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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.

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

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

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

ISO 19901-4 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 7, *Offshore structures*.

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

— *Part 4: Geotechnical and foundation design considerations*

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

The following parts of ISO 19901 are under preparation:

— *Part 1: Metocean design and operating considerations*

— *Part 2: Seismic design procedures and criteria*

— *Part 3: Topsides structure*

— *Part 6: Marine operations*

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

ISO 19901 is one of a series of standards for offshore structures. The full series consists of the following International Standards.

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

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

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

Introduction

The offshore structures International Standards 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.

The offshore structures International Standards are intended to provide a wide latitude in the choice of structural configurations, materials and techniques without hindering innovation. Sound engineering judgement is therefore necessary in the use of these International Standards.

The overall concept of structural integrity is described above. 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.

The design practice for the foundations of offshore structures has proved to be an innovative and evolving process over the years since the 1950s. This evolution is expected to continue and is encouraged. Therefore, circumstances can arise when the procedures described herein or in the other International Standards ISO 19902 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. The scope of the site investigation for one structure is not necessarily adequate for another. Extra caution is necessary when dealing with unfamiliar soils or foundation concepts. This part of ISO 19901 is intended to provide wide latitude in the choice of site investigation techniques and foundation solutions, without hindering innovation. Sound engineering judgement is therefore necessary in the use of this part of ISO 19901.

For an offshore structure and its foundations, 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 may be considered as actions on the foundation's subsystem(s) and this approach is followed in this part of ISO 19901.

To meet certain needs of industry for linking software to specific elements in this part of ISO 19901, a special numbering system has been permitted for figures, tables and equations.

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 Annex B. There is, as yet, insufficient knowledge and understanding of such soils to produce normative requirements.

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 requirements and recommendations 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 characterization,

— soil and rock characterization,

— design and installation of foundations supported by the seabed (shallow foundations), and

— identification of hazards.

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.

NOTE 1 Particular requirements for the design of piled foundations, which have a traditional association with fixed steel structures, are given in ISO 19902.

NOTE 2 Particular requirements for the design of shallow gravity foundations, which have a traditional association with fixed concrete structures, are detailed in ISO 19903.

NOTE 3 Particular requirements for the anchor points of mooring systems of floating structures are detailed in ISO 19901-7 [65].

NOTE 4 Particular requirements for the design of spud can foundations, which have a traditional association with jack-up mobile offshore units (MOUs), are detailed in ISO 19905 (all parts).

2 Normative references

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

ISO 19900, *Petroleum and natural gas industries — General 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 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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19900 and the following apply.

3.1
design actions
combination of representative actions and partial safety factors representing a design situation for use in checking the acceptability of a design

3.2
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

3.3
effective foundation area
reduced foundation area having its geometric centre at the point where the resultant action vector intersects the foundation base level

3.4
material factor
partial safety factor applied to the strength of the soil

3.5
sea floor
interface between the sea and the seabed

3.6
seabed
materials below the sea in which a structure is founded, whether of soils such as sand, silt or clay, cemented materials or of rock

NOTE 1 The seabed can be considered as the half-space below the sea floor.

NOTE 2 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 rocks. Thus, the term “soil” does not exclude any other material at or below the sea floor.

NOTE 3 As yet there are no universally accepted definitions of the various types of soil and rock, see A.6.4.3.

3.7
settlement
permanent downward movement of a structure as a result of its own weight and other actions

3.8
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

3.9
undrained shear strength
maximum shear stress at yielding or at a specified maximum strain in an undrained condition

NOTE Yielding is the condition of a material in which a large plastic strain occurs at little or no stress increase.

4 Symbols

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

A total foundation area

A' effective foundation area

A_h embedded vertical cross-sectional area of foundation

a soil attraction

B' effective width of foundation

c_u undrained shear strength of clay

$c_{u,ave}$ average undrained shear strength between sea floor and base level for linearly increasing isotropic undrained shear strength with depth

$c_{u,0}$ undrained shear strength at base level

D_b depth to base level

H_b factored horizontal total action on base area

K_c correction factor, which accounts for inclined actions, foundation shape, and depth of embedment

K_{rd} drained horizontal soil reaction coefficient

K_{ru} undrained horizontal soil reaction coefficient

L effective length of foundation area

p'_0 effective overburden stress at base level (skirt tip level when skirts are used)

$Q_{d,h}$ design sliding resistance

$Q_{d,v}$ design bearing capacity in the absence of horizontal actions

$q_{d,v}$ design unit bearing capacity in the absence of horizontal actions

V_b factored vertical total action on base area

γ_m material factor

γ' submerged unit weight of soil

κ rate of increase of undrained shear strength with depth

ϕ' effective angle of internal friction

5 General requirements

5.1 General

The foundation shall be designed to carry static and dynamic (repetitive as well as transient) actions without causing excessive deformation of or vibrations in the structure. Special attention shall be given to the effects of repetitive and transient actions on the structural response, as well as on the strength of the supporting soils. The possibility of movement of the seabed shall be considered. Any actions resulting from such movements on foundation members shall be considered in the design. The potential for disturbance to foundation soils by conductor installation or shallow well drilling shall be assessed (see 5.3).

5.2 Testing and instrumentation

Where there is uncertainty regarding the behaviour of foundations, testing or instrumentation should be undertaken. Possible methods include the following.

a) Load testing.

   Load testing or large-scale field testing should be performed where there is particular uncertainty in the foundation capacity and where safety and/or economy are of particular importance.

b) Model tests.

   Model tests should be performed where

   1) the foundation configuration differs significantly from earlier configurations where operational experience exists,

   2) the soil conditions differ significantly from those where operational experience exists,

   3) new methods of installation or removal are envisaged, or

   4) a high degree of uncertainty exists as to how the structure or its foundation will behave.

c) Temporary instrumentation.

   Structures should be fitted with temporary instrumentation where

   1) the installation method presupposes the existence of measured data for control of the operation, or

   2) an installation method is to be applied with which little or no experience has been gained.

d) Permanent instrumentation.

   Structures should be fitted with permanent instrumentation where

   1) the safety or behaviour of the foundation is dependent on active operation,

      EXAMPLE Where drainage systems are used, data shall be immediately accessible to the user.

   2) the foundation configuration, the soil conditions, or the actions differ substantially from those with which experience has been gained,

   3) there is a need for monitoring of the whole foundation with regard to penetration, settlement, tilt, or other behaviour, or

   4) the method of removal presupposes the existence of measured data for control of the operation.

5.3 Conductor installation and shallow well drilling

The planning for conductor installation and shallow well drilling shall take into account the potential for disturbance to foundation soils and the consequent risk of a reduction in stability of the structure or of adjacent conductors.

Soil disturbances during drilling operations can result from hydraulic fracture, washout (uncontrolled enlargement of the drilled hole), or shallow gas pockets. Hydraulic fracture occurs where drilling fluid pressure is too high and fluid is lost into the formation, possibly softening the surrounding soil. Washout generally occurs in granular soils and can, in part, be induced by high drilling fluid circulation rates or drilling without mud. Washout can produce large voids in the soil structure and lead to stress relief in the surrounding soils. These incidents can be accompanied by loss of circulation of drilling fluids, return of these fluids to the sea floor other than through the conductor, or the creation of sea floor craters. Thereby the stability of foundations can be reduced and displacements increased. These detrimental effects can occur whether the drilling takes place after installation of the structure or before, e.g. through a pre-installed template or for an exploration well.

Records of conductor installation and shallow well drilling shall be available to the designer of the structure. The implications for foundation soils of any incidents of inadequate grouting, excessive loss of circulation, return of drilling fluids to the sea floor other than through the conductor, or creation of sea floor craters should be assessed. The cuttings from the well drilling operation, if allowed to accumulate on the sea floor, should be taken into account in the foundation design, installation procedure and structure removal.

6 Geotechnical data acquisition and integrated geoscience studies

6.1 Geotechnical assessment

The determination of geotechnical parameters and the assessment of geological hazards and constraints result from an integrated study of the area using geophysics, geology and geotechnical engineering. Geophysical data are acquired to develop a geological model so as to better understand depositional and other processes and features of an area. The geophysical data are also used to help interpret the stratigraphy from geotechnical boreholes, to define lateral variability across a site, and to provide guidance on optimizing the location of the proposed facilities. Incorporation of geotechnical data into the geological model gives insight into the potential impact of geological conditions on man-made facilities, such as structures, pipelines, anchors and wellheads.

6.2 Shallow geophysical investigation

Shallow geophysical investigation can provide information about soil stratigraphy and evidence of geological features, such as slumps, scarps, irregular or rough topography, mud volcanoes, mud lumps, collapse features, sand waves, slides, faults, diapirs, erosional surfaces, gas bubbles in the sediments, gas seeps, buried channels, and lateral variations in stratum thicknesses. The areal extent of shallow soil layers can sometimes be mapped if good correspondence is established between the soil boring and *in situ* test information and the results from the seabed surveys.

The types of equipment for performing shallow geophysical investigation that should be considered are discussed below.

a) Echo sounders or swathe bathymetric systems (in which a series of sweeps of the bathymetric equipment are used) define water depths and sea floor morphology. On complex sea floors, swathe systems have the advantage of providing higher data density and better definition of variable topography. Seismic three-dimensional data acquired for exploration purposes also provide useful data for developing water-bottom (bathymetry) maps.

   These data should only be used for preliminary evaluations because the resolution could be of the order of a few metres depending on the variability of the topography.

b) Sub-bottom profilers (tuned transducers) define structural features within the near-surface sediments.

NOTE These systems can also provide data to develop water-bottom maps.