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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 sismique et critères

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Foreword

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

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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, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*, Subcommittee SC 7, *Offshore structures,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 12, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 19901-2:2017), which has been technically revised.

The main changes are as follows:

— the seismic hazard maps have been updated;

— Clause 3 has been updated.

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.

Introduction

The International Standards on offshore structures prepared by TC 67 (i.e. ISO 19900, ISO 19902, ISO 19903, ISO 19904 and ISO 19906) address design requirements and assessments of all offshore structures used by the petroleum and natural gas industries worldwide. Through their application, the intention is to achieve reliability levels appropriate for manned and unmanned offshore structures, whatever the type of structure and the nature or combination of the materials used.

Structural integrity is an overall concept comprising models for describing actions, structural analyses, design or assessment rules, safety elements, workmanship, quality control procedures and national requirements, all of which are mutually dependent. The modification of one aspect of design or assessment 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 International Standards on offshore structures prepared by TC 67 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. Some additional considerations apply for seismic design. These include the magnitude and probability of seismic events, the use and importance of the offshore structure, 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 document 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 International Standard, ISO 19900, and within the structure-specific International Standards, ISO 19902, ISO 19903, ISO 19904 and ISO 19906. The consideration of seismic events in connection with mobile offshore units is addressed in the ISO 19905 series.

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

Part 2: Seismic design procedures and criteria

1 Scope

This document contains requirements for defining the seismic design procedures and criteria for offshore structures; guidance on the requirements is included in Annex A. The requirements focus on fixed steel offshore structures and fixed concrete offshore structures. The effects of seismic events on floating structures and partially buoyant structures are briefly discussed. The site-specific assessment of jack-ups in elevated condition is only covered in this document 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 exposure level of the offshore structure 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 abnormal limit state (ALS) to ensure that it meets reserve strength and energy dissipation requirements.

Procedures and requirements for a site-specific probabilistic seismic hazard analysis (PSHA) are addressed for offshore structures in high seismic areas and/or with high exposure levels. However, a thorough explanation of PSHA procedures is not included.

Where a simplified design approach is allowed, worldwide offshore maps, which are included in Annex B, show the intensity of ground shaking corresponding to a return period of 1 000 years. In such cases, these maps can be used with corresponding scale factors to determine appropriate seismic actions for the design of a structure, unless more detailed information is available from local code or site-specific study.

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. Seismic requirements for floating structures are contained in ISO 19904, for site-specific assessment of jack-ups and other MOUs in the ISO 19905 series, for arctic structures in ISO 19906 and for topsides structures in ISO 19901-3.

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 19901-8, *Petroleum and natural gas industries — Specific requirements for offshore structures – Part 8: Marine soils Investigation*

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

ISO 19903, *Petroleum and natural gas industries — 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.

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
abnormal level earthquake
ALE
intense earthquake of abnormal severity with a very low probability of occurring during the life of the structure

Note 1 to entry: The ALE event is comparable to the abnormal event in the design of fixed structures that are described in ISO 19902 and ISO 19903.

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

3.3
deaggregation
separation of seismic hazard contribution from different faults and seismic source zones

3.4
escape and evacuation system
system provided on the offshore structure to facilitate escape and evacuation in an emergency

EXAMPLE Passageways, chutes, ladders, life rafts and helidecks.

3.5
extreme level earthquake
ELE
strong earthquake with a reasonable probability of occurring during the life of the structure

Note 1 to entry: The ELE event is comparable to the extreme environmental event in the design of fixed structures that are described in ISO 19902 and ISO 19903.

3.6
fault movement
movement occurring on a fault during an earthquake

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

Note 1 to entry: A fixed offshore structure is founded in or on the *seabed* (3.17) and consequently only seabed motions are of significance. The expression "ground motions" is used rather than seabed motions for consistency of terminology with seismic design for onshore structures.

Note 2 to entry: Ground motions can be at a specific depth or over a specific region within the seabed.

3.8
liquefaction
fluidity of 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 volcano
diapiric intrusion of plastic clay causing high pressure gas-water seepages which carry mud, fragments of rock (and occasionally oil) to the surface

Note 1 to entry: 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* (3.7) characteristics

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

EXAMPLE The annual probability of exceedance of a specified magnitude of ground acceleration, ground velocity or ground displacement.

3.13
response spectrum
function representing the peak elastic response for single degree of freedom oscillators with a specific damping ratios in terms of absolute acceleration, pseudo velocity, or relative displacement values against natural frequency or period of the oscillators

3.14
safety system
systems provided on the offshore structure to detect, control and mitigate hazardous situations

EXAMPLE Gas detection, emergency shutdown, fire protection, and their control systems.

3.15
sea floor
interface between the sea and the *seabed* (3.17)

3.16
seabed slide
failure of *seabed* (3.17) slopes

3.17
seabed
soil material below the sea in which a structure is founded

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 annual *probability of exceedance* (3.12) against a measure of seismic intensity

Note 1 to entry: The seismic intensity measures can include parameters such as peak ground acceleration, *spectral acceleration* (3.22), or *spectral velocity* (3.23).

3.20
seismic reserve capacity factor
factor indicating the structure's ability to sustain ground motions due to earthquakes beyond the level of the *extreme level earthquake* (3.5)

Note 1 to entry: The seismic reserve capacity factor is a structure specific property that is used to determine the extreme level earthquake acceleration from the *abnormal level earthquake* (3.1) acceleration.

3.21
site response analysis
wave propagation analysis permitting the evaluation of the effect of local geological and soil conditions on the *ground motions* (3.7) as they propagate up from depth to the surface at the site

3.22
spectral acceleration
maximum absolute acceleration response of a single degree of freedom oscillator subjected to *ground motions* (3.7) due to an earthquake

3.23
spectral velocity
maximum pseudo velocity response of a single degree of freedom oscillator subjected to *ground motions* (3.7) due to an earthquake

Note 1 to entry: The pseudo velocity spectrum is computed by factoring the displacement or acceleration spectra by the oscillator's circular frequency or the inverse of its frequency, respectively. The pseudo spectrum is either relative or absolute, depending on the type of response spectra that is factored.

3.24
spectral displacement
maximum relative displacement response of a single degree of freedom oscillator subjected to *ground motions* (3.7) due to an earthquake

3.25
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* (3.15)

Note 1 to entry: The vertical movement of the sea floor is often associated with fault rupture during earthquakes or with *seabed slides* (3.16).

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 (shorter periods) 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 Formulae (7) and (10)

C_v site coefficient, a correction factor applied to the velocity part (longer periods) of a response spectrum

D scaling factor for damping

G_{max} initial (small strain) shear modulus of the soil

g acceleration due to gravity

M magnitude of an earthquake measured by the energy released at its 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 soil

q_{cl} normalized cone penetration resistance of soil

$\bar{q}_{cl}$ average normalized cone penetration resistance of sand in the effective 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

$\bar{S}_{a,Pe}(T)$ 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

s_u	undrained shear strength of the soil
$\bar{s}_u$	average undrained shear strength of the soil in the effective seabed
T	natural period of a simple, single degree of freedom oscillator
T_{dom}	dominant modal period of the structure
T_{return}	return period
v_s	representative shear wave velocity
$\bar{v}_s$	average of representative shear wave velocity in the effective seabed
ρ	mass density of soil
η	per cent of critical damping
σ_{LR}	logarithmic standard deviation of uncertainties not captured in a seismic hazard curve
σ'_{v0}	in situ vertical effective stress of soil

4.2 Abbreviated terms

L1, L2, L3	exposure level derived in accordance with the International Standard applicable to the type of offshore structure
MOU	mobile offshore unit
PGA	peak ground acceleration
TLP	tension leg platform
ULS	ultimate limit state

5 Earthquake hazards

Actions and action effects due to seismic events shall be evaluated 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 of indicative seismic accelerations; however, for many areas, depending on indicative accelerations and exposure levels, seismicity shall be determined on the basis of detailed seismic hazard investigations (see Clause 8).

Evaluation of seismic events for seismically active regions shall include investigation of the characteristics of ground motions and of 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, when warranted, should be addressed by special studies (e.g. mudflow loading, seabed deformation). The following hazards can be caused by a seismic event:

— soil liquefaction;

— seabed 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 (e.g. simultaneous seabed and structure excitation, spatially varying motions).

6 Seismic design principles and methodology

6.1 Design principles

This clause addresses the design of structures to the ultimate limit state (ULS) for frequent earthquakes (ELE) and to the abnormal limit state (ALS) for rare earthquakes (ALE).

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. It is recommended that the structure 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 can be modified to meet targets set by owners in consultation with regulators, or to meet regional requirements where they exist. Regional requirements for select regions are found in Annex C.

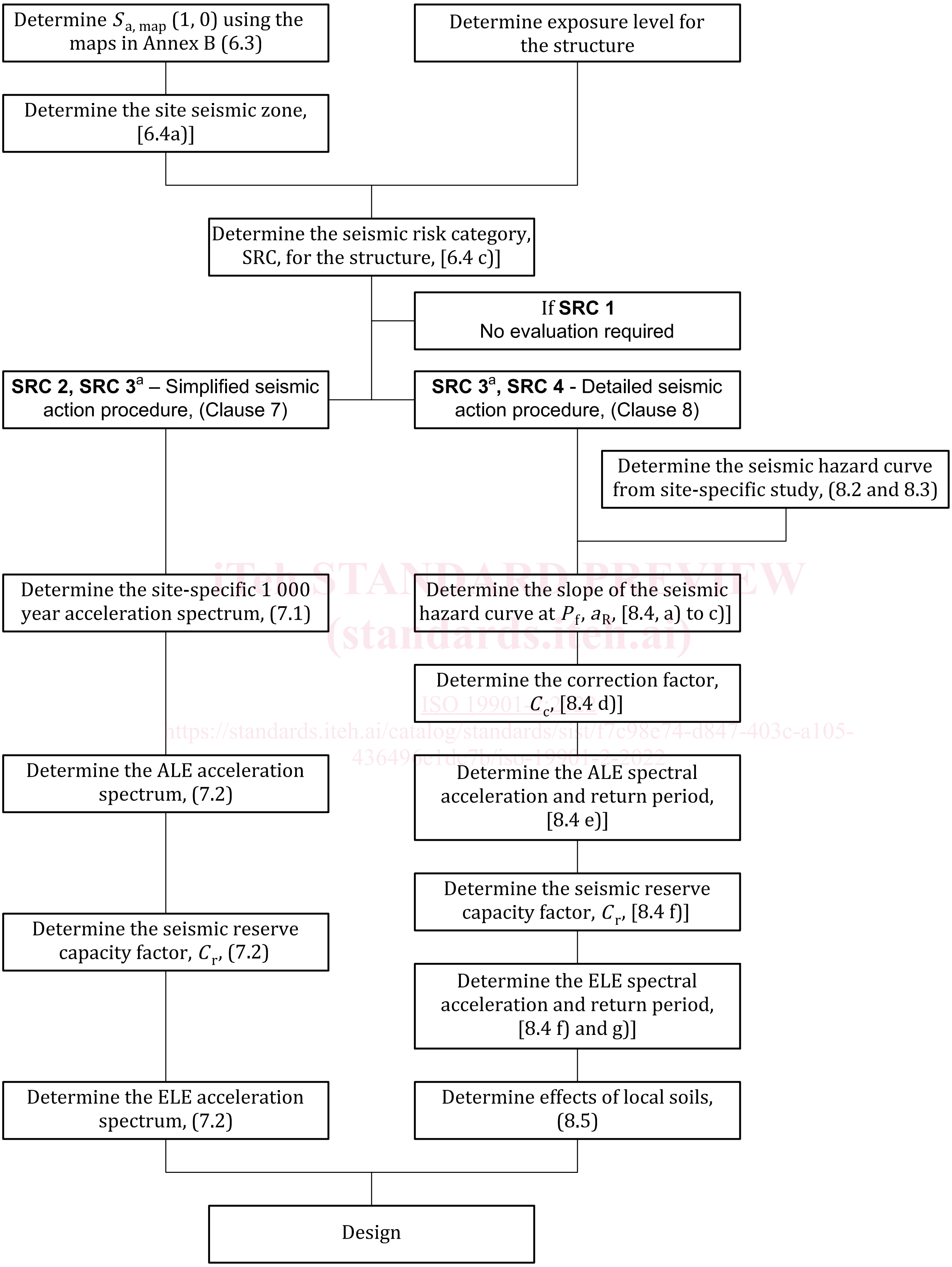
6.2 Seismic design procedures

6.2.1 General

Two procedures for seismic design are provided: a simplified method and a detailed method. The simplified method may be used where seismic considerations are unlikely to govern the design of a structure. 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 (see Clause 7) allows the use of generic seismic maps provided in Annex B; while the detailed procedure (see 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.

When a structural design is asymmetric in geometric configuration or directional capacity, additional analyses shall be included to demonstrate suitable performance in weaker directions. For time history analyses, this can require different orientations of the earthquake horizontal records to demonstrate performance requirements (see Clause 9).

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



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

Figure 1 — Seismic design 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 methods of analysis may be used for the ELE design check:

a) the response spectrum analysis method;

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. Damping compatible with the ELE deformation levels should be used in the ELE design, as guided by the recommendations in the relevant International Standards on offshore structures prepared by TC 67 (see Introduction) Higher values of damping due to hydrodynamics or soil deformation (hysteretic and radiation) may be used; however, the damping used 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. The complete quadratic combination (CQC) method can be used to capture the correlation between closely spaced modes. Sufficient modes should be included in the modal combination to obtain at least 90 % structural mass participation in each horizontal direction. 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 square 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 four 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. Satisfactory performance shall be achieved for either the greater of four or half the total sets of time history records. Satisfactory performance of a given time history record constitutes all code utilizations being less than or equal to 1,0.

Equipment on the deck shall be designed to withstand motions that account for the transmission of ground motions through the structure. The structure can amplify the ground motion such that the deck accelerations are much higher than the earthquake excitation. The time history analysis method shall be used for obtaining deck motions (especially relative motions) and deck motion response spectra (typically absolute acceleration spectra).

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

6.2.3 Abnormal level earthquake design

In high seismic areas, it is uneconomic to design a structure such that the ALE event would be resisted without non-linear behaviour. Therefore, the ALE design check allows non-linear methods of analysis, e.g. structural elements are allowed to behave plastically, foundation piles are allowed to reach axial