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Petroleum and natural gas industries — Specific requirements for offshore structures —

Part 4:
Geotechnical and foundation design considerations

Industries du pétrole et du gaz naturel — Exigences spécifiques relatives aux structures en mer —

Partie 4: Bases conceptuelles des fondations

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Foreword

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

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

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

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

For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for the petroleum, petrochemical and natural gas industries*, Subcommittee SC 7, *Offshore structures*.

This second edition cancels and replaces the first edition (ISO 19901-4:2003), which has been technically revised.

ISO 19901 consists of the following parts, under the general title *Petroleum and natural gas industries — Specific requirements for offshore structures*:

— *Part 1: Metocean design and operating considerations*

— *Part 2: Seismic design procedures and criteria*

— *Part 3: Topsides structure*

— *Part 4: Geotechnical and foundation design considerations*

— *Part 5: Weight control during engineering and construction*

— *Part 6: Marine operations*

— *Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units*

— *Part 8: Marine soil investigations*

The following part is under preparation:

— *Part 9: Structural integrity management*

ISO 19901 is one of a series of standards for offshore structures. The full series consists of the following International Standards which are relevant to offshore structures for the petroleum and natural gas industries:

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

— ISO 19901 (all parts), *Petroleum and natural gas industries — Specific requirements for offshore structures*

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

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

— ISO 19904, *Petroleum and natural gas industries — Floating offshore structures*

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

— ISO/TR 19905-2, *Petroleum and natural gas industries — Site-specific assessment of mobile offshore units — Part 2: Jack-ups commentary and detailed sample calculation*

— ISO 19905-3, *Petroleum and natural gas industries — Site specific assessment of mobile offshore units — Part 3: Floating units (under preparation)*

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

Other ISO standards can have implications for the geotechnical design of foundations for offshore structures, in particular:

— ISO 13623 (all parts), *Petroleum and natural gas industries — Pipeline transportation systems*

— ISO 13628 (all parts), *Petroleum and natural gas industries — Design and operation of subsea production systems*

Introduction

The International Standards for offshore structures, ISO 19900 to 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 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.

For foundations, some additional considerations apply. These include the time, frequency and rate at which actions are applied, the method of foundation installation, the properties of the surrounding soil, the overall behaviour of the seabed, effects from adjacent structures and the results of drilling into the seabed. All of these, and any other relevant information, need to be considered in relation to the overall reliability of the foundation.

These International Standards are intended to provide wide latitude in the choice of structural configurations, materials and techniques without hindering innovation. The design practice for the foundations of offshore structures has proved to be an innovative and evolving process over the years. This evolution is expected to continue and is encouraged. Therefore, circumstances can arise when the procedures described herein or in ISO 19900 to ISO 19906 (or elsewhere) are insufficient on their own to ensure that a safe and economical foundation design is achieved.

Seabed soils vary. Experience gained at one location is not necessarily applicable at another, and extra caution is necessary when dealing with unconventional soils or unfamiliar foundation concepts. Sound engineering judgment is therefore necessary in the use of this part of ISO 19901.

For an offshore structure, the action effects at the interface between the structure’s subsystem and the foundation’s subsystem(s) are internal forces, moments and deformations. When addressing the foundation’s subsystem(s) in isolation, these internal forces, moments and deformations can be considered as actions on the foundation’s subsystem(s) and this approach is followed in this part of ISO 19901.

Some background to and guidance on the use of this part of ISO 19901 is provided for information in Annex A. Guidance on foundations in carbonate soils is provided for information in A.6.4, but there is, as yet, insufficient knowledge and understanding of such soils to produce normative requirements.

In this part of ISO 19901, in accordance with the latest edition of the ISO/IEC Directives, Part 2, the following verbal forms are used:

— ‘shall’ and ‘shall not’ are used to indicate requirements strictly to be followed in order to comply with the document and from which no deviation is permitted;

— ‘should’ and ‘should not’ are used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited;

— ‘may’ and ‘need not’ are used to indicate a course of action permissible within the limits of the document;

— ‘can’ and ‘cannot’ are used for statements of possibility and capability, whether material, physical or causal.

Petroleum and natural gas industries — Specific requirements for offshore structures —

Part 4: Geotechnical and foundation design considerations

1 Scope

This part of ISO 19901 contains provisions for those aspects of geoscience and foundation engineering that are applicable to a broad range of offshore structures, rather than to a particular structure type. Such aspects are:

— site and soil characterization;

— identification of hazards;

— design and installation of shallow foundations supported by the seabed;

— design and installation of pile foundations;

— soil-structure interaction for auxiliary structures, e.g. subsea production systems, risers and flowlines (guidance given in A.10);

— design of anchors for the stationkeeping systems of floating structures (guidance given in A.11).

Particular requirements for marine soil investigations are detailed in ISO 19901-8.

Aspects of soil mechanics and foundation engineering that apply equally to offshore and onshore structures are not addressed. The user of this part of ISO 19901 is expected to be familiar with such aspects.

ISO 19901-4 outlines methods developed primarily for the design of shallow foundations with an embedded length (L) to diameter (D) ratio $L/D < 1$ (Clause 7) and relatively long and flexible pile foundations with $L/D > 10$ (Clause 8). This part of ISO 19901 does not apply to intermediate foundations with $1 < L/D < 10$. Such intermediate foundations, often known as 'caisson foundations', comprise either shallow foundations with skirts penetrating deeper into the seabed than the width of the foundation, or shorter, more rigid and larger diameter piles than those traditionally used for founding offshore structures. The design of such foundations can require specific analysis methods; it is important that any extrapolation from the design methods described in this part of ISO 19901 to intermediate foundations be treated with care and assessed by a geotechnical specialist.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

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

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

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

ISO 19901-7:2013, *Petroleum and natural gas industries — Specific requirements for offshore structures — Part 7: Stationkeeping systems for floating offshore structures and mobile offshore units*

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

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

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

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*

ISO/TR 19905-2, *Petroleum and natural gas industries — Site-specific assessment of mobile offshore units — Part 2: Jack-ups commentary and detailed sample calculation*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19900, ISO 19901 (all parts) and the following apply.

3.1
action
external load applied to the structure (direct action) or an imposed deformation or acceleration (indirect action)

Note 1 to entry: An imposed deformation can be caused by fabrication tolerances, differential settlement, temperature change or moisture variation. An earthquake typically generates imposed accelerations.

[SOURCE: ISO 19900:2013, 3.1]

3.2
action factor
partial safety factor applied to a design action

3.3
basic variable
one of a specified set of variables representing physical quantities which characterize actions, environmental influences, geometric quantities, or material properties including soil properties

[SOURCE: ISO 19900:2013, 3.7]

3.4
characteristic value
value assigned to a basic variable associated with a prescribed probability of not being violated by unfavourable values during some reference period

Note 1 to entry: 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.

Note 2 to entry: For variable actions, the characteristic value corresponds to either of the following (see ISO 2394:2015, 2.2.30):

— an upper value with an intended probability of not being exceeded or a lower value with an intended probability of being achieved, during some specific reference period;

— a nominal value, which may be specified in cases where a statistical distribution is not known.

[SOURCE: ISO 19900:2013, 3.10]

3.5
design actions
combination of representative actions and partial safety factors representing a design situation for use in checking the acceptability of a design

3.6
design value
value derived from the representative value for use in the design verification procedure

[SOURCE: ISO 19900:2013, 3.18]

3.7
drained condition
condition whereby the applied stresses and stress changes are supported by the soil skeleton and do not cause a change in pore pressure

[SOURCE: ISO 19901-8:2014, 3.11]

3.8
effective foundation area
reduced foundation area having its geometric centre at the point where the resultant action vector intersects the foundation base level

3.9
limit state
state beyond which the structure no longer satisfies the relevant design criteria

[SOURCE: ISO 19900:2013, 3.2]

3.10
material factor
partial safety factor applied to the characteristic strength of the soil, the value of which reflects the uncertainty or variability of the material property

Note 1 to entry: See ISO 19900.

3.11
representative value
value assigned to a basic variable for verification of a limit state

[SOURCE: ISO 19900:2013, 3.38]

3.12
resistance
capacity of a component, or a cross-section of a component, to withstand action effects without failure

[SOURCE: ISO 19900:2013, 3.39]

3.13
resistance factor
partial safety factor applied to the characteristic capacity of a foundation, the value of which reflects the uncertainty or variability of the component resistance including those of material property

3.14
scour
removal of seabed soils caused by currents, waves and ice

[SOURCE: ISO 19900:2013, 3.43]

3.15
seabed
materials below the seafloor, whether of soils such as sand, silt or clay, cemented materials or of rock

Note 1 to entry: Offshore foundations are most commonly installed in soils, and the terminology in this part of ISO 19901 reflects this. However, the requirements equally apply to cemented seabed materials and rock. Thus, the term 'soil' does not exclude any other material at or below the seafloor.

3.16
seafloor
interface between the sea and the seabed

3.17
serviceability
ability of a structure or structural member to perform adequately for a normal use under all expected actions

[SOURCE: ISO 2394:2015, 2.1.32]

3.18
settlement
permanent downward movement of a structure as a result of its own weight and other actions

3.19
strength
mechanical property of a material indicating its ability to resist actions, usually given in units of stress

Note 1 to entry: See ISO 19902.

3.20
undrained condition
condition whereby the applied stresses and stress changes are supported by both the soil skeleton and the pore fluid and do not cause a change in volume

[SOURCE: ISO 19901-8:2014, 3.42]

4 Symbols and abbreviated terms

4.1 General

Commonly used symbols are listed in 4.2 to 4.5; other symbols are defined in the text following the applicable formula. It should be noted that symbols can have different meanings between formulae.

4.2 Symbols for shallow foundations design

A actual (cross-sectional plan) foundation area

A' effective foundation area depending on eccentricity of actions

A_h vertical projected area of the foundation in the direction of sliding

A_p projected area of skirt tip

A_s side surface area of skirt embedded at a particular penetration depth

$A_{idealized}$ idealized rectangular foundation area, for irregular foundation shapes

b_c, b_q, b_γ bearing capacity correction factors related to foundation base inclination

B minimum lateral foundation dimension (also foundation width)

B' minimum effective lateral foundation dimension (also foundation effective width)

C compression index of soil over loading range considered

d_c, d_q, d_γ bearing capacity correction factors related to foundation embedment depth

D foundation diameter (for circular foundations)

D_b depth below seafloor to foundation base level

e eccentricity of action

e_0 initial void ratio of the soil

e_1 eccentricity of action in coordinate direction 1

e_2 eccentricity of action in coordinate direction 2

f unit skin friction resistance along foundation skirts during installation

F bearing capacity correction factor to account for undrained shear strength heterogeneity

g_c, g_q, g_γ correction factors related to seafloor inclination

G elastic shear modulus of soil

h soil layer thickness

H horizontal action

H_b horizontal action on effective area component of the base

H_d design value of resistance to pure sliding

ΔH_d horizontal soil resistance due to active and passive earth pressures on foundation skirts

H_{ult} ultimate horizontal capacity in yield surface design method

i_c, i_q, i_γ bearing capacity correction factors related to foundation action inclination

K_c , K_q, K_γ correction factors that account for inclined actions, foundation shape, depth of embedment, inclination of base, and inclination of the seafloor

K_p coefficient of passive earth pressure

K_{rd} drained horizontal soil reaction coefficient

K_{ru} undrained horizontal soil reaction coefficient

L maximum lateral foundation dimension (also foundation length)

L' maximum effective lateral foundation dimension (also foundation effective length)

M overturning moment

M_{ult}	moment capacity in yield surface design method
N_{c}	undrained bearing capacity factor, equal to 5,14
N_{q}, N_{γ}	drained bearing capacity factors, as a function of ϕ'
p'_{in}	*in situ* effective overburden stress at skirt tip level inside the skirts of a skirted foundation
p'_{out}	*in situ* effective overburden stress at skirt tip level outside the skirts of a skirted foundation
q	unit end bearing resistance on foundation skirt tip, during penetration
q_{d}	design value of vertical bearing resistance in the absence of horizontal actions
Q	vertical action
Q_{f}	skirt friction resistance
Q_{p}	end bearing resistance from skirt tips
Q_{r}	soil resistance during skirt penetration
Q_{ult}	vertical capacity in yield surface design method
R	radius of the base of a circular foundation
RP	reference point for action transfer
s_{u}	undrained shear strength
s_{u0}	undrained shear strength at foundation base level (skirt tip level for skirted foundations)
$s_{\mathrm{u,ave}}$	average undrained shear strength from seafloor to foundation base level
$s_{\mathrm{u,2}}$	equivalent undrained shear strength below foundation base
s_{c}, s_{q}, s_{γ}	bearing capacity correction factors related to foundation shape
T	torsional moment
u_{Q}, u_{H}	vertical and horizontal displacements at foundation base level
β	ground inclination angle in radians, in calculation of inclination factors
δ	interface friction angle between soil and foundation
$\Delta\sigma'_{v,z}$	increment of effective vertical stress in a given soil layer at the specified time due to the increment of vertical action applied to foundation
ϕ'	effective angle of internal friction angle of the soil for plane strain conditions
γ'	submerged unit weight of soil
$\gamma\mathrm{L}$	live load partial factor
γ_{m}	material factor
κ	rate of increase of undrained shear strength with depth
$\sigma'_{\mathrm{v0,z}}$	effective overburden stress at level of a given soil layer
σ'_{v0}	*in situ* effective overburden stress at foundation base level (skirt tip level when skirts are used)

ν Poisson's ratio of the soil

υ foundation base inclination angle in radians, in calculation of inclination factors

θ_M, θ_T displacements at foundation base level under overturning and torsion loading

4.3 Symbols for pile foundations design

A_{pile} gross end area of pile, $A_{pile} = \dfrac{\pi \cdot D^2}{4}$

A_r pile displacement ratio, $A_r = \dfrac{A_w}{A_{pile}} = 1 - \left(\dfrac{D_i}{D}\right)^2$

A_w cross-sectional area of pile annulus, $A_w = \dfrac{\pi}{4} \cdot \left(D^2 - D_i^2\right)$

A_s side surface area of pile in soil

C_1, C_2, C_3 dimensionless coefficients determined as function of ϕ', for p–y curves for sand

D pile outside diameter

D_i pile inside diameter, $D_i = D - 2\ WT$

D_{50} mean soil particle diameter

D_{CPT} diameter of CPT tool, D_{CPT} = 36 mm for a standard cone penetrometer with a cone area of 1 000 mm^2

D_r relative density of sand, for CPT-based methods 1 and 4

E_S initial modulus of subgrade reaction

f unit skin friction

$f(z)$ unit skin friction at depth z

$f_c(z)$ unit skin friction in compression at depth z

$f_p(z)$ unit skin friction between sand soil plug and inner pile wall, for CPT-based method 4

$f_t(z)$ unit skin friction in tension at depth z

f_{lim} limiting unit skin friction value

h distance above pile tip = $L - z$

J dimensionless empirical constant, for p–y curves for clay

k initial modulus of subgrade reaction, for p–y curves for sand

K_0 coefficient of lateral earth pressure at rest

L embedded length of pile below original seafloor

L_s length of soil plug in sand layers