International Standard 6258

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Nuclear power plants — Design against seismic hazards

Centrales nucléaires — Conception antisismique

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Foreword

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Contents

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Nuclear power plants — Design against seismic hazards

0 Introduction

Earthquakes have the potential to cause serious damage to nuclear power plants and to jeopardize their safety. Therefore, at any nuclear power plant site the acceptability of ground motions shall be determined and the plant designed to withstand these motions.

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It should be understood that the parameters of the design ground motions by themselves do not represent the overall antiseismic protection of the plants; the whole set of assumptions taken into account in the structural analysis, including soil, is equally important. Therefore, an unrealistic increase of the design ground motion parameters, or unrealistic conservative assumptions during the structural analysis process, do not necessarily represent a better protection of the plant and do not guarantee a more conservative design. The conservatism of the antiseismic protection of a nuclear power plant should be achieved by harmonizing the safety margins during the whole process — from the definition of the design ground motion parameters to the assessment of the allowable stresses in the structural elements.

The amplitude and nature of the earth motions selected depend on the position of the site and on the specified risk level that the plant is designed to achieve. The specification of the risk level and of the design basis earthquake (DBE, see 2.2.18) to be used is the responsibility of national regulatory authorities and is not dealt with in this International Standard.

In preparing this International Standard, account has been taken of existing national standards and codes of practice. The requirements of this International Standard are compatible with IAEA 50-C-S [1] and for some subjects1) in line with the approaches presented in IAEA 50-SG-S1 [2] and IAEA 50-SG-S2 [3]. However, for some other subjects2), the approaches are different from those followed in IAEA 50-SG-S1 [2] and IAEA 50-SG-S2 [3].

1 Scope and field of application

This International Standard specifies the requirements to be taken into consideration when designing a nuclear power plant in relation to seismic hazards.

It specifies the data required and the way in which these data should be used in order to determine the earth motions to be taken as the design basis ground motion for design purposes.

It does not specify, on the other hand, earthquake levels for other purposes, for example inspection level earthquakes or operating basis earthquakes, which in reality have no simple relationship to the DBE (see 2.2.18) and other seismic motions; thus the specification and use of these other motions shall be agreed with national regulatory authorities.

This International Standard specifies the way in which the proof of seismic design adequacy should be established and documented for the various parts of the plant (foundation material, buildings, systems and components); the instrumentation is also specified.

The methods to be used for both probabilistic and deterministic methods for the determination of the DBE are covered in this International Standard and either method is acceptable. The detailed requirements in this International Standard are applicable to sites in which the maximum potential ground motion is predicted to be equivalent to intensity MSK VII or above.

This International Standard is entirely applicable when the DBE is greater than or equal to intensity VII on the MSK scale. When the DBE is less than intensity VII on the MSK scale, the structural analysis (see clause 5 *et seq.*) could also be performed by using simpler rules which are outside the scope of this International Standard.

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1) For example the seismotectonic approach.

2) For example, probabilistic approach, seismic analysis and absence of a lower level design basis earthquake (S1).

2 Definitions

2.1 Terms concerning geology and seismology

2.1.1 magnitude: The Briggsian logarithm of the maximum amplitude of motion, in micrometres, recorded by a standard seismograph at 100 km from the epicentre of the earthquake. Magnitude gives an approximate measure of the energy released as seismic waves.

NOTE — As several methods for determining magnitude exist, it is necessary to specify the way in which magnitude was determined.

The Richter magnitude originally defined by Richter (M_L) was the Briggsian logarithm of the maximum deviation, in micrometres, recorded by a standard seismograph at 100 km from the epicentre in California.

Symbol: M, with a subscript indicating the method of determination (M_b, body wave; M_L, Richter magnitude; M_S, surface wave; M_D, magnitude determined over a period).

2.1.2 seismic intensity: An expression, according to a conventionalized scale, of the extent of the felt or observed effects of an earthquake at a particular point.

A maximum degree of intensity corresponding to a given earthquake can be defined by evaluating the maximum effects ascribable to it, these latter generally being observed in the epicentral area. The symbol for this maximum intensity is I_0.

2.1.3 isoseismal (line): Line, characterized by a value of seismic intensity, which divides a zone where the intensity is equal or superior to this value from a zone where it is inferior.

2.1.4 zone of damage: Region where damage is observed, generally bounded by the isoseismal VII (MSK) (see the annex).

2.1.5 macroseismic epicentre: The centre of the region where the maximum seismic intensity is observed.

2.1.6 amplitude of seismic motion: A general expression used to specify the ground motion at a given point. It may correspond to the maximum value of one of the parameters characterizing the seismic motion: acceleration, velocity, displacement.

2.1.7 seismic source: The region within the Earth where the energy of an earthquake is released.

2.1.8 focus; hypocentre:

2.1.8.1 instrumental focus: The point that can be computed using the arrival times of seismic waves in different localities and which represents the first point of rupture of the rocks.

2.1.8.2 energetic focus: The centre of gravity of the volume within which the energy of the earthquake is released; for some applications, this volume is taken as a sphere.

2.1.9 instrumental epicentre: The point on the Earth's surface situated directly above the instrumental focus.

2.1.10 inactive fault: A fault showing no signs of recent geologic movement or of significant seismic activity.

2.1.11 active fault: A fault presenting any proper significant seismic activity or any potential of proper significant seismic activity, whether or not the existence of recent geologic movement related to it can be proven.

2.1.12 capable fault; fault capable of seismic activity: A fault which has significant potential for relative displacement at or near the ground surface.

2.1.13 surface faulting: The cracks or offsets on the ground surface caused by the movement of a fault at or beneath the ground surface.

2.1.14 free field ground motion: The ground motion resulting from an earthquake in the absence of discontinuities caused by construction features.

2.1.15 macroearthquake: An earthquake sufficiently intense for it to be felt by man.

2.1.16 microearthquake: An earthquake detected by instrumental means only.

2.1.17 microtremor: The virtually continuous, extremely low amplitude ground vibrations from natural or man-made sources such as wind, waves and industrial activity.

2.1.18 earthquake prone structure: Geologic structures likely to bring about earthquakes.

2.1.19 seismotectonic province: A geographic region typified by a similarity in geologic structures and in the characteristics of its earthquakes.

2.2 Terms concerning testing and interpretation methods for seismic evaluation of structures, systems and components

2.2.1 time history motion: A representation as a function of time of the vibratory motion of supports expressed in terms of acceleration, velocity or displacement.

2.2.2 ground time history motion: A representation as a function of time of one or more earthquake motions in the free field of the ground at the foundation level of the buildings or structures or at other defined free field ground locations.

2.2.3 design ground time history motion: A representation as a function of time in which time-scales or amplitudes have been suitably modified to take into account the variability and uncertainty of input earthquake motions.

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2.2.4 floor time history motion: A representation as a function of time of one or more earthquake motions at a particular building or structure elevation.

2.2.5 design floor time history motion: A representation as a function of time in which time-scales or amplitudes have been suitably modified to take into account the variability and uncertainty in input earthquake motion and in building and foundation characteristics.

2.2.6 response spectrum: A plot of the maximum response of a family of oscillators each having a single degree of freedom with fixed viscous damping, as a function of natural frequencies of these oscillators when subjected to vibratory motion input at their supports.

2.2.7 ground response spectrum: A response spectrum determined from vibratory ground motion input in the free field of the ground at the foundation level of buildings or structures or at other defined free field ground locations.

2.2.8 design ground response spectrum: A response spectrum obtained by modifying one or more ground response spectra in order to take into account the variability and uncertainty of input earthquake motions.

2.2.9 floor response spectrum: The response spectrum of the motion at a particular level of a structure for a given earthquake.

2.2.10 design floor response spectrum: The response spectrum defined at a particular building elevation and obtained by modifying one or more floor response spectra in order to take into account the variability and uncertainty of input earthquake motion and of building and foundation characteristics.

2.2.11 static analysis: An analysis carried out using a static force or displacement which represents the earthquake motion acting on an item without explicit consideration of the dynamic characteristics or the dynamic nature of the input motion.

2.2.12 dynamic analysis: An analysis carried out using either a static or dynamic force or displacement which represents the earthquake motion acting on an item with explicit consideration of the dynamic characteristics and the dynamic nature of the input motion.

2.2.13 damping: A progressive diminution of the response motion amplitude resulting from energy loss in structural elements due to friction and hysteretic losses within the material as well as small non-linearities such as cracking, joint slippage and other changes in structural element stiffness during the response to earthquake input motions. Structural damping as used in modal analysis is normally expressed as a percentage of the viscous critical damping.

2.2.14 liquefaction: The significant loss of strength and rigidity of saturated, cohesionless soils due to vibratory ground motion.

2.2.15 soil-structure interaction: Change of the foundation motion in relation to the free field motion, due to the presence of foundations and the building.

2.2.16 rigid range: The high frequency range of a response spectrum for which the amplified response acceleration does not exceed the input maximum acceleration (zero period acceleration) by more than 10 %.

2.2.17 rigid item: An item which has all its natural frequencies in the rigid range of the applicable support point response spectra considering all three input directions.

2.2.18 design basis earthquake; DBE: The set of free field ground motions derived for design purpose.

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2.3 Terms concerning seismic instrumentation

2.3.1 acceleration pick-up: An instrument which measures acceleration and transforms it into a signal which can be transmitted.

2.3.2 acceleration measuring device: A device which measures and records the absolute acceleration as a function of time. The device consists essentially of an acceleration pick-up, recorder and seismic trigger.

2.3.3 triaxial measuring instrument: An instrument which measures linear acceleration in three orthogonal directions, one of which is vertical.

2.3.4 seismic trigger: A seismic detector which causes the detection and recording of the measured values of acceleration to commence and cease.

2.3.5 seismic detector: A measuring device which emits signals when a measured value of acceleration exceeds a preset level.

2.3.6 recorder: An instrument capable of making a permanent record of absolute acceleration as a function of time after actuation by a seismic trigger.

3 Collection and presentation of geologic and seismic information

3.1 Information and investigation of earthquakes

Earthquake data of two types can be collected:

a) historical data;

b) instrumental data.

3.1.1 Historical data

A major part of the information base for determining DBEs is a complete set of historical relevant earthquake data. Therefore it is necessary to collect all available historical records, extending as far back in time as possible. Most such records will naturally be of a descriptive nature, for example the number of houses damaged or destroyed, or the behaviour of the population. But from such information a measure of the intensity scale value of each earthquake in seismic intensity scale values may be determined.

A comparison between various intensity scales is given in the annex. It shall be clearly stated what intensity scale is used for the description of the earthquake.

To evaluate effective ground motions of the site area, information has to be collected for all historical earthquakes within a region which includes the seismotectonic province of the site. This requires consideration of an area which depends upon the characteristics of the region. This area shall be big enough to allow the collection and consideration of all the geologic or geophysical data in relation to the seismicity of the site.

The information to be obtained, subject to availability, is as follows:

- the intensity scale value at the epicentre or maximum intensity scale value, as appropriate;
- the intensity at the site area;
- isoseismal maps related also to the local geologic conditions;
- the magnitude;
- the locations of the epicentre and the hypocentre.

In the absence of instrumental data, intensity scale values, building damage and ground effects data, in conjunction with a knowledge of local faults, are used to the maximum extent possible to determine the epicentre and magnitude of each historical earthquake.

3.1.2 Instrumental and reported data

It is necessary to collect all available earthquake information derived from instrumental recordings in the region. The following information to be obtained, subject to availability, is

- the location of the epicentre and the hypocentre;
- the origin time;
- the magnitude;
- the aftershock zone;
- the maximum reported intensity;
- isoseismal maps;
- the ground motions and intensity in the site area;
- the earthquake mechanisms and other available information that may be helpful in evaluating seismotectonics.

When the determination of earthquake level at the site relies upon the definition and localization of faults, it may prove necessary in some seismotectonic areas of unusual geologic complexity, such as areas of complex neotectonics or where unreliable seismicity data exist, to supplement the available historical and instrumental data on earthquakes by establishing a network of sensitive seismographs having microearthquake recording capability within a few tens of kilometres of the site. Earthquakes recorded within and near the network shall be carefully located for use in seismotectonic studies of the region and to determine the appropriate design basis ground motions.

NOTE — Microearthquakes cannot be used as such to determine design basis ground motion.

Strong motion recordings are available for some parts of the world. These recordings shall be collected and used in developing seismic wave attenuation functions appropriate for use in the region and in developing the design response spectra for the proposed nuclear power plant. Where there is a reasonable expectation of obtaining recordings not otherwise available, strong motion accelerographs may be installed within the site area.

3.2 Geologic information and investigations

3.2.1 Regional geologic data

The main purpose of the regional geologic information and investigations is to provide knowledge of the general geologic setting and tectonic framework of the region needed to interpret the earthquake data to define seismotectonic provinces. The information also serves to identify the types of geologic hazards that exist in the region and to study them in relation to the seismic and geologic investigations of the site area and site vicinity, described in 3.2.1.1 to 3.2.1.5. The following regional scale information shall be obtained.

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3.2.1.1 Characteristics of the ground

Where geologic maps exist, special attention shall be given to identifying lithologic units — crystalline, volcanic, sedimentary, alluvium, etc.

3.2.1.2 Stratigraphy

Superposition and age of strata, their lateral extent, and possibly their depth, thickness and relationship to one another shall be investigated.

3.2.1.3 Regional tectonics

Faults are given special attention. Topography and geomorphology may be useful for showing possible recent ground displacements. Consideration shall also be given to the tectonic style of the region, i.e. horizontal continuity of strata, folding and faulting as well as tectonic history, particularly the age of folding and faulting.

3.2.1.4 Characteristics of tectonic features

Style and type of faulting in the region and large faults associated with seismotectonic provinces shall be described. The length, depth, strike, and dip of faults, structural relationships among faults, and their age and history of movements shall be studied for information on the possible presence of seismically active or capable faults. Particular attention shall be given to the evaluation of Quaternary deposits and detailed neotectonic studies shall be carried out.

3.2.1.5 Subsurface characteristics

Where there is no surface manifestation of base rock and where appropriate data exist, a structural map of the base rock surface (hypogeologic map) is prepared, by using information available from regional geophysical investigations, such as seismic, gravimetric, and magnetic prospecting, to obtain the necessary subsurface details. This map may permit a determination of possible relationships between historical earthquake activity and deep tectonic structures which may lack direct expression at the surface.

Regional geologic data are usually obtained from published sources. An extensive use of remote sensing data, such as satellite photographs, sidescan radar, aerial photographs, aeromagnetics and gravimetrics, is necessary. Where published information is insufficient, it is permissible to make a demonstrably conservative assessment of the deep structure characteristics or it is necessary to perform field investigations, such as boring, trenching and the use of seismic reflection and refraction methods particularly in some areas of unusual geologic complexity, to supplement the published information on regional geology and to aid interpretation of the remote sensing data.

3.2.2 Site area and site vicinity geologic data

It is necessary to conduct a special detailed investigation of the geology of the site area and the site vicinity to identify tectonic structures which might localize earthquakes in the site area, to establish a basis for determining the age of movement of faults that may be present, to identify geologic hazards such as solutioning or subsidence that may affect the safety of the nuclear power plant, and to determine seismic energy transmission characteristics of the site area.

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Local geologic and physical conditions, such as properties of soils, can influence ground motion spectra and can consequently modify the observed effects. The following investigations are necessary.

3.2.2.1 A determination of the geologic and physical characteristics, such as thickness, depth, and properties, of strata in the site area.

3.2.2.2 An assessment of the local tectonics, including the presence of faults on or beneath the surface of the site vicinity and their geometry, such as length, inclination and where possible, depth. The structural relationship of local faults to regional faults, particularly to active or capable faults and correlation with historical earthquakes shall be assessed.

It is also necessary to carry out field and laboratory investigations as described in 3.2.2.2.1 to 3.2.2.2.4. Regarding the site area, the investigations shall be conducted with due consideration to the proposed design of the nuclear power plant.

3.2.2.2.1 Bearing strata studies

Local bearing strata investigations and laboratory tests shall be conducted to determine the depth and properties of the different layers namely, Poisson ratio, Young modulus, shear modulus and density.

3.2.2.2.2 Borings

For moderately shallow strata the configuration of the bearing strata and of the bedrock 1) and in some cases of the base rock 2) can be determined by boring. As borings are made, samples shall be taken at different depths for soil and rock property tests.

3.2.2.2.3 Test excavations

When bearing strata and/or bedrock properties and structure cannot be clearly determined by either seismic methods or boring, a test excavation, trench, shaft or tunnel shall be made. The practicability of such excavations is dependent upon the characteristics of the bearing strata and the depth of the bedrock.

3.2.2.2.4 Vibration testing of models

The natural vibration frequencies of buildings, structures and equipment are influenced by the properties of the bearing strata under the foundation of the facility. Therefore a knowledge of the range of effective values of the stiffness properties of the bearing strata in evaluating structural response during earthquake is required.

4 Methods for deriving design basis ground motions

Design basis earthquakes (DBEs) may be established either by a deterministic analysis including seismotectonic and geologic techniques or by a probabilistic analysis.

The use of probabilistic analysis in general is practical only in regions where there exists a reliable data base of relatively long duration (several hundred years). In most cases, this corresponds to DBEs equal to or less than VII MSK intensity.

4.1 Deterministic analysis

A deterministic approach consists of the consideration of a logical sequence of events starting from an assumed initiating event; to each element of the sequence is assigned a unique description which includes the conservatism factors, i.e. pessimism or prudence factors, which can "reasonably" be associated to the elements.

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1) **bedrock** : The first hard geologic formation to be encountered from the Earth's surface downwards, the mechanical properties of which contrast considerably with those of the overlying deposits.

2) **base rock** : The well consolidated geologic formation that may be considered on a regional scale as being homogeneous as far as the transmission of seismic waves is concerned.

Seismotectonic techniques consist of :

a) identifying the region, the seismically active structures and their maximum earthquake potential, the seismotectonic provinces and their maximum earthquake potential ;

b) evaluating the design basis ground motion produced at the site by the occurrence of this maximum earthquake potential at the nearest point to the site on the seismically active structure or at the borders of the seismotectonic provinces. If the seismically active structure is close to the site the physical dimension of the source may, if possible, be taken into account.

4.1.1 Identification of seismotectonic provinces

The purpose of seismotectonic studies is to define geographic regions which have similar earthquake potential.

The seismotectonic provinces will be the areas identified by similarity of geologic structures and of the characteristics of the seismicity.

The seismic and geologic data previously discussed shall be developed into a coherent well-documented description of the regional tectonic characteristics, listing details of tectonic structure, tectonic history and present-day earthquake activity which distinguish various seismotectonic provinces. For example a seismotectonic province boundary may separate areas which show strongly contrasting tectonic framework, areas which have greatly different late Tertiary and Holocene tectonic histories.

A number of precautions shall be observed in defining the boundaries of seismotectonic provinces. All the structures in a contiguous area which have the same seismotectonic or geologic style shall be included in the same province. Each tectonic structure relevant to the seismicity shall in its entirety lie within the same seismotectonic province. When there is doubt that one structure is a continuation of another, then both shall be considered as one structure and consequently included in the same province.

In some areas of the world, the boundaries of lithospheric plates present a special problem. For example where the mode of plate interaction is subduction, the lower (subducting) plate is generally considered a separate seismotectonic province from the upper (crustal) plate. It has been demonstrated that different sectors of plates have different potential for maximum earthquakes. These sectors may also be considered seismotectonic provinces.

Significant differences in rates of seismicity may suggest different tectonic conditions that can be used in defining seismotectonic provinces. The length of time during which historical data are available should be long enough to demonstrate that conclusions based on these data are reasonable. However, significant differences in hypocentre depth (for example 10 to 30 km versus 200 to 400 km) may alone justify the differentiation.

Alternative interpretations of the seismotectonics of the region given in available literature sources shall be discussed. When alternative interpretations are judged to explain the observed seismic and geologic data equally well the interpretation which results in the more conservative assessment of the potential ground motion at the site area shall be used.

4.1.2 Association of earthquakes with seismically active structures and seismotectonic provinces

The fundamental data needed for associating earthquakes with tectonic structure and seismotectonic province shall be collected and properly prepared.

4.1.2.1 Association of earthquakes with seismically active structures

Whenever an earthquake epicentre or a group of earthquake epicentres can be reasonably associated with a tectonic structure, the rationale for the association shall be given together with consideration of the characteristics of the structure, its geographic extent and its structural relationship to the regional tectonic framework. This assessment shall include consideration of methods used to determine the earthquake epicentres and an estimate of the errors in their locations. A detailed comparison of these tectonic structures with others in the same seismotectonic province with regard to factors such as age of origin, sense of movement and history of movement shall be made. Other available seismologic information, such as source mechanisms, stress environments and aftershock distributions, shall also be evaluated. Tectonic structures with which significant seismicity is correlated shall be considered seismically active.

4.1.2.2 Identification of maximum earthquake potential associated with seismically active structures

For seismically active structures, which are pertinent to determining the earthquake potential for the site, the maximum earthquake potential which can reasonably be expected in association with these structures shall be determined.

The geologic and seismologic data previously discussed and relating to the dimensions of the structure, amount and direction of displacement, maximum historical earthquake and earthquake frequency shall be used in this determination. The dimensions of fault rupture in an earthquake can often be determined from the distribution of aftershocks. In the absence of suitable local data, the maximum earthquake potential for a tectonic structure can be estimated based on methods[4] which relate the dimensions (length and vertical depth, displacement) of the fault rupture with the magnitude. However, to use these relationships the fraction of the total length of a structure which can move in a single earthquake has to be known. A value of about one half of the total fault length has been assumed in certain regions of the world.

In applying this methodology, it has to be remembered that earthquake magnitude is a function of both the source dimensions and the stress drop. Stress drop usually will not be known, but reasonable upper bound values based on available published studies may be used.

An alternative method[5] for estimating the maximum earthquake potential for a seismically active structure or for a seismotectonic province has been described. This method is based mainly on the statistical analysis of earthquake data associated with the structure or province.

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When sufficient information about the seismicity and geologic history of the movement of a fault or fault zone is available, a method exists for evaluating the maximum magnitude potential from total area and maximum slip of the fault in the Quaternary period[6]. In this method the usual hypothesis is made for the statistical distribution of the number of earthquakes as a function of their magnitude. The slip is then correlated with seismic moment and therefore with the magnitude. Finally, from the total slip the maximum magnitude may be estimated.

4.1.3 Earthquake not associated with seismically active structures

The maximum earthquake potential not associated with tectonic structures which can be reasonably expected with a very low probability in the tectonic province shall be evaluated on the basis of historical data and on the seismotectonic characteristics of the region. Comparison with similar regions where very extensive historical data exist may be useful, but considerable judgement is needed for this evaluation.

4.2 Probabilistic analysis

The objective of the probabilistic approach is to determine the level and form of ground motion that has an acceptably low probability of being exceeded during the operating life of the plant. This requires a basic data sample of the intensity of ground motion experienced in the region from historical earthquakes and also an acceptable probabilistic model. A number of mathematical models for determining earthquake probabilities have been proposed. In general, all of the models require conditions on the data sample that cannot be fully demonstrated for most areas of the world. If, however, the sample of earthquakes experienced in a region is accepted as being adequate (i.e. meeting the requirements of the model), the calculations are relatively simple.

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In calculations of earthquake probability, the confidence level on the estimates depends strongly on the time span of the available data sample and to a lesser degree on the completeness of the data set. Thus, to make estimates of ground motion intensities which have an acceptably high confidence level, the data set has to cover the longest possible time span. This usually requires the use of pre-instrumental data which are known to be incompletely and inaccurately reported. An assessment of the completeness and accuracy of the available data set shall be made and taken into account in making the probability calculations. One simple but useful method[7] for assessing the completeness of a data set is described in the literature.

When this method is used to make the probability calculations, it may be desirable to augment the available data set with low ground motion intensities measured in the region. This may be important in areas with limited historical records. Part of the required data can be obtained by operating an earthquake recording network such as described in 3.1.2. However, it shall be stressed that a probabilistic law cannot be extrapolated on the basis of these data alone. In using earthquake data, caution has to be exercised in taking into account poor data on epicentre locations and the tendency of earthquakes to cluster in time.

4.3 Determination of site ground motion

The evaluation may be performed as follows.

a) For each seismically active structure, the maximum earthquake potential is considered to be moved to the appropriate location on the structure closest to the site area. For earthquakes near to the site the physical dimension of the source may be taken into account.

b) The maximum earthquake potential in the seismotectonic province of the site that cannot be associated with seismically active structures is assumed to occur at a certain distance from the site. In certain countries this distance may be accepted by the regulatory body on the basis of studies and investigations which ensure that within this distance there are no seismically active structures and, therefore, that the related probability of earthquakes occurring therein is very low. This distance may be in the range of a few to tens of kilometres and depends on the focal depth of the earthquakes of the province. In evaluating it the physical dimension of the source shall also be considered[8].

c) Maximum earthquake potential in seismotectonic provinces adjacent to the province of the site is assumed to occur at the locations on the province boundaries nearest to the site.

d) An appropriate attenuation function is used to determine the ground motion which these earthquakes would cause at the site.

For the probabilistic method, on the basis also of seismic considerations, the evaluation may be performed as follows.

a) For each seismic source that can affect the site, a mathematical model called "earthquake-generating source" is selected (models of point sources, linear sources and sources distributed superficially are available)[9 to 11].

b) A probability density function is derived for a range of earthquake sizes (usually in terms of epicentral intensity or magnitude) for each earthquake-generating source.

c) The probability of not exceeding a selected level of ground motion at a site (in terms of acceleration, velocity, displacement or intensity) is determined for each earthquake-generating source using an attenuation law.

d) The level of ground motion which will not be exceeded at the site with a selected total probability is determined by combining the contributions from all earthquake-generating sources.

4.4 Induced seismicity

Special attention shall be given to potential induced seismicity particularly that from large dams or reservoirs, and extensive fluid injection into or extraction from the ground. Modification of the stress conditions in rocks and geologic structures due to these conditions may produce seismic activity. Earthquakes resulting from such phenomena usually have shallow foci and are located in the vicinity of the reservoir or of the injection or extraction area. In the case of reservoir loading, some earthquakes have had relatively high magnitude (close to magnitude 6). Usually the larger earthquakes have occurred in association with deep reservoirs, but no simple rule regarding a fixed reservoir depth above which induced seismicity occurs can be applied everywhere. Earthquakes associated with fluid injection and extraction activity are generally smaller in magnitude than those caused by reservoir loading. Seismic networks in areas where the potential for such a problem exists may provide useful information for assessing the significance of induced seismicity.

4.5 Free field ground motion characteristics [12]

The ground motion characteristics may be characterized either

a) by free field response spectra for various damping coefficients, or

b) by time history or histories,

both characteristics preferably being specified at free field surface ground level; however, other locations are acceptable as long as these are precisely described.

4.5.1 Spectral shape appropriate to the site area

The spectral shape of the ground motion is determined according to the relative influences of the source spectral characteristics for earthquakes in the region and the attenuation characteristics of geologic materials which transmit the seismic waves from the hypocentres to the site area. In strata above the base rock the seismic waves in the free field are amplified or attenuated according to the frequency transfer characteristics of the strata and the strain level of the vibration. Therefore, the response spectra of accelerograms of several different earthquakes obtained at the same site area at the surface and on base rock have different frequency characteristics.

The following alternative methods are acceptable for obtaining the design ground response spectra.

4.5.1.1 Site specific response spectrum

Wherever possible, response spectra shall be developed from strong motion time histories recorded at the site. However, for the majority of sites an adequate sample of strong motion time histories cannot be obtained in a reasonable number of years. Therefore, response spectra obtained at places having similar seismic, geologic and soil characteristics may be useful in establishing the response spectrum specific to the site. An evaluation shall be performed to determine whether response spectra obtained at these other places appropriately reflect the site area response energy absorption characteristics, as well as the source mechanisms generating earthquakes affecting the site. Due consideration shall be paid to the different frequency characteristics associated with different strain levels of the ground motions.

In conclusion the method may be summarized as follows:

a) collection of strong motion accelerograms from the site or more probably from similar sites;

b) normalization of these accelerograms to the zero period ground acceleration defined for the site;

c) evaluation of the response spectrum for each accelerogram using various damping factors;

d) modification of the shape of the normalized spectrum taking into account the strain level in the subsurface by the ground motion and other uncertainties.

4.5.1.2 Standard response spectrum

An alternative method is to use a standard response spectrum with a relatively smooth shape which is generalized for application and which has been obtained from many response spectra derived from records of past earthquakes. However, in certain parts of the world higher values in some frequency fields have been observed so that some modifications of this spectrum may be required. This standard response spectrum is scaled up to the value of ground acceleration, velocity displacement, etc. If this approach is followed, a specific study or a justification should be carried out in order to verify the applicability of the standard response spectrum to the specific site.

4.5.2 Radiation damping

It is important to select realistic values of soil radiation damping since an overly conservative selection of soil damping values can distort the frequency response of a free field system.

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4.5.3 Time histories of earthquake ground motion

Time histories can be developed for the site area. The time histories take account of the maximum velocity (or alternatively, maximum acceleration or spectral intensity) and the duration of "deterministic intensity function" which represents the envelope of the ground motion intensity time history.

For design, the time histories of vibratory ground motion may be based on:

a) strong motion records obtained in the site vicinity from past earthquakes, or adequate modifications thereto, such as adjusting the peak acceleration, applying an appropriate frequency filter, combinations of records, etc.;

b) strong motion records obtained at places which have similar seismic, geologic, and soil characteristics. In some cases these records may need appropriate modifications, such as applying wave propagation theory to modify frequency characteristics;

c) calculation models simulating earthquake ground motion, such as generating random time series by computer and filtering out to obtain the specific frequency characteristics.

Regardless of the procedure used, the design time histories and the design response spectra shall be compatible. This implies that it is necessary to choose a sufficient number of time histories with pertinent characteristics so that the envelope of their response spectra does not lie significantly below the smoothed design response spectrum throughout the entire frequency range of interest.

4.5.4 Ratio of motion in vertical and horizontal directions

The design response ground spectra and design time histories for the vertical direction shall be evaluated using the same procedure as for the horizontal direction. Appropriate vertical time histories may be the basis for this evaluation. If no specific information is available on the peak acceleration of vertical ground motion at the site, the ratio of peak acceleration in the vertical direction to the horizontal should not be assumed to be less than 1/2.

5 Classification of plant equipment and building

Seismic classification of plant items depends on the specific safety requirements of the plant and shall be in agreement with the national regulatory authority requirements, since such seismic classification lies beyond the scope of this International Standard.

6 Design methods

6.1 General

The verification of the adequacy of the seismic design of nuclear safety class structures and components is divided into a number of categories and subcategories as shown in the figure. In general, either test or experimental methods or analytical techniques employing mathematical models of the system to be evaluated are used. Combined methods can also be used.

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Verification by test is more typically used when the potential failure modes either in terms of structural or functional adequacy cannot be easily identified in terms of stress-strain or deformation outputs from an analytical solution. Seismic verification test procedures are discussed in general in IEEE Std 344[13] and will not be discussed in detail in this International Standard. However, since the referenced procedures are written specifically for electrical components, care should be taken in applying the requirements of this recommended practice directly to mechanical components and structures.

The analytical methods used to verify seismic design adequacy fall into two main categories: dynamic analysis and static analysis, as shown in the figure. The dynamic analysis category is further divided into four subcategories, consisting of seismic input, damping, model and analytical techniques. Static analysis may be used extensively in seismic design verification, particularly for relatively low seismic intensity sites.

In static analysis, dynamic characteristics of components and structures are not determined explicitly. In such cases, an inertia acceleration taken as some coefficient times gravity is selected as representative of seismic acceleration and applied statically to the mass distribution of the component to determine seismic inertia forces in the component. This method is used on conventional building structures and is well-documented in national building codes. In nuclear power plant design, the maximum value of the seismic static coefficient is taken as 1,5 times the peak of the applicable response spectrum. Values less than 1,5 times the peak of the applicable response spectrum may be used, provided valid analytical justifications are presented.

In dynamic analysis the dynamic characteristics of the components are normally expressed in terms of frequency and mode shape and are used to determine the characteristic response of the component. The dynamic characteristics of frequency and mode shape can be used with the applicable response spectra or time histories to define seismic forces. For some systems, particularly non-linear system components, direct integration of the equations of motion is utilized to determine seismic response.

6.2 Civil engineering structures

6.2.1 Safety related buildings

6.2.1.1 Seismic input

Two horizontal components or a resultant ground motion in the form of response spectra or time histories of motion constitute inputs for the dynamic analysis. The vertical component may be considered in the same manner as the horizontal motions or a constant static value for the vertical component may be assumed if no foundation-structure interaction is present and the structure is sufficiently rigid vertically.

6.2.1.2 Modelling of structures

The model of the structure shall take foundation-structure interaction into account when the foundation media has a shear wave velocity less than 1 200 m/s. To this end, consideration is given to rigid body translational, rocking and torsional modes, either individually or coupled as appropriate.

Subsystems (which may include inertia effects of contained liquids) located in the building should also be taken into account in the model of the building structures, depending on the nature of the subsystem. The following procedures may be used:

a) for rigid items rigidly connected to the structure, or subsystems that meet the decoupling criteria presented in references [14 and 15] (see 6.4), it is necessary to include the mass of the subsystem in the mass of the structure;

b) for parts connected to the structure the fundamental frequency of which is less than one quarter of that of the structure, the subsystem may be neglected in the analysis of the structure;

c) for other subsystems, it is necessary to include the subsystem in the analysis of the main structural model.

6.2.1.3 Analytical methods

A dynamic analysis is performed in order to obtain seismic response motions or loads. Both time history and response spectrum inputs are acceptable.