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

Part 2:
Seismic design procedures and criteria

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

Partie 2: Procédures de conception et critères sismiques

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Contents

Page

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 19901-2 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 1: Metocean design and operating considerations*

— *Part 2: Seismic design procedures and criteria*

— *Part 4: Geotechnical and foundation design considerations*

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

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

The following parts of ISO 19901 are under preparation:

— *Part 3: Topsides structure*

— *Part 6: Marine operations*

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 19904-1, *Petroleum and natural gas industries — Floating offshore structures — Part 1: Monohulls, semi-submersibles and spars*

— ISO 19904-2, *Petroleum and natural gas industries — Floating offshore structures — Part 2: Tension leg platforms*

— 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 series of International Standards applicable to types of offshore structure, ISO 19900 to ISO 19906, constitutes 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 nature or combination of the materials used.

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

The series of International Standards applicable to types of offshore structure is 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. Some additional considerations apply for seismic design. These include the magnitude and probability of seismic events, the use and importance of the platform, the robustness of the structure under consideration and the allowable damage due to seismic actions with different probabilities. All of these, and any other relevant information, need to be considered in relation to the overall reliability of the structure.

Seismic conditions vary widely around the world, and the design criteria depend primarily on observations of historical seismic events together with consideration of seismotectonics. In many cases, site-specific seismic hazard assessments will be required to complete the design or assessment of a structure.

This part of ISO 19901 is intended to provide general seismic design procedures for different types of offshore structures, and a framework for the derivation of seismic design criteria. Further requirements are contained within the general requirements standard ISO 19900 and within the structure-specific standards, ISO 19902, ISO 19903, ISO 19904 and ISO 19906. The consideration of seismic events in connection with mobile offshore units is addressed in ISO 19905.

Some background to and guidance on the use of this part of ISO 19901 is provided in informative Annex A. The clause numbering in Annex A is the same as in the normative text to facilitate cross-referencing.

Regional information on expected seismic accelerations for offshore areas is provided in informative Annex B.

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

Part 2: Seismic design procedures and criteria

1 Scope

This part of ISO 19901 contains requirements for defining the seismic design procedures and criteria for offshore structures; guidance on the requirements is included in Annex A. The requirements are applicable to fixed steel structures and fixed concrete structures. The effects of seismic events on floating structures and partially buoyant structures are also briefly discussed. The site-specific assessment of jack-ups in elevated condition is only covered in this part of ISO 19901 to the extent that the requirements are applicable.

Only earthquake-induced ground motions are addressed in detail. Other geologically induced hazards such as liquefaction, slope instability, faults, tsunamis, mud volcanoes and shock waves are mentioned and briefly discussed.

The requirements are intended to reduce risks to persons, the environment, and assets to the lowest levels that are reasonably practicable. This intent is achieved by using:

a) seismic design procedures which are dependent on the platform's exposure level and the expected intensity of seismic events;

b) a two-level seismic design check in which the structure is designed to the ultimate limit state (ULS) for strength and stiffness and then checked to abnormal environmental events or the accidental limit state (ALS) to ensure that it meets reserve strength and energy dissipation requirements.

For high seismic areas and/or high exposure level fixed structures, a site-specific seismic hazard assessment is required; for such cases, the procedures and requirements for a site-specific probabilistic seismic hazard analysis (PSHA) are addressed. However, a thorough explanation of PSHA procedures is not included.

Where a simplified design approach is allowed, worldwide offshore maps are included in Annex B that show the intensity of ground shaking corresponding to a return period of 1 000 years. In such cases, these maps may be used with corresponding scale factors to determine appropriate seismic actions for the design of a structure.

NOTE For design of fixed steel offshore structures, further specific requirements and recommended values of design parameters (e.g. partial action and resistance factors) are included in ISO 19902, while those for fixed concrete offshore structures are contained in ISO 19903. Specific seismic requirements for floating structures are to be contained in ISO 19904[2], for site-specific assessment of jack-ups and other MOUs in ISO 19905[3], for arctic structures in ISO 19906[4] and for topsides structures in ISO 19901-3[1].

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[1)], *Petroleum and natural gas industries — Fixed steel offshore structures*

ISO 19903[1)], *Petroleum and natural gas industries — Fixed concrete offshore structures*

3 Terms and definitions

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

3.1
abnormal level earthquake
ALE
intense earthquake of abnormal severity under the action of which the structure should not suffer complete loss of integrity

NOTE The ALE event is comparable to the abnormal event in the design of fixed structures which are described in ISO 19902 and ISO 19903. When exposed to the ALE, a manned structure is supposed to maintain structural and/or floatation integrity for a sufficient period of time to enable evacuation to take place.

3.2
attenuation
decay of seismic waves as they travel from a source to the site under consideration

3.3
directional combination
combination of response values due to each of the three orthogonal components of an earthquake motion

3.4
escape and evacuation systems
systems provided on a platform to facilitate escape and evacuation in an emergency

NOTE Escape and evacuation systems include passageways, chutes, ladders, life rafts and helidecks.

3.5
extreme level earthquake
ELE
earthquake with a severity which the structure should sustain without major damage

NOTE The ELE event is comparable to the extreme environmental event in the design of fixed structures which are described in ISO 19902 and ISO 19903. When exposed to an ELE, a structure is supposed to retain its full capacity for all subsequent conditions.

3.6
fault movement
movement occurring on a fault during an earthquake

3.7
ground motions
accelerations, velocities or displacements of the ground produced by seismic waves radiating away from earthquake sources

NOTE A fixed offshore structure is founded in or on the seabed and consequently only seabed motions are of significance. The term ground motions is used rather than seabed motions for consistency of terminology with seismic design for onshore structures.

1) To be published.

3.8
liquefaction
fluidity of cohesionless soil due to the increase in pore pressures caused by earthquake action under undrained conditions

3.9
modal combination
combination of response values associated with each dynamic mode of a structure

3.10
mud volcanoes
diapiric intrusion of plastic clay causing high pressure gas-water seepages which carry mud, fragments of rock (and occasionally oil) to the surface

NOTE The surface expression of a mud volcano is a cone of mud with continuous or intermittent gas escaping through the mud.

3.11
probabilistic seismic hazard analysis
PSHA
framework permitting the identification, quantification and rational combination of uncertainties in earthquakes' intensity, location, rate of recurrence and variations in ground motion characteristics

3.12
probability of exceedance
probability that a variable (or that an event) exceeds a specified reference level given exposure time

EXAMPLES Examples of probabilities of exceedance during a given exposure time are the annual probability of exceedance of a specified magnitude of ground acceleration, ground velocity or ground displacement.

3.13
response spectrum
plot representing structural response in terms of absolute acceleration, pseudo velocity, or relative displacement values against natural frequency or period

3.14
safety systems
systems provided on a platform to detect, control and mitigate hazardous situations

NOTE Safety systems include gas detection, emergency shutdown, fire protection, and their control systems.

3.15
sea floor
interface between the sea and the seabed

3.16
sea floor slide
failure of sea floor slopes

3.17
seabed
materials below the sea in which a structure is founded

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

3.18
seismic risk category
SRC
category defined from the exposure level and the expected intensity of seismic motions

3.19
seismic hazard curve
curve showing the probability of exceedance against a measure of seismic intensity

NOTE The seismic intensity measures can include parameters such as peak ground acceleration, spectral acceleration, or spectral velocity.

3.20
seismic reserve capacity factor
ratio of spectral acceleration which causes structural collapse or catastrophic system failure to the ELE spectral acceleration

3.21
site response analysis
wave propagation analysis permitting the evaluation of the effect of local geological and soil conditions on the design ground motions at a given site

NOTE The site response analysis results can include amplitude, frequency content and duration.

3.22
spectral acceleration
maximum absolute acceleration response of a single degree of freedom oscillator subjected to ground motions due to an earthquake

3.23
spectral velocity
maximum pseudo velocity response of a single degree of freedom oscillator subjected to ground motions due to an earthquake

3.24
spectral displacement
maximum relative displacement response of a single degree of freedom oscillator subjected to ground motions due to an earthquake

3.25
static pushover method
static pushover analysis
application and incremental increase of a global static pattern of actions on a structure, including equivalent dynamic inertial actions, until a global failure mechanism occurs

3.26
tsunami
long period sea waves caused by rapid vertical movements of the sea floor

NOTE The vertical movement of the sea floor is often associated with fault rupture during earthquakes or with seabed mud slides.

4 Symbols and abbreviated terms

4.1 Symbols

a_R slope of the seismic hazard curve

C_a site coefficient, a correction factor applied to the acceleration part of a response spectrum

C_c correction factor applied to the spectral acceleration to account for uncertainties not captured in a seismic hazard curve

C_r seismic reserve capacity factor, see Equation (7)

C_v site coefficient, a correction factor applied to the velocity part of a response spectrum

c_u undrained shear strength of the soil

$\bar{c}_u$ average undrained shear strength of the soil of the top 30 m of the seabed

D scaling factor for damping

G_{max} low amplitude shear modulus of the soil

g acceleration due to gravity (9,81 m/s^2)

M magnitude of a given seismic source

N_{ALE} scale factor for conversion of the site 1 000 year acceleration spectrum to the site ALE acceleration spectrum

p_a atmospheric pressure

P_{ALE} annual probability of exceedance for the ALE event

P_e probability of exceedance

P_{ELE} annual probability of exceedance for the ELE event

P_f target annual probability of failure

q_c cone penetration resistance of sand

q_{cl} normalized cone penetration resistance of sand

$\bar{q}_{cl}$ average normalized cone penetration resistance of sand of the top 30 m of the seabed

$S_a(T)$ spectral acceleration associated with a single degree of freedom oscillator period T

$\bar{S}_a(T)$ mean spectral acceleration associated with a single degree of freedom oscillator period T; obtained from a PSHA

$S_{a,ALE}(T)$ ALE spectral acceleration associated with a single degree of freedom oscillator period T

$\bar{S}_{a,ALE}(T)$ mean ALE spectral acceleration associated with a single degree of freedom oscillator period T; obtained from a PSHA

$S_{a,ELE}(T)$ ELE spectral acceleration associated with a single degree of freedom oscillator period T

$\bar{S}_{a,ELE}(T)$ mean ELE spectral acceleration associated with a single degree of freedom oscillator period T; obtained from a PSHA

$S_{a,map}(T)$ 1 000 year rock outcrop spectral acceleration obtained from maps associated with a single degree of freedom oscillator period T

NOTE The maps included in Annex B are for oscillator periods of 0,2 s and 1,0 s.

$\bar{S}_{a,Pe}(T)$ mean spectral acceleration associated with a probability of exceedance P_e and a single degree of freedom oscillator period T; obtained from a PSHA

$\bar{S}_{a,Pf}(T)$ mean spectral acceleration associated with a target annual probability of failure P_f and a single degree of freedom oscillator period T; obtained from a PSHA

$S_{a,site}(T)$ site spectral acceleration corresponding to a return period of 1 000 years and a single degree of freedom oscillator period T

T natural period of a simple, single degree of freedom oscillator

T_{dom} dominant modal period of the structure

T_{return} return period

u_i code utilization in time history analysis i

$\hat{u}$ median code utilization

v_s shear wave velocity

$\bar{v}_s$ average shear wave velocity of the top 30 m of the seabed

ρ mass density of soil

η percent of critical damping

σ_{LR} logarithmic standard deviation of uncertainties not captured in a seismic hazard curve

σ'_{v0} vertical effective stress of soil

4.2 Abbreviated terms

ALE abnormal level earthquake

ALS accidental limit state

ELE extreme level earthquake

L1, L2, L3 exposure level derived in accordance with the International Standard applicable to the type of offshore structure[2)]

MOU mobile offshore unit

PGA peak ground acceleration

PSHA probabilistic seismic hazard analysis

SRC seismic risk category

TLP tension leg platform

ULS ultimate limit state

5 Earthquake hazards

Actions and action effects due to seismic events shall be considered in the structural design of offshore structures in seismically active areas. Areas are considered seismically active on the basis of previous records of earthquake activity, both in frequency of occurrence and in magnitude. Annex B provides maps indicative of seismic accelerations, however for many areas, depending on indicative accelerations and exposure levels, seismicity shall be determined on the basis of detailed investigations, see 6.5.

2) International Standards applicable to types of offshore structure, include ISO 19902 and ISO 19903, and when available, ISO 19904 (all parts), ISO 19905 (all parts) and ISO 19906. See the Bibliography.

Consideration of seismic events for seismically active regions shall include investigation of the characteristics of ground motions and the acceptable seismic risk for structures. Structures in seismically active regions shall be designed for ground motions due to earthquakes. However, other seismic hazards shall also be considered in the design and should be addressed by special studies. The following hazards can be caused by a seismic event:

— soil liquefaction;

— sea floor slide;

— fault movement;

— tsunamis;

— mud volcanoes;

— shock waves.

Effects of seismic events on subsea equipment, pipelines and in-field flowlines shall be addressed by special studies.

6 Seismic design principles and methodology

6.1 Design principles

Clause 6 addresses the design of structures against base excitations, i.e. accelerations, velocities and displacements caused by ground motions.

Structures located in seismically active areas shall be designed for the ultimate limit state (ULS), abnormal environmental events and the accidental limit state (ALS) using different levels of earthquake.

The ULS requirements are intended to provide a structure which is adequately sized for strength and stiffness to ensure that no significant structural damage occurs for a level of earthquake ground motion with an adequately low likelihood of being exceeded during the design service life of the structure. The seismic ULS design event is the extreme level earthquake (ELE). The structure shall be designed such that an ELE event will cause little or no damage. Shutdown of production operations is tolerable and the structure should be inspected subsequent to an ELE occurrence.

The ALS requirements are intended to ensure that the structure and foundation have sufficient reserve strength, displacement and/or energy dissipation capacity to sustain large inelastic displacement reversals without complete loss of integrity, although structural damage can occur. The seismic ALS design event is the abnormal level earthquake (ALE). The ALE is an intense earthquake of abnormal severity with a very low probability of occurring during the structure's design service life. The ALE can cause considerable damage to the structure, however, the structure shall be designed such that overall structural integrity is maintained to avoid structural collapse causing loss of life and/or major environmental damage.

Both ELE and ALE return periods depend on the exposure level and the expected intensity of seismic events. The target annual failure probabilities given in 6.4 may be modified to meet targets set by owners in consultation with regulators, or to meet regional requirements where they exist.

6.2 Seismic design procedures

6.2.1 General

Two alternative procedures for seismic design are provided. A simplified method may be used where seismic considerations are unlikely to govern the design of a structure, while the detailed method shall be used where seismic considerations have a significant impact on the design. The selection of the appropriate procedure depends on the exposure level of the structure and the expected intensity and characteristics of seismic events. The simplified procedure (Clause 7) allows the use of generic seismic maps provided in Annex B;

while the detailed procedure (Clause 8) requires a site-specific seismic hazard study. In all cases, the simplified procedure may be used to perform appraisal and concept screening for a new offshore development.

Figure 1 presents a flowchart of the selection process and the steps associated with both procedures.

6.2.2 Extreme level earthquake design

During the ELE event, structural members and foundation components are permitted to sustain localized and limited non-linear behaviour (e.g. yielding in steel, tensile cracking in concrete). As such, ELE design procedures are primarily based on linear elastic methods of structural analysis with, for example, non-linear soil-structure interaction effects being linearized. However, if seismic isolation or passive energy dissipation devices are employed, non-linear time history procedures shall be used.

For structures subjected to base excitations from seismic events, either of the following two methods of analysis are allowed for the ELE design check:

a) the response spectrum analysis method, or

b) the time history analysis method.

In both methods, the base excitations shall be composed of three motions, i.e. two orthogonal horizontal motions and the vertical motion. Reasonable amounts of damping compatible with the ELE deformation levels are used in the ELE design. The International Standard applicable to the type of offshore structure[3)] shall be consulted when available. Higher values of damping due to hydrodynamics or soil deformation shall be substantiated with special studies. The foundation may be modelled with equivalent elastic springs and, if necessary, mass and damping elements; off-diagonal and frequency dependence can be significant. The foundation stiffness and damping values shall be compatible with the ELE level of soil deformations.

In a response spectrum analysis, the methods for combining the responses in the three orthogonal directions shall consider correlation between the modes of vibration. When responses due to each directional component of an earthquake are calculated separately, the responses due to the three earthquake directions may be combined using the root of the sum of the squares method. Alternatively, the three directional responses may be combined linearly assuming that one component is at its maximum while the other two components are at 40 % of their respective maximum values. In this method, the sign of each response parameter shall be selected such that the response combination is maximized.

If the time history analysis method is used, a minimum of 4 sets of time history records shall be used to capture the randomness in seismic motions. The earthquake time history records shall be selected such that they represent the dominating ELE events. Component code checks are calculated at each time step and the maximum code utilization during each time history record shall be used to assess the component performance. The ELE design is satisfactory if the code utilization maxima are less than 1,0 for half or more of the records; a scale factor of 1,05 shall be applied to the records if less than 7 sets of records are used.

Equipment on the deck shall be designed to withstand motions that account for the transmission of ground motions through the structure. Deck motions can be much higher than those experienced at the sea floor. The time history analysis method is recommended for obtaining deck motions (especially relative motions) and deck motion response spectra.

The effects of ELE-induced motions on pipelines, conductors, risers and other safety-critical components shall be considered.

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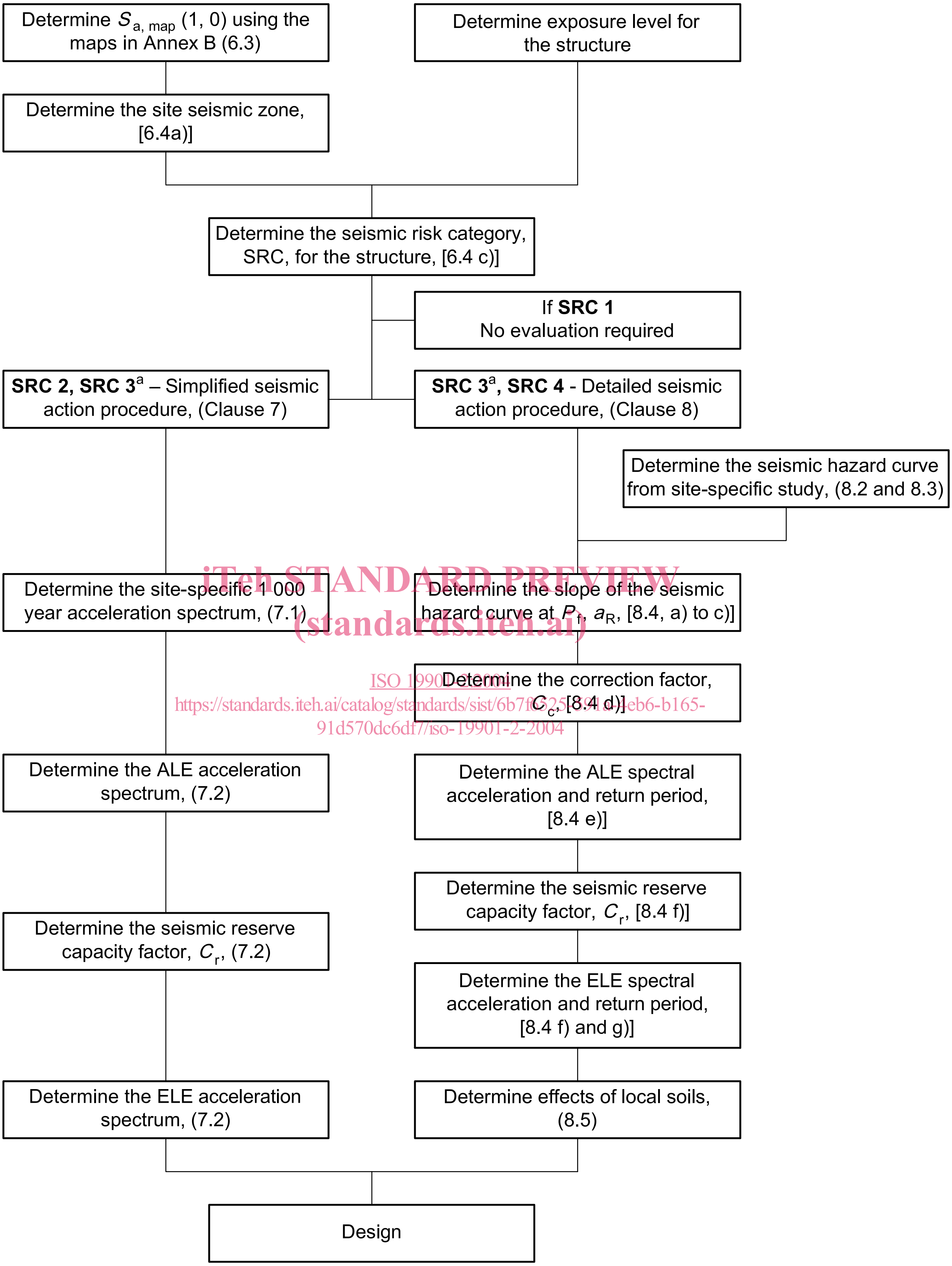
3) International Standards applicable to types of offshore structure, include ISO 19902 and ISO 19903, and when available, ISO 19904 (all parts), ISO 19905 (all parts) and ISO 19906. See the Bibliography.



a SRC 3 structures may be designed using either a simplified or detailed seismic action procedure, see Table 4.

Figure 1 — Seismic design procedures