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Oil and gas industries including lower carbon energy — Specific requirements for offshore structures —

Part 4:
Geotechnical design considerations

Industries du pétrole et du gaz y compris les énergies à faible teneur en carbone — Exigences spécifiques relatives aux structures en mer —

Partie 4: Bases conceptuelles géotechniques

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Contents

Page

iTeh Standards (https://standards.iteh.ai) Document Preview

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iTeh Standards
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Document Preview
ISO/FDIS 19901-4
https://standards.iteh.ai/catalog/standards/sist/f105b91e-7d5b-42af-a8ae-fd88047b47e6/iso-fdis-19901-4

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Document Preview
ISO/FDIS 19901-4

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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 document 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).

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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, *Oil and gas industries including lower carbon energy*, Subcommittee SC 7, *Offshore structures*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 12, *Oil and gas industries including lower carbon energy*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 19901-4:2016), which has been technically revised.

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ISO/FDIS 19901-4
https://standards.iteh.ai/catalog/standards/iso/f105b91e-7d5b-42af-a8ae-fd88047b47e6/iso-fdis-19901-4

The main changes are as follows:

— guidance extended on representative and design values for soil parameters (Clause 5);

— guidance added for geotechnical design of intermediate foundations for fixed structures and clause renamed to ‘Design of shallow and intermediate foundations’ (Clause 7);

— requirements added on installation resistance, yield envelope approaches for ultimate limit state, and performance- based design for shallow skirted and intermediate foundations (Clause 7);

— new unified CPT method for axial capacity in sands to replace the former main text method, new TZ curve definition in sands, new unified CPT method for clays introduced into the Clause A.8, new PY curve methodology for clays to replace the existing method (Clause 8);

— new requirements added on reassessment of pile capacity for existing structures (Clause 9);

— a new clause for pipelines, conductors and risers (Clause 10);

— references have been reviewed, updated and reduced where possible.

A list of all parts in the ISO 19901 series can be found on the ISO website.

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 (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 oil and gas industries worldwide. Through their application, the intention is to achieve reliability levels appropriate for offshore structures, whatever the type of structure and the nature of the materials used. Application specific requirements for different energy industries are given in the relevant standards. For example, for the offshore wind industry, IEC 61400-1 and IEC 61400-3-1 outline the design requirements (e.g. return periods) for offshore wind turbine support structures.

This document may be applied for the design of foundations used in the offshore wind industry. In this case, it should be verified that the type and dimension of the foundation, as well as the type of actions acting upon it, are consistent with those used in the development of the design methods. For example, the pile design methods of Clauses 8 are not necessarily applicable to the design of monopiles for which *L/D* is less than 10 and their validity for such cases should be assessed. Offshore wind structures can also have other requirements, such as a characterisation of foundation stiffness, that are beyond the scope of this document. Reference should be made to the overarching application specific codes and standards such as IEC 61400-3-1.

It is important to recognize that structural integrity is an overall concept comprising models for describing actions, structural analyses, design rules, safety elements, quality of work, 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, should be considered in relation to the overall reliability of all offshore structural systems.

For geotechnical design (engineering science dealing with the properties of soil: sand, silt, clay and rock), some additional considerations apply. These include the time, frequency and rate at which actions are applied, the method of 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, should be considered in relation to the overall reliability of the structure.

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The International Standards on offshore structures prepared by TC 67 are intended to provide wide latitude in the choice of structural configurations, materials and techniques without hindering innovation. Geotechnical design practice for 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 in this document or the International Standards on offshore structures prepared by TC 67 (or elsewhere) are insufficient on their own to ensure that a safe and economical design is achieved.

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

Some background to and guidance on the use of this document is provided in Annex A.

ISO 19905 provides requirements and detailed guidance on foundations for mobile offshore units.

Figure 1 set outs a typical workflow for design of offshore foundations with reference to other relevant International Standards.

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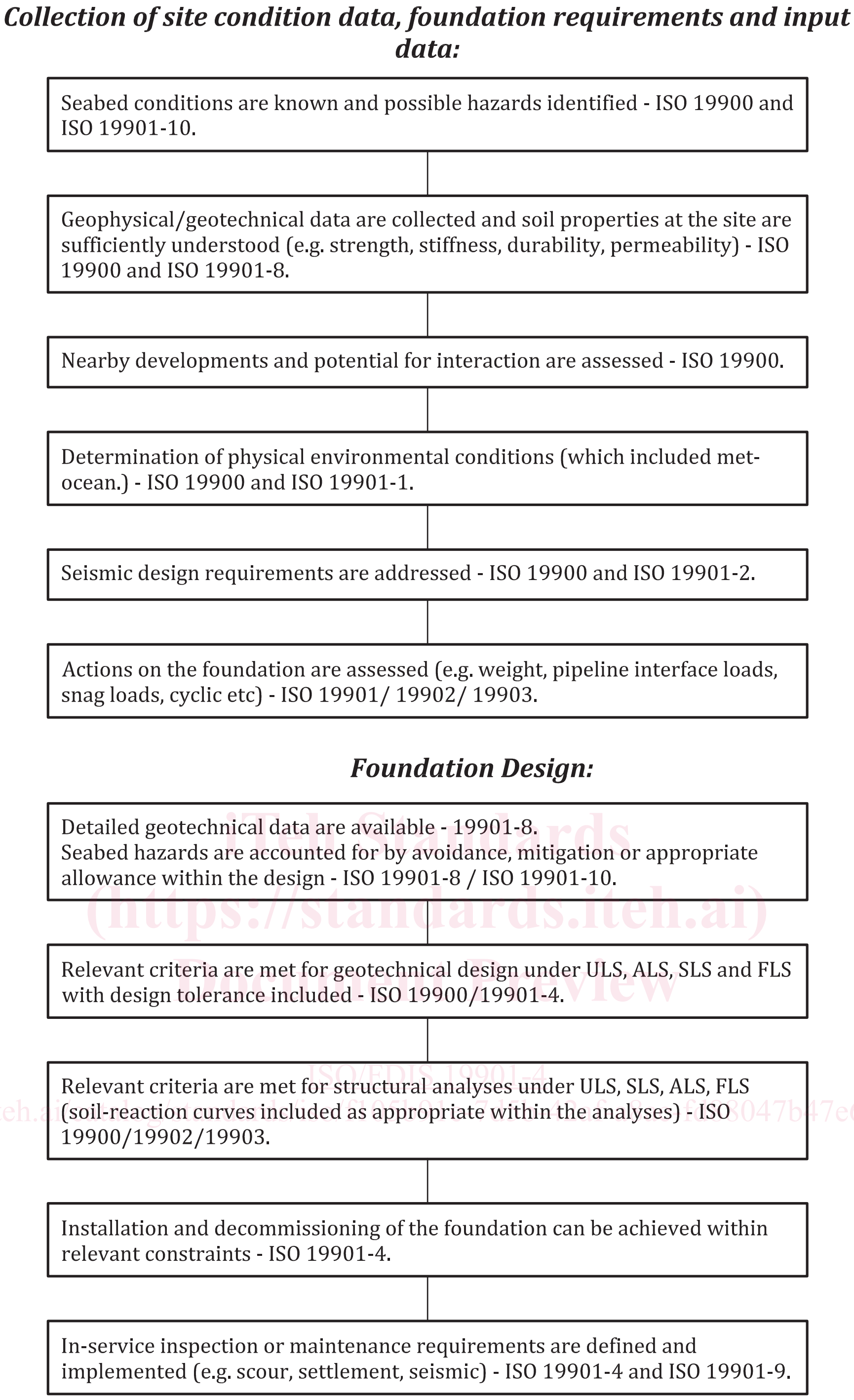

NOTE Specific design and installation constraints can apply for structures in arctic regions (see ISO 19906), for mobile offshore units, especially for jack-ups (see ISO 19905) and for anchors for floating units (see ISO 19901-7 Design can be an iterative process from concept (initial feasibility and applicability study), basic to final design. Different level of details and objectives are required in the various design stages.

Figure 1 — Flowchart showing typical design process for offshore foundations

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Oil and gas industries including lower carbon energy — Specific requirements for offshore structures —

Part 4: Geotechnical design considerations

1 Scope

This document contains provisions for geotechnical engineering design that are applicable to a broad range of offshore structures, rather than to a particular structure type. This document outlines methods developed for the design of shallow foundations with an embedded length (L) to diameter (D) ratio L/D < 0,5, intermediate foundations, which typically have 0,5 ≤ L/D ≤ 10 (see Clause 7), and long and flexible pile foundations with L/D > 10 (see Clauses 8 and 9).

This document also provides guidance on soil-structure interaction aspects for flowlines, risers and conductors (see Clause 10) and anchors for floating facilities (see Clause 11). This document contains brief guidance on site and soil characterization, and identification of hazards (see Clause 6).

This document can be applied for foundation design for offshore structures used in the lower carbon energy industry.

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ISO/FDIS 19901-4

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

ISO 19901-7, *Oil and gas industries including lower carbon energy — Specific requirements for offshore structures — Part 7: Station-keeping systems for floating offshore structures and mobile offshore units*

ISO 19901-8, *Oil and gas industries including lower carbon energy — Offshore structures — Part 8: Marine soil investigations*

ISO 19901-9, *Oil and gas industries including lower carbon energy — Specific requirements for offshore structures — Part 9: Structural integrity management*

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

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

ISO 19904-1, *Petroleum and natural gas industries — Floating offshore structures — Part 1: Ship-shaped, semi-submersible, spar and shallow-draught cylindrical structures*

ISO 19905 (all parts), *Oil and gas industries including lower carbon energy — Site-specific assessment of mobile offshore units*

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

DNV-RP-F110, *Global buckling of submarine pipelines*

DNV-RP-F114, *Pipe-soil interaction for submarine pipelines*

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3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

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

3.1
action
external loading 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* (3.18), temperature change or moisture variation. An imposed acceleration can be caused by an earthquake.

[SOURCE: ISO 19900:2019, 3.3]

3.2
action factor
partial factor whose value reflects the uncertainty or randomness of the action

3.4
basic variable
variable representing physical quantities which characterize actions and environmental influences, geometric quantities, or material properties including soil properties

[SOURCE: ISO 19900:2019, 3.7, modified — Note 1 to entry has been removed.]

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

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ISO/FDIS 19901-4
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3.6
design value
value derived from the *representative value* (3.11) for use in *limit state* (3.9) verification

Note 1 to entry: Design values can be different in different design/assessment situations due to different partial factors.

Note 2 to entry: The term “characteristic value” used in ISO 19900 is not used in this document; and both terms “characteristic value” and “representative value” are considered equivalent for geotechnical and foundation design.

[SOURCE: ISO 19900:2019, 3.14, modified — Note 2 to entry has been added.]

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

[SOURCE: ISO 19901-8:2023, 3.9]

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

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3.9
limit state
state beyond which the structure or structural component no longer satisfies the design/assessment criteria

[SOURCE: ISO 19900:2019, 3.31]

3.10
material factor
partial factor applied to the representative *strength* (3.19) 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* (3.4) for verification of a *limit state* (3.9) in a design/assessment situation

[SOURCE: ISO 19900:2019, 3.40, modified — Note 1 to entry has been removed.]

3.12
resistance
ability of a structure, or a structural component, to withstand action effects

[SOURCE: ISO 19900:2019, 3.41]

3.13
partial resistance factor
factor used for *limit state* (3.9) verification, the value of which reflects the uncertainty or variability of the foundation *resistance* (3.12) including those of material properties

3.14
scour
removal of *seabed* (3.15) material caused by currents, waves or ice

[SOURCE: ISO 19900:2019, 3.45, modified — "or ice" has been added.]

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ISO/FDIS 19901-4
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3.15
seabed
materials at or below the *seafloor* (3.16), whether soils such as sand, silt and clay, cemented materials or rock

Note 1 to entry: Offshore foundations are most commonly installed in soils, and the terminology in this document 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* (3.15)

3.17
serviceability
ability of a structure or structural member to perform adequately for 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.

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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 19901-8:2023, 3.44]

3.21
undrained shear strength
maximum shear stress at yielding or at a specified maximum strain in an *undrained condition* (3.20)

Note 1 to entry: Yielding is the condition of a material in which a large plastic strain occurs at little or no stress increase.

[SOURCE: ISO 19901-8:2023, 3.45]

4 Symbols and abbreviated terms

4.1 Symbols for shallow and intermediate foundation 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
$A_\mathrm{idealized}$	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
c'	effective cohesion
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

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Document Preview
ISO/FDIS 19901-4
https://standards.iteh.ai/catalog/standards/iso/f105b91e-7d5b-42af-a8ae-fd88047b47e6/iso-fdis-19901-4

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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 vertical bearing capacity factor, equal to 5,14

N_{q}, N_{γ} drained vertical bearing capacity factors, as a function of ϕ'

p'_{in} in situ vertical effective stress at skirt tip level inside the skirts of a skirted foundation

p'_{out} in situ vertical effective 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

s_{u} undrained shear strength

s_{uCR} undrained strength of crust

s_{u0} undrained shear strength at foundation base level (skirt tip level for skirted foundations)

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$s_{u,ave}$ average undrained shear strength from seafloor to foundation base level

$s_{u,2}$ 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 soil unit weight

γ_D permanent action factor

γ_L live action factor

γ_m material factor

κ rate of increase of undrained shear strength with depth

σ'_{v0} in situ vertical effective overburden stress at foundation base level (skirt tip level when skirts are used)

$\sigma'_{v0,z}$ effective vertical stress at level of a given soil layer

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

4.2 Symbols for pile foundation design

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

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

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

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

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ISO/FDIS 19901-4
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