

Date of Issue: January 2019

Affected Publication: API Recommended Practice 2EQ, *Seismic Design Procedures and Criteria for Offshore Structures*, First Edition, November 2014

Addendum 1

Annex B: The first paragraph shall read:

The maps shown in Figures B.1 to B.26 of this annex give generic 5 % damped spectral accelerations, expressed in g , for bedrock outcrop for a 0.2 s oscillator period and for a 1.0 s oscillator period, respectively, for determining the site seismic zone (see 6.4) of an area and for use in the simplified seismic action procedure (see Clause 7). See Table B.1 for maps by region.

Annex B: The following table shall be added:

Table 1—List of Ground-Motion Maps by Region

Region	Figure
Canada—British Columbia	B.1
Canada—Arctic	B.2
Canada—Atlantic Seaboard	B.3
United States—Pacific Coast (35° N–49° N)	B.4
United States—Southern California	B.5
United States—Gulf of Mexico	B.6
United States—Atlantic Seaboard	B.7
United States—Alaska Arctic	B.8
United States—Alaska Aleutians	B.9
United States—Alaska Panhandle	B.10
Mexico	B.11
Central America and Caribbean	B.12
South America	B.13
Europe—North Atlantic, North Sea, and Baltic Sea	B.14
Eastern Mediterranean Sea and Black Sea	B.15
Western Mediterranean Sea, France, Portugal, and Spain	B.16
Africa—Atlantic Ocean and Indian Ocean	B.17
Middle East	B.18
Asia—Pakistan and India	B.19
Asia—Russian Arctic	B.20
Asia—Russia, China, Korea, and Japan	B.21
Asia—Southeast (to 120° E)	B.22
Asia—Southeast (east of 118° E)	B.23
Australia—NW Shelf Region and East Indonesia Island Arc (to ~130° E)	B.24
Australia—Other than NW Shelf Region	B.25
New Zealand	B.26

Annex B: All of the figures in this annex are new as of this addendum. Figure titles are as follows:

Figure B.1a—5 % damped spectral response acceleration (g) at 0.2 sec period, for British Columbia, Canada	Figure B.14a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Europe Atlantic, and North and Baltic Seas.
Figure B.1b—5 % damped spectral response acceleration (g) at 1.0 sec period, for British Columbia, Canada	Figure B.14b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Europe Atlantic, and North and Baltic Seas.
Figure B.2a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Canada Arctic	Figure B.15a—5 % damped spectral response acceleration (g) at 0.2 sec period, for the East Mediterranean and Black Seas.
Figure B.2b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Canada Arctic	Figure B.15b—5 % damped spectral response acceleration (g) at 1.0 sec period, for the East Mediterranean and Black Seas.
Figure B.3a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Atlantic Seaboard Canada.	Figure B.16a—5 % damped spectral response acceleration (g) at 0.2 sec period, for the West Mediterranean.
Figure B.3b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Atlantic Seaboard Canada	Figure B.16b—5 % damped spectral response acceleration (g) at 1.0 sec period, for the West Mediterranean.
Figure B.4a—5 % damped spectral response acceleration (g) at 0.2 sec period, for United States Pacific Coast (35°N - 49°N).	Figure B.17a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Africa Atlantic and Indian Oceans.
Figure B.4b—5 % damped spectral response acceleration (g) at 1.0 sec period, for United States Pacific Coast (35°N - 49°N).	Figure B.17b—5 % damped spectral response acceleration (g) at 1.0 sec period, . for Africa Atlantic and Indian Oceans.
Figure B.5a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Southern California, United States.	Figure B.18a. 5 % damped spectral response acceleration (g) at 0.2 sec period, for the Middle East.
Figure B.5b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Southern California, United States.	Figure B.18b—5 % damped spectral response acceleration (g) at 1.0 sec period, for the Middle East.
Figure B.6a—5 % damped spectral response acceleration (g) at 0.2 sec period, for United States Gulf of Mexico.	Figure B.19a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Asia, Pakistan, India.
Figure B.6b—5 % damped spectral response acceleration (g) at 1.0 sec period, for United States Gulf of Mexico.	Figure B.19b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Asia, Pakistan, India.
Figure B.7a—5 % damped spectral response acceleration (g) at 0.2 sec period, for United States Atlantic Seaboard.	Figure B.20a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Asia Russian Arctic.
Figure B.7b—5 % damped spectral response acceleration (g) at 1.0 sec period, for United States Atlantic Seaboard.	Figure B.20b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Asia Russian Arctic.
Figure B.8a—5 % damped spectral response acceleration (g) at 0.2 sec period for United States Alaska Arctic.	Figure B.21a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Asia Far East (Russia, China, Korea and Japan).
Figure B.8b—5 % damped spectral response acceleration (g) at 1.0 sec period, for United States Alaska Arctic.	Figure B.21b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Asia Far East (Russia, China, Korea and Japan).
Figure B.9a—5 % damped spectral response acceleration (g) at 0.2 sec period, for United States Alaska Aleutian Islands.	Figure B.22a—5 % damped spectral response acceleration (g) at 0.2 sec period, for SE Asia (to 120° E).
Figure B.9b—5 % damped spectral response acceleration (g) at 1.0 sec period, for United States Alaska Aleutian Islands.	Figure B.22b—5 % damped spectral response acceleration (g) at 1.0 sec period, for SE Asia (to 120° E).
Figure B.10a—5 % damped spectral response acceleration (g) at 0.2 sec period, for United States Alaska Panhandle.	Figure B.23a—5 % damped spectral response acceleration (g) at 0.2 sec period, for SE Asia (east of 120° E).
Figure B.10b—5 % damped spectral response acceleration (g) at 1.0 sec period, for United States Alaska Panhandle.	Figure B.23b—5 % damped spectral response acceleration (g) at 1.0 sec period, for SE Asia (east of 120° E).
Figure B.11a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Mexico.	Figure B.24a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Northwest Australia and East Indonesia.
Figure B.11b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Mexico.	Figure B.24b—5 % damped spectral response acceleration at 1.0 sec period, for Northwest Australia and East Indonesia.
Figure B.12a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Central America and the Caribbean.	Figure B.25a—5 % damped spectral response acceleration (g) at 0.2 sec period, for Australia (other than NW).
Figure B.12b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Central America and the Caribbean.	Figure B.25b—5 % damped spectral response acceleration (g) at 1.0 sec period, for Australia (other than NW).
Figure B.13a—5 % damped spectral response acceleration (g) at 0.2 sec period, for South America.	Figure B.26a—5 % damped spectral response acceleration (g) at 0.2 sec period, for New Zealand.
Figure B.13b—5 % damped spectral response acceleration (g) at 1.0 sec period, for South America.	Figure B.26b—5 % damped spectral response acceleration (g) at 1.0 sec period, for New Zealand.

Annex C.2, the following rows shall be added at the end of the table:

Annex B Regional Information	Replace Figures B.1 to B.11 with new/updated Figure B.1 to B.26.
Explanation: The new maps are larger scale and focus on sub-regions where digital ground-motion data exist for onshore and offshore areas. These areas contain many acceleration contours to provide better spatial definition of the variability of the ground motion.	

Seismic Design Procedures and Criteria for Offshore Structures

ANSI/API RECOMMENDED PRACTICE 2EQ
FIRST EDITION, NOVEMBER 2014

ADDENDUM 1, JANUARY 2019

REAFFIRMED, JANUARY 2021

**ISO 19901-2:2004 (Modified), Petroleum and natural gas
industries—Specific requirements for offshore structures—
Part 2: Seismic design procedures and criteria**



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API Foreword

The verbal forms used to express the provisions in this specification are as follows:

- the term “shall” denotes a minimum requirement in order to conform to the specification;
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Standards referenced herein may be replaced by other international or national standards that can be shown to meet or exceed the requirements of the referenced standard.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

This standard is under the jurisdiction of the API Subcommittee on Offshore Structures. This is standard modified from the English version of ISO 19901-2:2004. 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*.

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Foreword

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 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 3: *Topsides structure*,
- Part 4: *Geotechnical and foundation design considerations*,
- Part 5: *Weight control during engineering and construction*,
- Part 6: *Marine operations*,
- Part 7: *Stationkeeping systems for floating offshore structures and mobile offshore units*.

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 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 standards applicable to types of offshore structures, ISO 19900 to ISO 19906, API 2A-WSD, and 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 standards applicable to types of offshore structures 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 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.

Annex C provides a list and explanation of the deviations of this document to ISO 19901-2:2004.

Petroleum and natural gas industries—Specific requirements for offshore structures—Part 2: Seismic design procedures and criteria

1 Scope

This standard contains requirements for defining the seismic design procedures and criteria for offshore structures and is a modified adoption of ISO 19901-2. The intent of the modification is to map the requirements of ISO 19901-2 to the United States' offshore continental shelf (U.S. OCS). 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 to the extent that the requirements are applicable.

This document defines the seismic requirements for new construction of structures in accordance with API 2A-WSD, 22nd Edition and later. Earlier editions of API 2A-WSD are not applicable.

The majority of the ISO 19901-2 document is applicable to the U.S. OCS. Where necessary, this document provides guidance for aligning the ISO 19901-2 requirements and terminology with API. The key differences are as follows.

- a) API 2EQ adopts the ISO 19901-2 site seismic zones in lieu of those previously used in API 2A-WSD, 21st Edition and earlier.
- b) Only the maps in Figure B.2 are applicable, in lieu of those previously used in API 2A-WSD, 21st Edition and earlier.
- c) ISO 19901-2 seismic design approach is also adopted here with:
 - a two-level seismic design in which the structure is designed to the ultimate limit state (ULS) for strength and stiffness and then checked to the abnormal or accidental limit state (ALS) to ensure that it meets reserve strength and energy dissipation requirements;
 - the seismic ULS design event is the extreme level earthquake (ELE) [this is consistent with, but not exactly the same as the strength level earthquake (SLE) in API 2A-WSD, 21st Edition and earlier];
 - the seismic ALS design event is the abnormal level earthquake (ALE) [this is consistent with, but not exactly the same as the ductility level earthquake (DLE) in API 2A-WSD, 21st Edition and earlier].

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:

- seismic design procedures which are dependent on the platform's exposure level and the expected intensity of seismic events;
- 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 1000 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 are included in API 2A-WSD, 22nd Edition, 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 [3], for site-specific assessment of jack-ups and other MOUs in ISO 19905 [4], for arctic structures in ISO 19906 [5] or API 2N, 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.

API Recommended Practice 2A-WSD, *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms—Working Stress Design*, 22nd Edition

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

ISO 19903, *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 API 2A-WSD 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 is described in API 2A-WSD, 22nd Edition 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.

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.

EXAMPLE 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 a structural 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 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.

3.19**seismic reserve capacity factor**

Ratio of spectral acceleration which causes structural collapse or catastrophic system failure to the ELE spectral acceleration.

3.20**seismic risk category****SRC**

Category defined from the exposure level and the expected intensity of seismic motions.

3.21**site response analysis**

Upward wave propagation analysis from underlying bedrock to seafloor 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 displacement**

Maximum relative displacement response of a single degree of freedom oscillator subjected to ground motions due to an earthquake.

3.24**spectral velocity**

Maximum pseudo velocity 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 1000 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
$S_{a,map}(T)$	1000 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 1000 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 standard applicable to the type of offshore structure ¹
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.

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

¹ Standards applicable to types of offshore structure, include ISO 19902, ISO 19903, API 2A-WSD, API 2N, ISO 19904 (all parts), ISO 19905 (all parts), and ISO 19906. See the Bibliography.

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 extreme level earthquakes (ELE) using the ultimate limit state (ULS), and the abnormal level earthquakes using accidental limit state (ALS).

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 standard applicable to the type of offshore structure² 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.

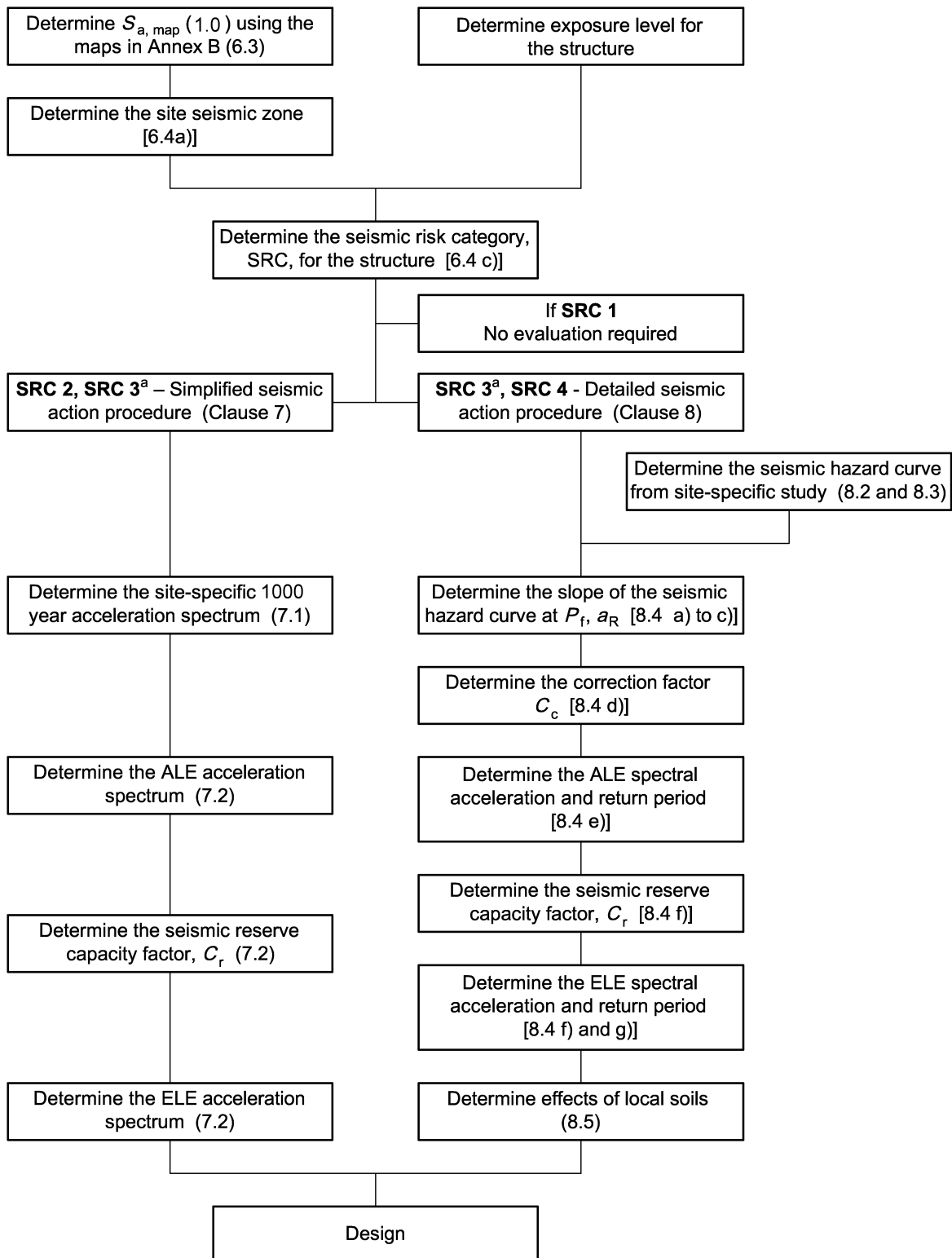
In a response spectrum analysis, the methods for combining the responses in the three orthogonal directions shall consider correlation between the modes of vibration. When responses due to each directional component of an earthquake are calculated separately, the responses due to the three earthquake directions may be combined using the 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 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.

² Standards applicable to types of offshore structure, include ISO 19902, ISO 19903, API 2A-WSD, API 2N, 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

6.2.3 Abnormal Level Earthquake Design

In most cases, it is not economical to design a structure such that the ALE event would be resisted without major 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 capacity or develop plastic behaviour, and skirt foundations are allowed to slide. In effect, the design depends on a combination of static reserve strength, ductility, and energy dissipation to resist the ALE actions.

Structural and foundation models used in an ALE analysis shall include possible stiffness and strength degradation of components under cyclic action reversals. The ALE analysis shall be based on best estimate values of modelling parameters such as material strength, soil strength, and soil stiffness. This can require reconsideration of the conservatism that is typically present in the ELE design procedure.

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

- a) the static pushover or extreme displacement method, or
- b) the non-linear time history analysis method.

The two methods can complement each other in most cases. The requirements in 6.2.2 for the composition of base excitations from three orthogonal components of motion and for damping also apply to the ALE design procedure.

The static pushover analysis method may be used to determine possible and controlling global mechanisms of failure, or the global displacement of the structure (i.e. beyond the ELE). The latter may be achieved by performing a displacement controlled structural analysis. The non-linear time history analysis method is the most accurate method for ALE analysis. A minimum of 4 time history analyses shall be used to capture the randomness in a seismic event. The earthquake time history records shall be selected such that they represent the dominating ALE events. If 7 or more time history records are used, global structure survival shall be demonstrated in half or more of the time history analyses. If fewer than 7 time history records are used, global survival shall be demonstrated in at least 4 time history analyses.

Extreme displacement methods may be used to assess survival of compliant or soft-link systems, e.g. tethers on a tension leg platform (TLP), or portal action of TLP foundations subjected to lateral actions. In these methods, the system is evaluated at the maximum ALE displacement, including the associated action effects for the structure. The hull structure of the TLP is designed elastically for the corresponding actions. The effect of large structure displacements on pipelines, conductors, risers and other safety-critical components shall be considered separately.

6.3 Spectral Acceleration Data

Only the maps in Figure B.2 are applicable in this document, in lieu of those previously used in API 2A-WSD, 21st Edition and earlier.

Generic seismic maps of spectral accelerations for the offshore areas of the world are presented in Annex B. These maps should be used in conjunction with the simplified seismic action procedure (Clause 7). For each area, two maps are presented in Annex B:

- one for a 0.2 s oscillator period;
- the other for a 1.0 s oscillator period.

The acceleration values are expressed in g and correspond to 5 % damped spectral accelerations on bedrock outcrop, defined as site class A/B in 7.1. These accelerations have an average return period of 1000 years and are designated as $S_{a,map}(0.2)$ or $S_{a,map}(1.0)$.

Results from a site-specific seismic hazard assessment may be used in lieu of the maps in a simplified seismic action procedure.

6.4 Seismic Risk Category

The complexity of a seismic action evaluation and the associated design procedure depends on the structure's seismic risk category, SRC, as determined below. The L2 exposure level is not applicable in seismic regions because it is not feasible to evacuate the platform prior to a seismic event. Acceleration levels taken from Annex B define the seismic zones, which are then used to determine the appropriate seismic design procedure. The selection of the procedure depends on the structure's exposure level as well as the severity of ground motion. The following steps shall be followed to determine the SRC.

- a) Determine the site seismic zone: from the worldwide seismic maps in Annex B, read the value for the 1.0 s horizontal spectral acceleration, $S_{a, \text{map}}(1.0)$; using this value, determine the site seismic zone from Table 1.

Table 1—Site Seismic Zone

$S_{a, \text{map}}(1.0)$	$< 0.03 g$	$0.03 g \text{ to } 0.10 g$	$0.11 g \text{ to } 0.25 g$	$0.26 g \text{ to } 0.45 g$	$> 0.45 g$
Seismic Zone	0	1	2	3	4

- b) Determine the structure's exposure level (consult the standard applicable to the type of offshore structure³). The target annual probabilities of failure associated with each exposure level are given in Table 2; these are required in the detailed procedure to determine seismic actions. Other target probabilities may be used in the detailed seismic action procedure if recommended or approved by local regulatory authorities. The simplified seismic action procedure has been calibrated to the target probabilities given in Table 2.

Table 2—Target Annual Probability of Failure, P_f

Exposure Level	P_f
L1	$4 \times 10^{-4} = 1/2500$
L3	$2.5 \times 10^{-3} = 1/400$

- c) Determine the structure's seismic risk category, SRC, based on the exposure level and the site seismic zone the SRC is determined from Table 3.

Table 3—Seismic Risk Category, SRC

Site Seismic Zone	Exposure Level	
	L3	L1
0	SRC 1	SRC 1
1	SRC 2	SRC 3
2	SRC 2	SRC 4
3	SRC 2	SRC 4
4	SRC 3	SRC 4

If the design lateral seismic action is smaller than 5 % of the total vertical action comprising the sum of permanent actions plus variable actions minus buoyancy actions, SRC 4 and SRC 3 structures may be recategorized as SRC 2.

6.5 Seismic Design Requirements

Table 4 gives the seismic design requirements for each SRC; these requirements are also shown in Figure 1.

³ Standards applicable to types of offshore structure, include ISO 19902, ISO 19903, API 2A-WSD, API 2N, ISO 19904 (all parts), ISO 19905 (all parts), and ISO 19906. See the Bibliography.

In seismically active areas, the designer shall strive to produce a robust and ductile structure, capable of withstanding extreme displacements in excess of normal design values. Where available for a given structure type, architectural and detailing requirements and recommendations for ductile design should be followed for all cases (except SRC 1). Consult the standard applicable to the type of offshore structure ⁴.

For floating structures, consideration of riser stroke, tether rotation angle, and similar geometric allowances shall be sufficient to address the ALE requirements.

Table 4—Seismic Design Requirements

SRC	Seismic Action Procedure	Evaluation of Seismic Activity	Non-linear ALE Analysis
1	None	None	None
2	Simplified	ISO maps or regional maps	Permitted
3 ^a	Simplified	Site-specific, ISO maps or regional maps	Recommended
	Detailed	Site-specific	Recommended
4	Detailed	Site-specific	Required

^a For an SRC 3 structure, a simplified seismic action procedure is in most cases more conservative than a detailed seismic action procedure. For evaluation of seismic activity, results from a site-specific probabilistic seismic hazard analysis (PSHA), see 8.2, are preferred and should be used, if possible. Otherwise regional or ISO seismic maps may be used. A detailed seismic action procedure requires results from a PSHA whereas a simplified seismic action procedure may be used in conjunction with either PSHA results or seismic maps (regional or ISO maps).

7 Simplified Seismic Action Procedure

7.1 Soil Classification and Spectral Shape

Having obtained the bedrock spectral accelerations at oscillator periods of 0.2 s and 1.0 s, $S_{a,map}(0.2)$ and $S_{a,map}(1.0)$, from Annex B, the following steps shall be followed to define the site response spectrum corresponding to a return period of 1000 years:

a) Determine the site class as follows.

The site class depends on the seabed soils on which a structure is founded and is a function of the average properties of the top 30 m of the effective seabed (see Table 5).

The average shear wave velocity in the top 30 m of effective seabed ($\bar{v}_s$) shall be determined from Equation (1):

$$\bar{v}_s = 30 / \sum_{i=1}^n \frac{d_i}{v_{s,i}} \quad (1)$$

where

n is the number of distinct soil layers in the top 30 m of effective seabed;

d_i is the thickness of layer i ;

$v_{s,i}$ is the shear wave velocity of layer i .

⁴ Standards applicable to types of offshore structure, include ISO 19902, ISO 19903, API 2A-WSD, API 2N, ISO 19904 (all parts), ISO 19905 (all parts), and ISO 19906. See the Bibliography.

Table 5—Determination of Site Class

Site Class	Soil Profile Name	Average Properties in Top 30 m of Effective Seabed		
		Soil Shear Wave Velocity $\bar{v}_s$ m/s	Sand: Normalized Cone Penetration Resistance $\bar{q}_{cl}$ ^a	Clay: Soil Undrained Shear Strength $\bar{c}_u$ kPa
A/B	Hard rock/rock, thickness of soft sediments < 5 m	$\bar{v}_s > 750$	Not applicable	Not applicable
C	Very dense hard soil and soft rock	$350 < \bar{v}_s \leq 750$	$\bar{q}_{cl} \geq 200$	$\bar{c}_u \geq 200$
D	Stiff to very stiff soil	$180 < \bar{v}_s \leq 350$	$80 \leq \bar{q}_{cl} < 200$	$80 \leq \bar{c}_u < 200$
E	Soft to firm soil	$120 < \bar{v}_s \leq 180$	$\bar{q}_{cl} < 80$	$\bar{c}_u < 80$
F	—	Any profile, including those otherwise classified as A to E, containing soils having one or more of the following characteristics: $\bar{v}_s < 120$; soils vulnerable to potential failure or collapse under seismic actions such as liquefiable soils, highly sensitive clays, collapsible weakly cemented soils; ooze ^b with a thickness of more than 10 m; soil layers with high gas content or ambient excess pore pressure greater than 30 % of <i>in situ</i> effective overburden; layers greater than 2 m thick with sharp contrast in shear wave velocity (greater than ± 30 %) and/or undrained shear strength (greater than ± 50 %) compared to adjacent layers.		

^a $q_{cl} = (q_c/p_a) \times (p_a/\sigma'_{v0})^{0.5}$
 where
 q_c is the cone penetration resistance;
 p_a is atmospheric pressure = 100 kPa;
 σ'_{v0} is the vertical effective stress.

^b Clay containing more than 30 % calcareous or siliceous material of biogenic origin.

Similarly, the average of normalized cone penetration resistance ($\bar{q}_{cl}$) or soil undrained shear strength ($\bar{c}_u$) shall be determined according to Equation (1) where v_s is replaced by q_{cl} or c_u .

For deep pile foundations, the site class should consider the 30 m of soil immediately below the seat of pile resistance, which will generally be at different depths for lateral and vertical actions. For deep pile foundations, the seat of resistance would be at the centroidal depth of P-Y resisting forces for lateral and of T-Z for vertical.

b) Determine C_a and C_v as follows.

- 1) For shallow foundations, determine the site coefficients, C_a and C_v , from Table 6 and Table 7. The values of C_a and C_v are dependent on the site class and either the mapped 0.2 s or 1.0 s spectral accelerations, $S_{a,map}(0.2)$ and $S_{a,map}(1.0)$.
- 2) For deep pile foundations, the site coefficients C_a and C_v are listed in Table 8.

Table 6—Values of C_a for Shallow Foundations and 0.2 s Period Spectral Acceleration

Site Class	$S_{a, \text{map}}(0.2)$				
	$\leq 0.25 g$	$0.50 g$	$0.75 g$	$1.0 g$	$\geq 1.25 g$
A/B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	a	a	a	a	a

^a A site-specific geotechnical investigation and dynamic site response analyses shall be performed.

Table 7—Values of C_v for Shallow Foundations and 1.0 s Period Spectral Acceleration

Site Class	$S_{a, \text{map}}(1.0)$				
	$\leq 0.1 g$	$0.2 g$	$0.3 g$	$0.4 g$	$\geq 0.5 g$
A/B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	a	a	a	a	a

^a A site-specific geotechnical investigation and dynamic site response analyses shall be performed.

Table 8—Values of C_a and C_v for Deep Pile Foundations

Site Class	C_a	C_v
A/B	1.0	0.8
C	1.0	1.0
D	1.0	1.2
E	1.0	1.8
F	a	a

^a A site-specific geotechnical investigation and dynamic site response analyses shall be performed.

c) Determine the site 1000 year horizontal acceleration spectrum as follows.

1) A seismic acceleration spectrum shall be prepared for different oscillator periods (T), as shown in Figure 2.

2) For periods, T , less than or equal to 0.2 s, the site spectral acceleration, $S_{a, \text{site}}(T)$, shall be taken as:

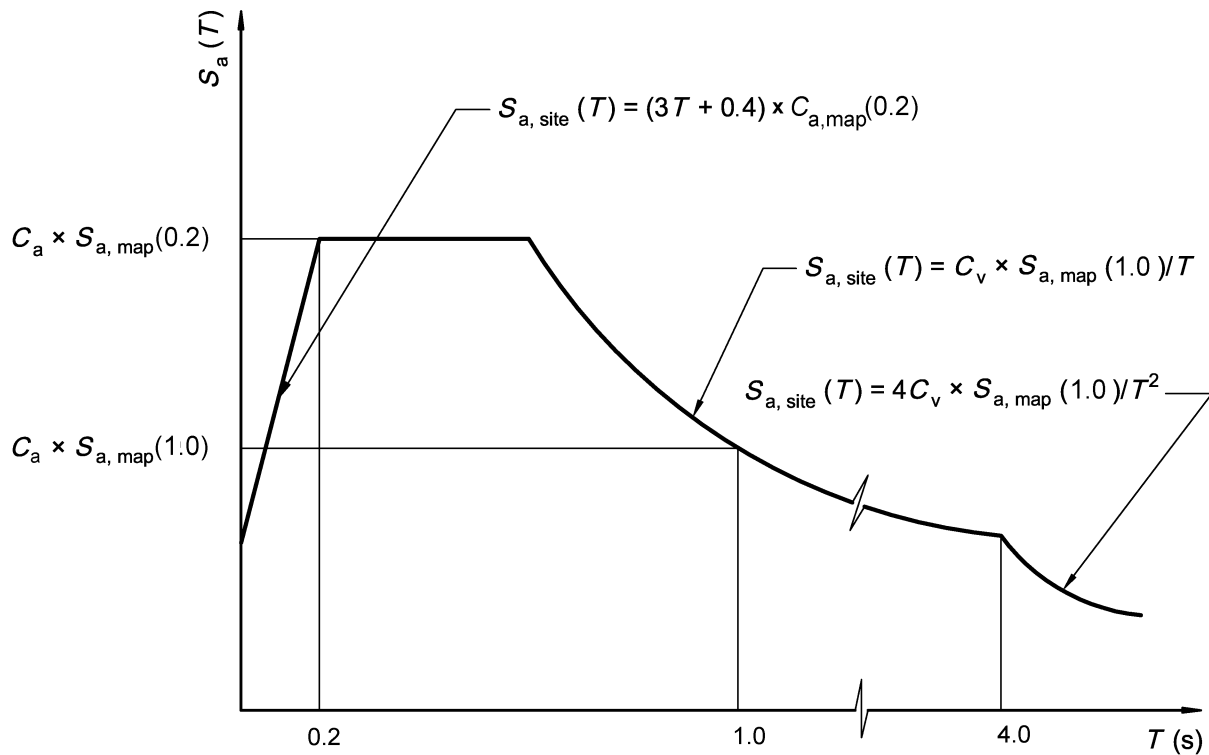
$$S_{a, \text{site}}(T) = (3T + 0.4)C_a \times S_{a, \text{map}}(0.2) \quad (2)$$

3) For periods greater than 0.2 s, the site spectral acceleration, $S_{a, \text{site}}(T)$, shall be taken as:

$$S_{a, \text{site}}(T) = C_v \times S_{a, \text{map}}(1.0)/T \quad \text{except that } S_{a, \text{site}}(T) \leq C_a \times S_{a, \text{map}}(0.2) \quad (3)$$

4) For periods greater than 4.0 s, the site spectral acceleration may be taken as decaying in proportion to $1/T^2$ instead of $1/T$ as given by Equation (4):

$$S_{a, \text{site}}(T) = 4C_v \times S_{a, \text{map}}(1.0)/T^2 \quad (4)$$

**Key**

T	natural period of a simple, single degree of freedom oscillator
C_a, C_v	site coefficients
$S_a(T)$	spectral acceleration
$S_{a,site}(T)$	site spectral acceleration corresponding to a return period of 1000 years and a single degree of freedom oscillator period T
$S_{a,map}(0.2)$	1000 year rock outcrop spectral acceleration obtained from maps in Annex B associated with a single degree of freedom oscillator period 0.2 s
$S_{a,map}(1.0)$	1000 year rock outcrop spectral acceleration obtained from maps in Annex B associated with a single degree of freedom oscillator period 1.0 s

Figure 2—Seismic Acceleration Spectrum for 5 % Damping

- d) The site vertical spectral acceleration at a period T shall be taken as half the corresponding horizontal spectral acceleration. The vertical spectrum shall not be reduced further due to water depth effects.
- e) The acceleration spectra obtained using the preceding steps correspond to 5 % damping. To obtain acceleration spectra corresponding to other damping values, the ordinates may be scaled by applying a correction factor D :

$$D = \frac{\ln(100/\eta)}{\ln(20)} \quad (5)$$

where η is the percent of critical damping.

As an alternative to the procedure given in a) to e), uniform hazard spectra obtained from PSHA may be modified by a detailed dynamic site-response analysis to obtain 1000 year site-specific design response spectra.

7.2 Seismic Action Procedure

The design seismic acceleration spectra to be applied to the structure shall be determined as follows.

For each oscillator period T , the ALE horizontal and vertical spectral accelerations are obtained from the corresponding values of the site 1000 year spectral acceleration [see 7.1 c) and 7.1 d)]:

$$S_{a,ALE}(T) = N_{ALE} \times S_{a,site}(T) \quad (6)$$

where the scale factor N_{ALE} is dependent on the structure exposure level and shall be obtained from Table 9.

The ELE horizontal and vertical spectral accelerations at oscillator period T may be obtained from:

$$S_{a,ELE}(T) = S_{a,ALE}(T)/C_r \quad (7)$$

where C_r is a seismic reserve capacity factor for the structural system that considers the static reserve strength and the ability to sustain large non-linear deformations of each structure type (e.g. steel versus reinforced concrete). The C_r factor represents the ratio of spectral acceleration causing catastrophic system failure of the structure, to the ELE spectral acceleration. The value of C_r should be estimated prior to the design of the structure in order to achieve an economic design that will resist damage due to an ELE and is at the same time likely to meet the ALE performance requirements. Values of C_r may be justified by prior detailed assessment of similar structures. Values of C_r for fixed steel structures are specified in Table 10. Values of C_r other than those recommended in the standard applicable to the type of offshore structure⁵ may be used in design, however such values shall be verified by an ALE analysis.

To avoid return periods for the ELE that are too short, C_r values shall not exceed 2.8 for L1 structures and 2.0 for L3 structures.

Table 9—Scale Factors for ALE Spectra

Exposure Level	ALE Scale Factor N_{ALE}
L3	0.85
L1	1.60

Table 10— C_r Factors for Steel Jacket of Fixed Offshore Platforms

Characteristics of Structure Design	C_r
The recommendations for ductile design in 5.3.6.4.3 are followed and a non-linear static pushover analysis according to API RP 2EQ is performed to verify the global performance of the structure under ALE conditions.	Variable up to 2.80, as demonstrated by analysis.
The recommendations for ductile design in 5.3.6.4.3 are followed, but a non-linear static pushover analysis to verify ALE performance is not performed.	Variable up to 2.00, as demonstrated by analysis.
The structure has a minimum of three legs and a bracing pattern consisting of leg-to-leg diagonals with horizontals, or X-braces without horizontals. The slenderness ratio (KL/r) of diagonal bracing in vertical frames is limited to no more than 80 and $F_y D/Et \leq 0.069$. For X-bracing in vertical frames the same restrictions apply, where the length L to be used depends on the loading pattern of the X-bracing. A non-linear analysis to verify the ductility level performance is not performed.	1.40
If none of the above characterizations apply.	1.10

⁵ Standards applicable to types of offshore structure, include ISO 19902, ISO 19903, API 2A-WSD, API 2N, ISO 19904 (all parts), ISO 19905 (all parts), and ISO 19906. See the Bibliography.

8 Detailed Seismic Action Procedure

8.1 Site-specific Seismic Hazard Assessment

The most widely used seismic input parameter for the seismic design and analysis of offshore structures is the design acceleration spectrum. In site-specific studies, the design acceleration spectrum is usually derived from an acceleration spectrum computed from a probabilistic seismic hazard analysis (PSHA) with possible modifications based on local soil conditions. Deterministic seismic hazard analysis may be used to complement the PSHA results. These analyses are described in 8.2 to 8.5.

8.2 Probabilistic Seismic Hazard Analysis

The different elements of a PSHA are shown graphically in Figure 3. In a probabilistic approach, ground motions at a site are estimated by considering the probability of earthquakes of different sizes on all potential sources (faults or areas) that can affect the site [Figure 3 a)]. A PSHA also accounts for the randomness in attenuation of seismic waves travelling from a source to the site [Figure 3 b)]. Summation over individual probabilities from different sources provides total annual probability of exceedance for a given level of peak ground acceleration (PGA) or spectral acceleration [Figure 3 c)]. The curve of probability of exceedance versus ground motion or response of the single degree of freedom oscillator (e.g. spectral acceleration, spectral velocity, or spectral displacement) is often referred to as a “hazard curve.” Spectral response varies with the natural period of the oscillator, therefore a family of hazard curves for different periods T is obtained [see Figure 3 c)].

The results from a PSHA are used to derive a uniform hazard spectrum [Figure 3 d)], where all points on the spectrum correspond to the same annual probability of exceedance. The relationship between the return period of a uniform hazard spectrum and the target annual probability of exceedance (P_e) may be taken as:

$$T_{\text{return}} = 1/P_e \quad (8)$$

where T_{return} is the return period in years.

Since a PSHA is a probability-based approach, it is important that uncertainty be considered in the definition of input parameters such as the maximum magnitude for a given source, the magnitude recurrence relationship, the attenuation equation, and geographical boundaries defining the location of a source zone.

The results from a PSHA are a series of hazard curves each for a spectral acceleration corresponding to a structure natural period, e.g. $T_1, T_2, \dots, T_N$ [see Figure 3 c)]. Because of uncertainties in PSHA input parameters, each of these hazard curves has an uncertainty band. The mean (or expected value) of each hazard curve should be used to construct a uniform hazard spectrum corresponding to a given exceedance probability P_e [see Figure 3 d)]. All references to hazard curves in 8.4 refer to the mean of the hazard curve.

8.3 Deterministic Seismic Hazard Analysis

Deterministic estimates of ground motion extremes at a site are obtained by considering a single event of a specified magnitude and distance from the site. To perform a deterministic analysis, the following information is needed:

- definition of an earthquake source (e.g. a known fault) and its location relative to the site;
- definition of a design earthquake magnitude that the source is capable of producing;
- a relationship which describes the attenuation of ground motion with distance.

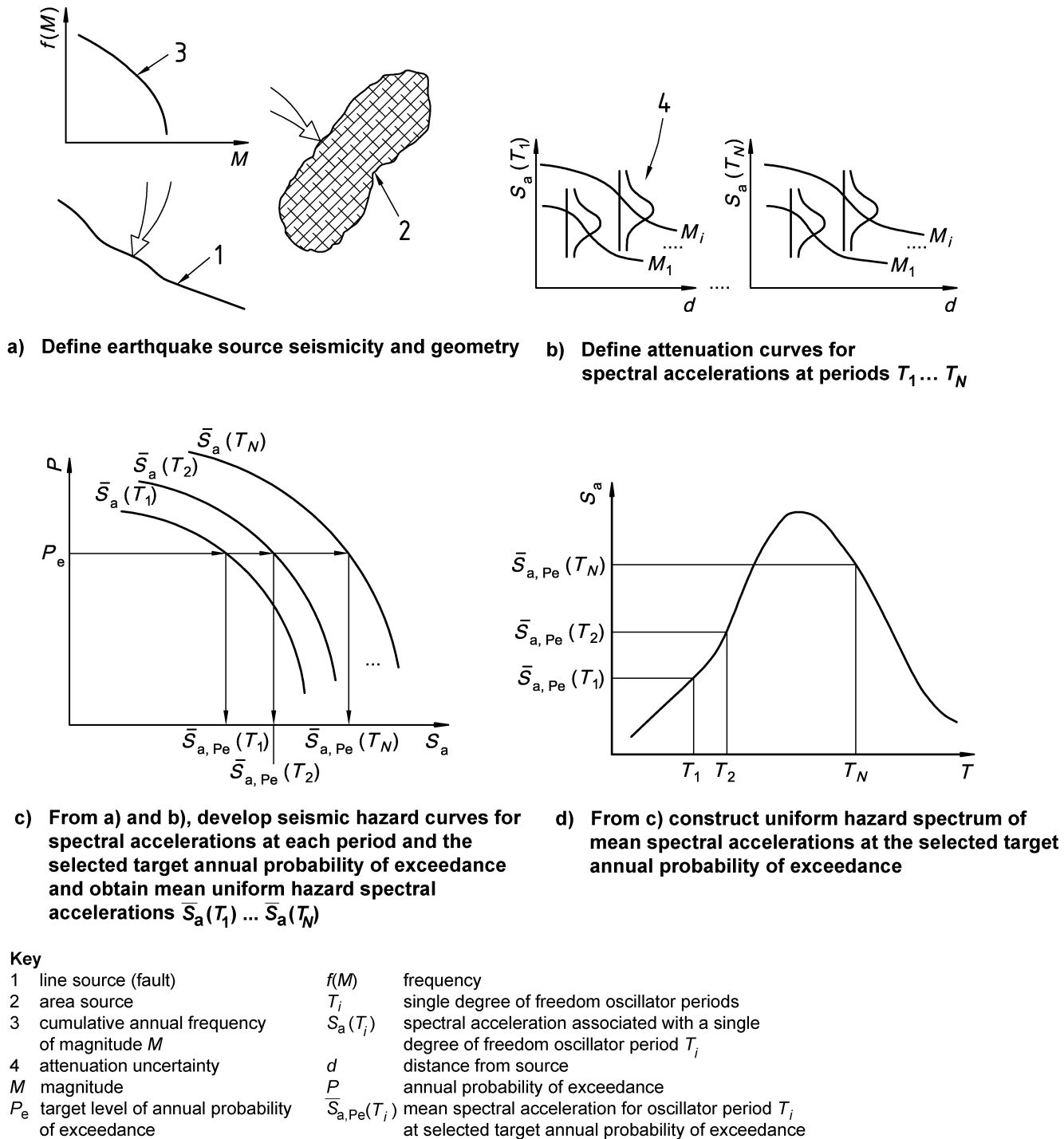


Figure 3—Probabilistic Seismic Hazard Analysis Procedure

A site can have several known active faults in its proximity. A maximum magnitude is defined for each fault. The maximum magnitude is a function of the fault length and historical knowledge of past earthquakes on that particular source.

Deterministic ground motion estimates are not associated with a specific return period, such as 1000 years, although the particular earthquake event used can have a return period associated with it. The return period for the maximum event on a given fault can vary from several hundred to several thousand years, depending on the activity rate of the fault.

A deterministic seismic hazard analysis may be performed to complement the PSHA results.

8.4 Seismic Action Procedure

This procedure is based on the results of a PSHA (see 8.2 and Figure 3). The site-specific seismic hazard curve shall have been determined in terms of the annual exceedance probability of a spectral acceleration corresponding to a period that is equal to the dominant modal period of the structure, $\bar{S}_a(T_{\text{dom}})$; such curves are illustrated in Figure 3 c). In lieu of more specific information about the dominant modal period of the structure, the seismic hazard curve may be determined for the spectral acceleration at a period of 1.0 s, $\bar{S}_a(1.0)$.

The ALE spectral accelerations are determined from the site-specific hazard curve and the target annual probability of failure, P_f , listed in Table 2. The specific steps to define the ALE and ELE events are illustrated in Figure 4 and are described in the following steps.

- Plot the site-specific hazard curve for $T = T_{\text{dom}}$ [a curve such as those shown in Figure 3 c)] on a $\log_{10}$ - $\log_{10}$ basis, i.e. showing the probability distribution of the parameter [see Figure 4 a)].
- Choose the target annual probability of failure, P_f , as a function of the exposure level as indicated in Table 2, and determine the site-specific spectral acceleration at P_f , from Figure 4 a).
- Determine the slope of the seismic hazard curve (a_R) in the region close to P_f by drawing a tangent line to the seismic hazard curve at P_f . The slope a_R is defined [see Figure 4 a)] as the ratio of the spectral accelerations corresponding to two probability values, one at either side of P_f , that are one order of magnitude apart [P_1 and P_2 in Figure 4 a)]; P_1 should preferably be close to P_f].
- From Table 11 determine the correction factor, C_C , corresponding to a_R . This correction factor captures the uncertainties not reflected in the seismic hazard curve.

Table 11—Correction Factor, C_C

a_R	1.75	2.0	2.5	3.0	3.5
Correction Factor, C_C	1.20	1.15	1.12	1.10	1.10

- Determine the ALE spectral acceleration by applying the correction factor C_C to $\bar{S}_{a,\text{Pr}}(T_{\text{dom}})$, the site-specific spectral acceleration at the required P_f and the structural dominant period T_{dom} :

$$\bar{S}_{a,\text{ALE}}(T_{\text{dom}}) = C_C \times \bar{S}_{a,\text{Pr}}(T_{\text{dom}}) \quad (9)$$

The annual probability of exceedance for the ALE event (P_{ALE}) can then be directly read from the seismic hazard curve, see Figure 4 b). The ALE return period is determined from the annual probability of exceedance using Equation (8). P_{ALE} is smaller than P_f to accommodate uncertainties in action and resistance evaluations not represented in the seismic hazard curve (as captured in the correction factor C_C).

- f) For certain structure types whose reserve strength and ductility characteristics are known, the ELE spectral acceleration is next determined from:

$$\bar{S}_{a,ELE}(T_{dom}) = \bar{S}_{a,ALE}(T_{dom})/C_r \quad (10)$$

where C_r is the seismic reserve capacity factor for the structural system that considers static reserve strength and the ability to sustain large non-linear deformations of each structure type (e.g. steel versus reinforced concrete). The C_r factor represents the ratio of spectral acceleration causing catastrophic system failure of the structure to the ELE spectral acceleration. The value of C_r should be estimated prior to the design in order to achieve an economic design that will resist damage due to the ELE and is at the same time likely to meet the ALE performance requirements. Values of C_r may be justified by prior detailed assessment of similar structures. Values of C_r for fixed steel structures are specified in Table 10. Values of C_r , other than those recommended in the standard applicable to the type of offshore structure⁶, may be used in design, however such values shall be verified by an ALE analysis; see also A.8.4.

- g) The annual probability of exceedance for the ELE event (P_{ELE}) can now be read from the seismic hazard curve, Figure 4 b). The ELE return period is determined from the annual probability of exceedance using Equation (8). Having determined ALE and ELE return periods, obtain ALE spectral accelerations and ELE spectral accelerations for other natural periods from the PHSA results, i.e. $\bar{S}_{a,ALE}(T)$ and $\bar{S}_{a,ELE}(T)$.
- h) Modifications of ALE and ELE acceleration spectra for local geology and soil conditions shall be addressed by a site response analysis (see 8.5).

For floating structures (such as TLPs) and other structure types for which C_r is either not well defined or unknown, a design process which goes directly to avoiding catastrophic system failure in the ALE is recommended. Extreme displacements and shock waves are often of primary interest here, in order to design the mooring system. The hull structure is designed elastically for the corresponding actions.

Minimum ELE return periods are given in Table 12 to ensure economic viability of a design, as a function of exposure level. If the ELE return period that is obtained from the procedure in this subclause is lower than the corresponding return period listed in Table 12, the return period in Table 12 shall be used for $S_{a,ELE}(T)$.

Table 12—Minimum ELE Return Periods

Exposure Level	Minimum ELE Return Periods
L3	50
L1	200

8.5 Local Site Response Analyses

In the detailed seismic action procedure (8.4), the ALE and ELE design spectral accelerations $\bar{S}_{a,ALE}(T)$ and $\bar{S}_{a,ELE}(T)$ are based on uniform hazard curves where all points on the curves have the same return period. The return periods for ALE and ELE events are determined according to the procedure specified in 8.4. The probabilistic and deterministic seismic hazard analyses described in 8.2 and 8.3 produce ground motions applicable to moderately stiff, stiff, or bedrock sites. However, many offshore sites consist of a surface layer of soft soils overlying the stiffer materials. The ALE and ELE spectral accelerations shall be further modified to account for local soil conditions at the site. A dynamic site response analysis, using linear or non-linear models of the underlying soil, may be used to modify the ALE and ELE spectral accelerations and obtain site-specific spectral accelerations for design.

⁶ Standards applicable to types of offshore structure, include ISO 19902, ISO 19903, API 2A-WSD, API 2N, ISO 19904 (all parts), ISO 19905 (all parts), and ISO 19906. See the Bibliography.