structures and equipment placed on a supporting structure (fixed or floating) to provide some or all of a platform's functions

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

Note 2 to entry: Topsides design is addressed in ISO 19901-3.

[SOURCE: ISO 19900:2019, 3.54]

3.54
utilization
member utilization
joint utilization
maximum value of the ratio of the generalized representation of action effects in stress (force) units in a structural component to the generalized representation of the design resistance in stress (force) units of the component

Note 1 to entry: The utilization is the maximum absolute value of the ratio for all design situations being considered.

Note 2 to entry: Only utilizations smaller than or equal to 1,0 satisfy the design criteria for a particular limit state.

Note 3 to entry: The design action effect is the stress (force) due to factored actions: $F_d = F_r \gamma_f$. The design resistance is the representative resistance divided by the partial resistance factor: $R_d = R_r/\gamma_R$.

Note 4 to entry: For members and joints subjected to a single force, the utilization, U, is equal to: $F_d/R_d = F_r \gamma_f \gamma_R/R_r$.

Note 5 to entry: For members and joints subjected to combined action effects, the internal stress (force) pattern and the design resistance combine into a single interaction equation. If the interaction equation governing the design situation is, or can be, reduced to an inequality of the form $I \leq 1{,}0$, then the utilization is equal to I.

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3.55
yield strength
specified minimum yield strength
SMYS
value of stress in a tensile test corresponding to a 0,2% offset

Note 1 to entry: The offset value is as specified in ISO 6892.

Note 2 to entry: Alternative terminology for "yield strength" is used in different regions of the world and in different standards in the same region of the world. Commonly used terms include specified minimum yield strength, yield point and nominal yield strength. The term "characteristic yield strength" has also been used when it is in fact just the nominal value.

4 Symbols

The following is a summary of the main symbols that are used throughout this document. Many other symbols are locally defined where they are used. Local use includes main symbols with one or more subscripts when a more specific use and associated definition of the symbol is intended.

A accidental action (see ISO 19900)

A_r area

C coefficient in general

C_d hydrodynamic drag coefficient

C_m hydrodynamic inertia coefficient

$C_{m,i}$ moment reduction factor

C_r seismic reserve capacity factor

C_s shape coefficient

D diameter of a cylindrical element

D_R Palmgren-Miner's fatigue damage ratio

d diameter of tubular joint brace

E Young's modulus of elasticity

E_e extreme quasi-static metocean action due to wind, waves and current

E_o metocean action due to owner defined operating wind, wave and current parameters

F action

F_d design value of action (see ISO 19900)

F_r representative value of action (see ISO 19900)

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f	representative strength in general, in stress units
f_b	representative bending strength, in stress units
f_c	representative axial compressive strength, in stress units
f_{cu}	unconfined cube strength of grout
f_e	Euler buckling strength, in stress units
f_h	representative hoop buckling strength, in stress units
f_t	representative axial tensile strength, in stress units
f_v	representative shear strength, in stress units
f_y	representative yield strength, in stress units
G	permanent action (see ISO 19900)
g	gap
H	height of an individual wave
H_s	significant wave height
I	moment of inertia
K	effective length factor
K_c	Keulegan-Carpenter number
k	wave number
k_{DAF}	dynamic amplification factor
L	length
M	moment (bending or torsion) due to factored actions
M_d	design value of joint bending moment strength, in moment units
M_{uj}	representative value of joint bending moment strength, in moment units
m	inverse slope of the S-N curve
N	number of cycles to failure in fatigue of a specified constant amplitude stress range, S
n	number of occurrences of a specified stress range, S, during a specified time
P	member axial force due to factored actions
P_{CE}	carbon equivalent

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P_{CM} modified carbon equivalent

P_d design value of joint axial strength, in force units

P_{uj} representative value of joint axial strength, in force units

P_f probability of failure

P-Δ second order bending effect due to axial compressive force, P, and lateral deflection, Δ

$P(x)$ cumulative probability of variable x

p_a atmospheric pressure

$p(x)$ probability density function of variable x

p–y lateral soil resistance versus local pile displacement

Q variable action (see ISO 19900)

Q_f chord force factor

Q_g gap factor for a joint

Q_u chord strength factor

Q-z pile end bearing resistance versus pile tip displacement

Q_β geometrical factor for a joint

R radius of a circular cross-section

R_d design value of a component resistance (see ISO 19900)

R_e Reynolds number

R_{RS} reserve strength ratio

r radius of gyration

S internal force (action effect)

S constant amplitude stress range for fatigue assessments

S_r Strouhal number

T wall thickness of the chord member

T_i intrinsic wave period

T_z average zero-crossing wave period

t wall thickness

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t-z	soil pile shear transfer versus local pile displacement
U	utilization
V	beam shear due to factored actions
V_R	coefficient of variation
Z_e	elastic section modulus
Z_p	plastic section modulus
α	slope angle of a cone section
β	ratio of brace outside diameter to chord outside diameter
γ	ratio of chord outside radius to chord wall thickness
γ_f	partial action factor the value of which reflects the uncertainty or randomness of the action (from ISO 19900)
γ_R	partial resistance factor the value of which reflects the uncertainty or variability of the component resistance including those of material properties (from ISO 19900)
θ	angle in general
θ_m	mean wave direction
λ	wave length
λ	column slenderness parameter
ν	Poisson's ratio, which may be taken as 0,3 for structural steel, in lieu of more detailed information
ξ	fraction of critical damping
ρ_a	mass density of air, which may be taken as 1,22 kg/m^3 in lieu of more detailed information
ρ_s	mass density of steel, which may be taken as 7 850 kg/m^3 for structural steel, in lieu of more detailed information
ρ_w	mass density of sea water, which may be taken as 1 025 kg/m^3, in lieu of more detailed information
σ	stress in general
τ	shear stress in general
τ	ratio of brace wall thickness to chord wall thickness
υ	kinematic viscosity of water
Ω	ratio of frequency of excitation to natural frequency

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ω circular frequency

ω_e frequency of excitation

ω_n natural frequency in general

ω_1 first natural frequency

5 Abbreviated terms

ALE abnormal level earthquake

ALS accidental limit states including abnormal limit states

API American Petroleum Institute

ASD allowable stress design

CTOD crack tip opening displacement

CVN Charpy V-notch

DC design class

ELE extreme level earthquake

ERW electric resistance welded

FEA finite element analysis

FLS fatigue limit states

GS geometric stress

GSR geometric stress range

HAT highest astronomical tide

HAZ heat affected zone

HISC hydrogen-induced stress cracking

HV Vicker's hardness

RCS Recognized Classification Society

IC impressed current

ipb in-plane bending

JIP joint industry project

LAT lowest astronomical tide

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LBZ	local brittle zone
LRFD	load and resistance factor design
MC	material category
MIC	microbiologically influenced corrosion
MPI	magnetic particle inspection
MPM	most probable maximum
NDT	non-destructive testing
opb	out-of-plane bending
POD	probability of detection
PQR	procedure qualification record
PWHT	post weld heat treatment
QA	quality assurance
QC	quality control
QMS	quality management system
Q&T	quenched and tempered
RAO	response amplitude operator
rms	root-mean-square
RT	radiographic testing
SAW	submerged arc welding
SDOF	single degree of freedom
SLS	serviceability limit states
SRA	structural reliability analysis
SRC	seismic risk category
SSSV	subsurface safety valve
TMCP	thermo-mechanically controlled process
TRF	transfer function
ULS	ultimate limit states
UT	ultrasonic testing

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VIV vortex induced vibrations

WPS welding procedure specification

WSD working stress design

WPQ welding procedure qualification

6 Overall considerations

6.1 Types of fixed steel offshore structure

6.1.1 General

A fixed steel offshore structure can take many forms including:

— braced caisson (3.8);

— free-standing caisson (3.24);

— jacket (see 6.1.2);

— monotower (3.31);

— tower (see 6.1.3);

— steel gravity structure (3.47);

— jack-up (see 6.1.4).

NOTE 1 There have been historical differences in the usage and understanding of the terms “jacket” and “tower”, particularly between the USA and Europe. The difference in such understanding of the terms has no significant impact on the application of this document as long as the differences in structural behaviour are considered in the analyses of the different structures.

NOTE 2 There have been historical differences, which continue to exist, in the use and understanding of the term “caisson”. In the offshore oil and gas industry, this term, together with its variants "braced caisson" or "free-standing caisson", has traditionally been used to refer to a particular type of minimum fixed structure, where the main component is a relatively large diameter tubular member, with or without additional lateral support, intended to satisfy various functional requirements such as supporting one or more wells, or supporting small decks and associated facilities. Conversely, in the geotechnical arena the term “caisson” has traditionally been used to refer to "foundation caisson", i.e. foundation component/system consisting of shorter and more rigid chamber of larger diameter or larger lateral dimensions than the caisson structures described above.

6.1.2 Jackets

Jackets and towers are superficially similar structures, the essential differences between them being the arrangement of the foundation piles and, associated with this, the location of axial force transfer from the structure and topsides into the piles. The location and method of transferring the axial forces results in significant differences in the behaviour of jackets and towers.

A jacket is a welded tubular space frame with three or more vertical (or near vertical) tubular chords (the legs) and a bracing system between the legs. The jacket provides support for the foundation piles, conductors, risers, and other appurtenances.

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A jacket foundation typically includes leg piles that are inserted through the legs and are connected to the legs either at the top, by welding or mechanical means, or along the length of the legs, by grouting. Additional piles, called skirt piles, can be inserted through and connected to sleeves at the base of the structure. Leg and skirt piles jointly anchor the structure and transfer both vertical and horizontal actions to the seabed.

Where the foundation piles are connected to the legs only at the top of the jacket, the axial forces (including moments caused by shear forces) are transferred to the piles at the connection and the jacket "hangs" from the piles.

Where the foundation piles are connected to the legs by grouting along the full length of the leg, the jacket behaviour is similar to that of a tower, with the legs and piles acting together as composite components.

6.1.3 Towers

A tower type structure is supported by foundation arrangements at the base of the structure.

The tower is made of a welded tubular space frame with three or more vertical (or near vertical) tubular chords, called legs, with a bracing system between the legs. The tower provides support for the topsides, conductors, risers and other appurtenances.

A tower foundation usually includes cluster piles, which are inserted through and connected to sleeves around the (corner) legs at the base of the structure. Additional piles, called skirt piles, can be inserted through and connected to sleeves at the base and along the perimeter of the structure. As an alternative to piles, a tower can be supported by another non-superficial foundation system that supports it at its base, such as bucket foundations. Cluster and skirt piles, or another non-superficial foundation system, anchor the structure and transfer both vertical and horizontal actions to the seabed.

The global behaviour of a tower is that of a vertical cantilever, with all actions being transferred to the foundation system at the base of the tower.

6.1.4 Jack-ups

A jack-up comprises a floating hull and one or more legs, which can move up and down relative to the hull. A jack-up reaches its operational mode by lowering the leg(s) to the sea floor and then raising the hull to the required elevation. Most jack-ups have three or more legs, each of which can be moved independently, and which are supported on the sea floor by spudcans or mat type foundation.

Most jack-ups are built for short-term operations at different locations around the world. As metocean and foundation conditions vary between locations, such jack-ups are assessed for each particular location, see ISO 19905-1. A few jack-ups are purpose built for production operations at a single location, albeit that there can be an intent for eventual reuse at further locations.

Two options are available for a jack-up within the framework of the International Standards on offshore structures prepared by TC 67/SC 7. These are:

a) design and operation to the requirements of this document;

b) site-specific assessment to the requirements of ISO 19905-1, in which case either the periodic inspection requirements of a RCS or the alternative requirements for long-term deployment in ISO 19905-1 shall be satisfied.

NOTE 1 ISO 19905-1 applies only to structures holding valid certification as self-elevating units from an RCS, or equivalent.

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NOTE 2 See ISO 19905-1 for the definition of RCS.

Option a) above shall be used for a jack-up purpose built for production at a particular location and where option b) does not apply. Option b) should be used for a jack-up built to operate in a variety of locations. In other cases, when an existing jack-up is to be used for an extended period at a single location for production (rather than for exploration, appraisal or other short-term application) either the reuse requirements in ISO 19901-9 or the requirements of ISO 19905-1 shall apply.

When option a) is selected, some aspects of the requirements of this document do not apply, including the determination of environmental actions and action effects due to dynamic response, structural behaviour and foundation behaviour. The alternative procedures given in ISO 19905-1 may be used in such cases. However, the procedures shall be modified as necessary to give an equivalent level of structural integrity to that intended by this document. The foundation strength, the foundation preload, overturning, leg chord strength and the strength of the holding system shall be checked in accordance with the requirements of ISO 19905-1.

6.2 Planning

6.2.1 General

Adequate planning shall be completed before actual design is started to obtain a safe, workable, and economical offshore structure. The initial planning shall include the determination of hazards, design situations and design criteria upon which the design of the structure is to be based, following the general requirements and conditions specified in ISO 19900.

6.2.2 Hazards

Offshore structures are exposed to various hazards of greatly different types and having vastly different probabilities of occurrence. Hazards can be categorized in several ways, one of which is based on probability of occurrence. Using this criterion, hazards can be divided into three main groups:

— **group 1**

hazards with a probability of occurring or being exceeded of the order of 10^{-2} per annum (return periods of the order of 100 years);

— **group 2**

hazards with a 10 to 100 times lower probability of occurring or being exceeded, i.e. probabilities of the order of 10^{-3} to 10^{-4} per annum (return periods of the order of 1 000 to 10 000 years);

— **group 3**

hazards with a probability of occurring or being exceeded less than 10^{-4} per annum (return periods in excess of 10 000 years).

These probabilities (return periods) should be seen as an indication of the order of magnitude rather than as precise numbers, since accurate databases for such low probabilities of occurrence rarely exist.

The main hazards that are faced by an offshore structure include:

— extreme and abnormal metocean conditions;

— active geological processes such as extreme and abnormal earthquakes, seabed instability and scour;

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— ice and icebergs;

— vessel (ship) collisions;

— dropped objects;

— fires and explosions.

Designers can choose between avoiding a hazard (e.g. by taking special preventive measures such as operational restrictions), minimizing the (structural) consequences of the considered hazard (e.g. by implementing protective measures) or designing for the hazard. The options of avoiding the hazard and minimizing consequences are not extensively addressed in this document.

6.2.3 Designing for hazards

For an offshore structure, each hazard generates a number of design situations which, in accordance with ISO 19900, are dealt with by satisfying a number of limit states. Each limit state is verified by requiring that the associated action effects meet given design criteria.

Designing for hazards of group 1 from exposure to design environmental conditions is normally treated by the regular design process and incorporated in the verification of relevant limit states. Design wind, wave and current conditions and the corresponding extreme metocean parameters are described in ISO 19901-1, while the associated design actions (action effects) are given in Clause 9. The extreme level earthquake is described in ISO 19901-2 and the associated design actions (action effects) are given in Clause 11. Verification of the ultimate limit states (ULS) of structural components is described in Clauses 13, 14, 15 and 17. Verification of fatigue limit states (FLS) is described mainly in Clause 16 and partly in Clause 15.

Other hazards belonging to group 1 and not treated by the regular design process, as well as hazards belonging to group 2, are specially addressed by a requirement that the structure satisfy particular accidental and abnormal design situations, see 10.1.2 and 10.1.3.

Hazards falling into group 3 are normally neglected for design.

6.2.4 Design situations and criteria

Design situations as used herein include all the service and operational requirements resulting from the intended use of the structure (see 6.3). Criteria that are to be met by the design are directly related to the specific formulation of the design situations. Therefore, design situations and design criteria shall not be separated from one another. They are jointly specified in Clauses 8 to 17.

6.2.5 Design for inspection and maintenance

During the planning stage a philosophy for inspection and maintenance should be developed. The design of the structure as a whole, as well as the structural details, should be consistent with this philosophy. In preparing the philosophy, a realistic assessment should be made of the ability to actually achieve the intended quality of the results of inspection and maintenance efforts. This assessment should be taken into account during the design to fine-tune design situations and criteria. Relevant requirements related to inspection and maintenance requirements are given in ISO 19901-9.

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6.2.6 Foundations and active geological processes

The capacity and suitability of the foundations and the susceptibility to active geological processes shall be considered in selecting the type of structure and the location. Requirements and guidance are given in ISO 19901-2 and ISO 19901-4.

6.2.7 Regulations

Further to the requirements given in this document, depending upon the geographic location of the structure, additional national regulations and standards can apply. This is relevant to all phases of planning, design, fabrication, transportation, installation, service and removal.

6.3 Service and operational considerations

6.3.1 General considerations

The principal service and operational requirements to be considered to establish the design basis for fixed steel offshore structures are summarized in ISO 19900. Operational requirements include:

a) service requirements, i.e. function of the platform;

b) manning;

c) conductors and risers;

d) equipment and material layouts, including rig access to conductor slots;

e) personnel and material transfer;

f) motions and vibrations;

g) any special requirements;

h) location and orientation.

In addition, requirements for decommissioning and removal shall be considered.

6.3.2 Water depth

The water depth, surge height and tide shall be determined as accurately as possible, so that elevations can be established for boat landings, fenders, decks, and corrosion protection; see ISO 19901-1 for information on these parameters. The potential subsidence of the sea floor and settlement of the structure shall be considered when determining the design water depth.

6.3.3 Structural configuration

6.3.3.1 General

Requirements for the structural configuration are given in ISO 19900; some further requirements are given in 6.3.3.2 and 6.3.3.3.

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6.3.3.2 Deck elevation and air gap

In general, the elevation of the lowest deck, e.g. bottom of steel, and any facilities or equipment hanging below the lowest deck, shall be set to provide sufficient clearance (air gap) to allow the passage of wave crests because very large actions can occur if a wave hits the deck. Adequate deck elevation further ensures that green water does not interfere with platform operation or safety devices.

Air gap should be calculated considering uncertainty in water depth, structure settlement, sea floor subsidence, sea level rise, storm surge and tide, and extreme (ULS) or abnormal (ALS) crest height, as appropriate. Because the highest water surface is normally calculated as the most probable maximum value, there is a significant chance that it can be exceeded. For typical deck areas, for extreme crest heights this can result in water surface elevations some 15 % in excess of the calculated value – see ISO 19901-1 Clause A.8.7. Such increase should be accounted for in setting the required air gap or in the calculation of local forces on exposed parts, as appropriate. For abnormal crest heights, further investigations are necessary.

Whenever the air gap requirement is not satisfied, the structure shall be designed to resist any wave and current actions on the deck(s), including the actions on facilities or equipment supported by the deck(s). For water surfaces in excess of the calculated crest height, such actions may be treated as local actions only, i.e. have no impact of global loading.

A.6.3.3.2 provides guidance on the calculation of deck elevation.

6.3.3.3 Topsides reactions

Topsides support reactions and centres of gravity associated with permanent and variable actions shall be provided.

6.3.4 Access and auxiliary systems

The number and location of stairways and access boat landings on the structure shall, as a minimum, be governed by safety considerations. Consideration shall be given to providing access to the water level for sea escape and to facilitate self-rescue in man-overboard situations. Furthermore, operating requirements as well as installation, maintenance and inspection requirements shall be considered in determining the number and location of access platforms, walkways and stairways.

6.4 Safety considerations

General requirements for personnel safety and possible damage to or loss of the structure are presented in ISO 19900. With regard to methods of protecting against fires and explosions, the selection of the system depends upon the function of the platform. Procedures should conform to ISO 13702 [4]. National and regional requirements also apply, where they exist.

6.5 Environmental considerations

6.5.1 General

Information on environmental conditions and guidance on its use is provided in ISO 19900. Specific requirements are contained in ISO 19901-1, ISO 19901-2, ISO 19906, as well as in this document.

In the absence of site-specific information on the environmental conditions, ISO 19901-1 contains indicative values for the extreme conditions in certain areas. These values may be used for conceptual

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design studies. The owner shall review the validity of these values and, if necessary, use site specific data for the final design of a structure, see also 6.5.2 and 7.3.

6.5.2 Selecting design metocean parameters and action factors

Design in accordance with this document shall be based on a return period of 100 years. Where the data are available and sufficient, the 100-year return period may apply to responses (action effects) of the structure instead of to metocean design parameters. Further requirements and guidance are provided in Clause 9 and in ISO 19901-1.

In some cases, lower return periods may be considered, provided that the partial action factors used and the deck elevation selected can be demonstrated to provide structural reliability levels consistent with those implicit in this document.

Some aspects that can affect the selection of partial action factors are:

a) the intended use of the structure;

b) the structure design service life;

c) the time and duration of construction, installation, and actions due to environmental conditions during these operations;

d) the exposure level;

e) the requirements of regulators;

f) the uncertainty in actions associated with specific metocean parameters and with operating conditions, and the ability to predict the structure's resistance to the actions;

g) the probability of occurrence and magnitude of extreme and abnormal metocean actions, taking into account the joint frequency of occurrence of extreme winds, waves and currents (both in magnitude and direction);

h) the probability of occurrence and magnitude of actions due to extreme and abnormal earthquakes, see ISO 19901-2;

i) the probability of occurrence and magnitude of extreme and abnormal actions due to sea ice, see ISO 19906.

In addition to specifying extreme and abnormal environmental parameters, the owner shall specify the limiting corresponding conditions for performing any particular operation inducing specific actions, or for any particular situation of the platform.

6.6 Exposure levels

Structures can be categorized by various levels of exposure to determine criteria that are appropriate for the intended service of the structure. The levels (L1, L2, L3) are determined by consideration of life-safety and of environmental and economic consequences.

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

The consequence category considers the potential risk to life of personnel brought in to react to any incident, the potential risk of environmental damage and the potential risk of economic losses.

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Exposure levels (L1, L2, L3) are considered in detail in ISO 19900.

In this document, only L1 structures are addressed in detail. Some consideration is given to aspects of design of L2 and L3 structures.

NOTE More detailed requirements for L2 and L3 structures are planned for future editions.

6.7 Assessment of existing structures

Assessment of existing structures shall be performed in accordance with ISO 19900 and ISO 19901-9 to demonstrate either full compliance with the requirements of this document or fitness-for-service.

6.8 Structure reuse

Structures can be removed and relocated for use at a new location. In such cases, the structure shall be assessed in accordance with ISO 19900 and ISO 19901-9, and for the use (including exposure level) and conditions that are applicable at the new location.

7 General design requirements

7.1 General

The general principles on which structural design requirements given in Clauses 6 to 22 are based are documented in ISO 19900. ISO 19900 requires that structural design be performed with reference to a specified set of limit states. For each limit state, design situations shall be determined, and an appropriate calculation model shall be established. ISO 19900 describes:

— the variables that occur in a calculation model, comprising geometrical parameters, actions and properties of materials and soils;

— the analyses to be performed;

— the design format using partial action and partial resistance factors.

Clause 7 outlines the overall requirements for:

a) properties of materials (see 7.2);

b) incorporating limit states (see 7.3);

c) determining design situations (see 7.4);

d) structural modelling and analysis (see 7.5);

e) design of the structure (see 7.6 to 7.12).

These requirements are a minimum.

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7.2 Material properties for steel

The basic material properties necessary for the analysis and design of structures to this document are modulus of elasticity, Poisson's ratio, yield strength and ultimate tensile strength. Further material property requirements are presented in 19, 20, A.19 and A.20.

The values of modulus of elasticity (Young's modulus) and Poisson's ratio may be taken, in lieu of more detailed information, as 205 000 MPa and 0,3, respectively.

For design, yield strength is normally assumed as the specified minimum yield strength; see Clause 19.

7.3 Incorporating limit states

ISO 19900 divides the limit states into four categories:

a) Ultimate limit states (ULS)

The design actions to be used in the various ULS are specified in Clauses 8, 9 and 11. The design resistances and the application of the ULS are specified in Clauses 13, 14, 15 and 17.

b) Serviceability limit state (SLS)

The design shall comply with the serviceability requirements of caissons, conductors, risers and topsides interfaces, as defined by the owner.

c) Fatigue limit states (FLS)

The various FLS are addressed in Clause 16, covering methods, actions and resistances. Additionally, FLS requirements for grouted connections, mechanical connections and clamps are given in Clause 15.

d) Abnormal/accidental limit states (ALS)

ALS are addressed in Clause 10, in respect of actions and modifications to both partial action factors and partial resistance factors.

7.4 Determining design situations

Determination of situations for which structures are to be designed is the responsibility of the owner in accordance with the requirements of a regulator, where one exists. Aspects significant in determining design situations include:

a) service requirements for the intended function of the structure;

b) expected service life for each function;

c) method and duration of construction activities;

d) expected method of removal of the structure and, where applicable, any intended relocation;

e) hazards (accidental and abnormal events) to which the structure can be exposed during its design service life;

f) potential consequences of partial or complete structural failure;

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g) the nature and severity of environmental conditions to be expected during its construction and design service life.

Usually, three sets of environmental conditions should be considered: one associated with operating situations (normal conditions), one associated with extreme conditions, and one associated with abnormal conditions.

7.5 Structural modelling and analysis

Internal forces in components shall be determined by an analysis method that is suitable for statically indeterminate structures and that accounts for axial, bending, shear and torsion action effects. In general, a linear elastic model of the structure is sufficient; however, the non-linear behaviour of structure-foundation interaction shall be addressed. Non-linear geometrical effects (both p-δ and P-Δ) shall be addressed where applicable. For piled foundations, the non-linear behaviour of the axial and lateral pile-soil support shall be explicitly modelled to ensure load-deflection compatibility between the structure and pile-soil system. For a pile analysis, the effects of geometrical and material non-linearities shall also be considered within the structure-pile-soil system. Additional or adjusted partial action factors shall not be used as a substitute for a rational analysis to determine internal forces. Other aspects of structural modelling and analysis are discussed in Clauses 8 to 17.

7.6 Design for pre-service and removal situations

The structure shall be designed to resist actions occurring during fabrication, loadout, transportation, installation and removal, as specified in Clause 8. For structures that are intended to be relocated to new sites, actions resulting from removal, on-loading, transportation, upgrading, and re-installation shall be considered in the design, in addition to the above construction actions.

Methods for fabrication, assembly, loadout, transportation, installation and removal of the structure shall be considered during design to identify potential difficulties and limitations for available equipment. Design situations for partially fabricated components of the structure and for the assembled structure as a whole shall be established. Fabrication and assembly tolerances assumed in design shall be compatible with those specified in the construction specifications and achievable during construction.

7.7 Design for the in-place situation

The structure shall be designed to resist permanent actions, variable actions, environmental actions, repetitive actions and accidental actions occurring during its design service life, as well as rational combinations thereof, to obtain the most onerous conditions for all structural components. The representative values of these actions are given in Clauses 9 to 11. Clarification on the selection of representative values and return periods is provided in A.7.6.

7.8 Determination of component resistances

7.8.1 General

The resistances of components in a fixed steel offshore structure shall, wherever possible, be derived from the formulae given in Clauses 13 to 15. These formulae provide representative resistances to which the partial resistance factors are applied.

NOTE Clause 13, in addition to providing formulae for determining the strength of intact tubular members, also provides formulae for determining the strength of damaged tubulars, including the effects of repair by grouting.

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Where the resistance of a component is not adequately described in Clauses 13 to 15, the resistance shall be determined from a rational study of the behaviour of the component. Both physical testing and computer simulation may be used to derive representative resistances but, in both cases, the results shall be compared to any other available test data.

7.8.2 Physical testing to derive resistances

Physical tests may be used to derive resistances for specific components. Care shall be taken to account for the differences between the test arrangements and the arrangement of the component within the structure. Guidance on these differences is given in A.7.8.2.

Comparisons shall be made with other available test data to give an indication of the variability of the component behaviour.

A.7.8.2 describes a procedure to determine the design value of component resistance from test results assuming the results fit to a normal distribution. The design value is calculated to represent the 95 % fractile at a 75 % confidence level.

7.8.3 Resistances derived from computer simulations validated by physical testing

Computer simulations can provide an indication of resistance and can be particularly valuable for investigating the effects of changes of various parameters. Computer simulations shall be validated against physical test data wherever possible. If test data are not available, the requirements of 7.8.5 apply.

7.8.4 Resistances derived from computer simulations validated against design formulae

As an alternative to validation against physical test data, computer simulations may be validated against the formulae given in Clauses 13 to 15. It should be noted that Clauses 13 to 15 give representative resistances, and therefore take account of structural behaviour variability.

7.8.5 Resistances derived from unvalidated computer simulations

Unvalidated computer simulations may be used only when no physical test data or design formulae are available. The similarity of available data and the component being simulated is a matter of judgment, and the analyst shall take account of statistical variability of material and component behaviour, and limitations and errors that can be introduced in computer simulations.

7.9 Strength and stability checks

7.9.1 Action and resistance factors

A partial action factor shall be applied to each of the external actions in the combinations given in Clauses 8 to 11. The combination of factored representative actions results in design values of internal forces. These internal forces are designated by the symbol S in Clauses 8 to 11.

A partial resistance factor is applied to the strength of each member, joint and foundation component to determine its design resistance.

7.9.2 Strength and stability equations

Each component shall be proportioned to resist the internal forces, S. The appropriate strength and stability formulae are given in Clauses 13, 14, 15 and 17. These formulae comprise:

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a) the formulae for the representative strength of the component;

b) the partial resistance factors;

c) the internal force, *S*, from the design actions specified in Clauses 8 to 11.

7.9.3 Unfactored actions

Where actions are time-varying and non-synchronous, the most onerous values of action effects cannot generally be determined by simply adding factored individual actions. In some construction and installation situations, the action effects are best computed from unfactored actions and by investigating the sensitivity of the action effects with realistic variations of the governing parameters. The design values of the internal forces, *S*, may then be obtained by factoring the action effects by the partial action factors given in Clause 8.

7.10 Robustness

7.10.1 General

A structure shall incorporate robustness through consideration of the effects of all hazardous events and their probabilities of occurrence, to ensure that consequent damage is not disproportionate to the cause. A group 1 hazardous event (see 6.2.2) typically does not cause damage although limited localized damage can occur. Damage from an event due to a group 2 hazardous event (see 6.2.2) shall not lead to complete loss of integrity of the structure. In such cases, the structural integrity in the damaged state shall be sufficient to allow a process system shut down and a safe evacuation, see 7.10.2.

Robustness is achieved by:

a) designing the structure in such a way that any single load bearing component exposed to a hazardous event can become incapable of carrying its normal design actions without causing collapse of the structure or any significant part of it, or

b) ensuring (by design or by protective measures) that no critical component exposed to a hazardous event can be made ineffective, or

c) a combination of a) and b), above.

7.10.2 Damage tolerance

For new structures, or existing structures being assessed for compliance with this document, the extent of damage following a group 2 hazard event (accidental or abnormal) can only be determined by analysis (see 10.1). If a linear structural analysis of such an event indicates no damage, then no further checks for that situation are required. However, if damage is indicated, a reliable prediction of the nature and the extent of the damage normally requires the application of non-linear structural analysis methods (see 12.6).

The requirements for damage tolerance are, to an extent, dependent on the environmental conditions in the geographic area, regulatory requirements, and the owner's preference. The possible requirements vary between the following:

— the platform shall remain intact for a period sufficient for all personnel to be evacuated (if manned at the time of the hazardous event), for all process plant to be made safe and for all risk of pollution to be removed;

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— the platform shall remain intact and without further damage for such time as it takes for repairs to be effected and for the platform to be made fit-for-service;

— the platform shall remain fit-for-service throughout.

In lieu of specific requirements, the post-damage design situation shall be analysed using environmental conditions corresponding to actions (action effects) of a return period commensurate with twice a conservative assessment of the time required to effect sufficient repairs (including inspection, design, fabrication and installation) to restore the structure to a fit-for-service condition; the minimum return period shall be one year. The specified partial action factors for the in-place situation (see Clause 9) shall be used. For intact components, the partial resistance factors and strength requirements given in Clauses 13, 14, 15 and 17 shall be applied. For damaged tubular members, the strength shall be assessed either using the formulations given in Clause 13 together with the specified partial resistance factors or using a rational approach. For other damaged components, the strength shall either be assessed using a rational approach, e.g. the procedures of 7.8 (see A.7.8 for guidance on appropriate partial resistance factors), or shall be neglected.

7.11 Reserve strength

7.11.1 New structures

Generally, the design of fixed steel offshore structures proceeds on the basis of a component-based design approach. Alternatively, a system-based approach may be adopted in which the system reserve strength (the margin by which the system withstands metocean action effects in excess of the design action effects) is compared with a target value. Reserve strength ratio (RSR) has become an established measure of system reserve strength.

For the system approach, a common tool to determine system strength is (quasi-static) non-linear pushover analysis; see 12.5.4. For a dynamically-sensitive structure, a dynamic system strength analysis can be required. RSR is calculated using a non-linear pushover analysis in the following manner:

— Apply the unfactored permanent and variable actions that co-exist with the unfactored 100 year metocean action calculated in accordance with Clause 9.

— Apply the unfactored 100 year metocean action calculated in accordance with Clause 9 multiplied by a scaling factor, normally less than 1,0.

— Gradually increase the scaling factor until the ultimate strength, F_{collapse}, of the structure has been determined. This normally requires the analysis to be continued beyond the ultimate strength value.

— Compute the structure's RSR using Formula (7.11-1), in which F_{100} is the unfactored 100 year metocean action calculated in accordance with Clause 9:

$$R_{\text{RS}} = F_{\text{collapse}} / F_{100} \tag{7.11-1}$$

The calculation of RSR should proceed using actual values of yield strength rather than SMYS values. Such information is not normally available during the design phase of new structures, so the calculation may be based on yield strength values 10 % larger than the likely SMYS values.

Target values of RSR depend upon, amongst others, the geographical region in which the structure is located, exposure level, engineering practices in the region in question, regulator's requirements (where one exists) and owner's preferences.

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NOTE There is no industry consensus as to target values. Notwithstanding, a typical value for a L1 structure is given in A.7.11.1.3. However, this typical value can need adjusting to account for inaccuracies in the RSR analysis procedure; see A.12.6.1.

Subclause 9.10 describes application of both the component-based and system-based approaches to the design of fixed steel structures. The partial action factors for metocean actions shall be determined based on the considerations given in Clause 9.

When using this document for structures that provide less inherent system reserve strength (smaller RSR) for the metocean actions than a typical space frame type structure, the partial action factor for metocean actions shall be increased to yield the same RSR as for a typical space frame type structure; see A.7.11.1.3.

7.11.2 Existing structures

During its design service life, the reserve strength of a structure can vary (increase or decrease) due to a variety of causes. ISO 19901-9 provides requirements for the assessment of existing structures, including the use of system strength approaches.

7.12 Indirect actions

Consideration shall be given to internal forces and stresses induced by indirect actions, including imposed or constrained deformations, temperature changes, relaxation, and prestressing.

7.13 Structural reliability analysis

The objective of structural reliability analysis (SRA) is to determine the probability of an event (usually a failure event) occurring during a specified reference period. The failure probability during the structure's design service life (or for some other specified reference period) can be of use in economic risk models; annual failure probabilities are generally evaluated when considering life-safety issues.

SRA accounts for the effects of uncertainties in the actions, resistances and modelling of (parts of) a structure and its performance. Uncertainties exist due to the natural variation, the physical uncertainty or the randomness in the basic variables (aleatoric or Type I uncertainties), and due to those factors that are a function of a lack of complete understanding or knowledge (epistemic or Type II uncertainties).

Reliability models and methods should be tested prior to their application. Their predictions of failure rates should be compared with similarly derived values for geographical areas where there is experience of structural survival (and failure) in extreme storms and well-proven metocean data, where available. As well as testing the models and methods, the exercise aids the engineering judgment of subsequent results.

For areas where an established practice in the application of SRA exists (see A.9.9.3.3), target reliabilities have often been determined particularly where the application has led to the derivation of corresponding partial factors. These target reliabilities normally allow for the consequences and nature of failure and have been calibrated against well-established cases (jacket structures) known to have adequate safety but without unnecessary conservatism. New SRA users should compare their evaluated failure probabilities with such target values and, if significant differences are found, identify the source of such differences and adjust their modelling accordingly.

SRA is not normally undertaken as part of a new design in accordance with this document, but may be used during the initial design process to provide comparative data. SRA may be used in the (re)calibration of partial action and resistance factors for special or unusual circumstances, in decision analyses to support inspection and monitoring programmes, and in some cases in the structural assessment of

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existing structures – see ISO 19901-9. Normally, new designs shall be executed using the design procedures presented in this document.

8 Actions for pre-service and removal situations

8.1 General

8.1.1 Coverage

Clause 8 presents requirements for pre-service and removal situations. The requirements apply to both the structure and to any temporary components, such as buoyancy aids, mooring supports or sea fastenings attached to the structure for pre-service and removal situations.

The primary objective in addressing pre-service situations is to ensure that a structure begins its design service life at an offshore location with sufficient strength and structural integrity. Clause 8 covers the following topics:

a) the type of actions to be included;

b) procedures for determining representative values for the actions;

c) the partial action factors to be applied;

d) methods for determining the internal forces due to the effect of factored actions or combinations of factored actions.

8.1.2 Design situations

Pre-service design situations are generally governed by permanent and variable actions and include:

a) fabrication (including assembly during fabrication);

b) loadout (including float-out);

c) transportation;

d) installation (including launching and uprighting).

The requirements for b) to d) are primarily addressed in ISO 19901-6; however, some aspects are also addressed within this document.

Removal design situations can include those addressed from pre-service considerations. However, given the wide variability of techniques and procedures used for removal, it is difficult to provide an exhaustive list of corresponding design situations.

Further requirements concerning pre-service situations are given in Clause 19 to 22.

8.1.3 Actions

Actions associated with these design situations, mainly due to the weight of structural components, appurtenances and equipment, are predominantly static. When dynamic effects can be important, these shall be considered. When appropriate, environmental and accidental actions shall also be given due attention, following the requirements of Clauses 9 and 10.

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