INSTITUTE FOR NUCLEAR SAFETY AND PROTECTION

Basic Safety Rule I.2.c

Determination of the seismic motion
to be taken into account for the safety of major nuclear facilities

1. SCOPE

French regulatory practice requires that the main safety functions of a land-based major nuclear facility, in particular in accordance with its specific characteristics, safe shutdown, cooling and containment of radioactive substances, be assured during and/or after earthquake events that can plausibly occur at the site where the installation is located. This rule specifies an acceptable method for determining the seismic motion to be taken into account when designing a facility to address the seismic risk.

In regions where deformation factors are low, such as in metropolitan France, the intervals between strong earthquakes are long and it can be difficult to associate some earthquakes with known faults. In addition, despite substantial progress in recent years, it is difficult, given the French seismotectonic situation, to identify potentially seismogenic* faults and determine the characteristics of the earthquakes that are liable to occur. Therefore, the approach proposed in this Basic Safety Rule is intended to avoid this difficulty by allowing for all direct and indirect influences that can play a role in the occurrence of earthquakes, as well as all seismic knowledge.

Furthermore, as concerns calculation of seismic motion, the low number of records of strong motion in metropolitan France makes it necessary to use data from other regions of the world.

2. STATEMENT OF RULE

The basic approach for meeting the above objectives is deterministic, insofar as reference motion is associated with reference earthquakes. The first stage is to determine the Maximum Credible Earthquake, defined as the worst earthquakes liable to occur in a period equivalent to that for which there are historical records, i.e. approximately 1000 years. The second stage is to determine the Maximum Design Earthquakes. Meanwhile, the reference motion is determined on the basis of "seismic records"*.

For certain sites, allowance for paleoseismic data can result in supplementing of the motion associated with the Maximum Design Earthquakes. The principle of these studies is outlined in §2.3.5. and described in detail in Appendix 3.

For each site, an assessment of these earthquakes is made using the procedures detailed in §2.2. and §2.3.

The corresponding studies should be carried out as early as possible. The major nuclear facility safety analysis reports should include the main material used for characterising the Maximum Credible Earthquake(s) and the Maximum Design Earthquake(s) and the corresponding seismic motion.

2.1. Determination and quantification of the parameters of earthquakes representative of site seismicity

The basic approach consists of assuming that earthquakes equivalent to those for which historical records exist are liable to recur in the future at an epicentre* position representing the worst case in terms of its effects (in terms of intensity*) at the site, while remaining compatible with geological and seismological data.

Consideration is therefore given to the seismotectonic areas and the seismic data for the vicinity of the site, using a method detailed in §2.2. Investigation must cover a geographical area that is as broad as is necessary to be certain that all these earthquakes that are liable to have a significant effect on determination of the Maximum Credible Earthquake(s) have been taken into account.

This operation consists in determining, for a possible site, one or more Maximum Credible Earthquakes which are those, resulting from the previous process, that are liable to occur at a site with the greatest effect in terms of macroseismic intensity. A corresponding intensity is thus determined for the site (I_{MCE}). To allow for the uncertainties inherent[1] in determination of Maximum Credible Earthquakes, the safety margin is arbitrarily added as follows.

For each Maximum Credible Earthquake, a Maximum Design Earthquake is determined from the former by applying the following simple relationship based on site intensity:

$$I_{MDE} = I_{MCE} + 1 \qquad (1)$$

Except in the special case considered in §2.3.5., the Maximum Design Earthquakes are considered to represent the worst cases to be allowed for in assessment of the seismic hazard to be taken into consideration in the design basis of a facility.

It is postulated that Maximum Design Earthquakes can be preceded or followed by earthquakes of Maximum Credible Earthquake level.

2.2. Maximum Credible Earthquake assessment procedure

This is based on dividing the earth's crust into seismotectonic zones, which are sections with the same seismogenic potential. It is postulated that an earthquake which has occurred at a point in a given seismotectonic zone can occur anywhere in it.

2.2.1. *Determination of seismotectonic zones*

A review of the most recent geological, geophysical and seismic documents is necessary. A detailed study, covering the static and dynamic characteristics of the crust and seismicity also has to be submitted. A method of determining seismotectonic zones is described in Appendix 1.

2.2.2. *Seismicity study*

Historical seismicity data include inaccuracies concerning both the extent of knowledge of the occurrences and the assessment of the macroseismic intensities. The characteristics of the earthquakes liable to occur in determining the Maximum Credible Earthquake(s) must be established with the greatest possible precision with the available seismotectonic knowledge and instrumental and historic seismicity records.

[1] These uncertainties cover those associated with imprecise knowledge in the fields of seismotectonics and seismicity.

Use is to be made of the data stored in an up-to-date macroseismic data repository (such as the SISFRANCE* evolving database) as a source of basic information. Additional information may be necessary, and proper interpretation is indispensable.

The following factors can be involved in determining Maximum Credible Earthquakes:

- intensity of the epicentre,
- isoseismals*,
- epicentre, hypocentre* and focal depth*,
- magnitude*,
- regional intensity attenuation laws*.

One method of determining these characteristics is described in Appendix 2.

The most up-to-date instrumental seismic data must also be used to supplement knowledge of seismicity.

2.2.3. *Determination of Maximum Credible Earthquakes*

After determining the seismotectonic zones, the Maximum Credible Earthquake is taken to be the known historical earthquake(s) within the zone, occurring at the site with the highest intensity, i.e.:

a) earthquakes in the zone to which the site belongs are considered to occur at the site,

b) earthquakes from other zones are considered as being able to occur at the point nearest the site in the zone in which they belong.

2.3. Calculation of seismic motion

Seismic motion* is characterised by the response spectra* of the horizontal and vertical components of the surface motion of the land at the site. Characterisation can be supplemented with the other parameters mentioned in §2.3.3.

2.3.1. *Calculation of spectra corresponding to a given Maximum Credible Earthquake*

Calculation of the spectra is based on study of a large number of recordings in "seismic records". Using values of magnitude[2] M and focal distance R* of the Maximum Credible Earthquake considered, the response spectra corresponding to the horizontal and vertical components of the motion are calculated using an average attenuation law* as follows:

$$\log_{10} PSA = aM + bR - \log_{10} R + c \qquad (2)$$

where PSA is a value of the response spectrum (pseudo-acceleration) with a given frequency and damping.

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[2] The magnitude* of historical earthquakes is currently determined by a local magnitude. Determination of the magnitude used in the attenuation law proposed in the Basic Safety Rule corresponds to a surface magnitude. It can be considered that surface magnitude equals local magnitude at local magnitudes greater than 4.5.

As concerns the vertical component, it is acceptable to use the response spectrum of the horizontal components with all frequencies reduced by a coefficient of 2/3.

Correlation coefficients a, b and c, which vary with the frequency and the damping factor considered, are evaluated for two categories of site (see §2.3.4.). These coefficients are valid in a distance and magnitude bracket depending on the seismic records and seismological analysis (considering a distance R between 7 km and 100 km and a magnitude M between 4.5 and 7.3). The spectra are calculated for the 0.25 to 33 Hz frequency range at least.

For focal distances less than 7 km, the following conventional method can be used: the spectra are calculated considering that R is equal to the minimum distance and taking an upper-bound value of magnitude M such that the earthquake produces the same effect at the site (I_{MCE} and I_{MDE} being constant).

In the range of validity of law (2), acceleration at an infinite frequency (equal to the maximum ground motion acceleration) is considered to be equal to the value of the response spectrum for acceleration at a frequency of 33 Hz.

The seismic records, the method for determining the correlation coefficients and their domains of validity are described in Report IPSN/DPRE/SERGD/2000/0053 prepared in accordance with quality assurance requirements.

2.3.2. *Calculation of spectra corresponding to a given Maximum Design Earthquake*

The Maximum Design Earthquake spectrum is calculated using relationship (2), within its range of validity, considering that the increase in intensity of one degree between the Maximum Credible Earthquake and the Maximum Design Earthquake corresponds to an increase in magnitude conventionally set at 0.5.

2.3.3. *Calculation of other ground motion parameters*

The description of seismic motion in the form of a response spectrum can be supplemented with the following data in particular:

- duration of the strong motion phase,
- accelerograms,
- maximum ground velocity,
- A/V*,
- CAV*,
- Arias intensity*.

This data must be compatible with the physical characteristics of the earthquake (Maximum Credible Earthquake or Maximum Design Earthquake) and the site conditions indicated in §2.3.4.

The database used for determining the coefficients of equation (2) can be used for calculating the different parameters.

2.3.4. *Allowance for site effects*

Site effects are generally due to amplification of seismic motion as a result of a soil layer of low mechanical strength and planar geometry located near the surface. Equation (2) can be used to calculate the spectra for two site conditions, on the basis of the dynamic characteristics of the soil determined in accordance with Basic Safety Rule I.3.c:

- sites characterised by an average shear-wave* velocity in the first 30 metres of depth that is greater than 800 m/s,
- sites where the average velocity of shear waves in the first 30 metres is between 300 m/s and 800 m/s.

If the ground beneath the facility is not characterised, at least to a depth of 30 metres, or exhibits strong lateral variability, the dimension spectrum must englobe the spectra calculated with both site conditions.

In certain particular cases, complex sedimentary layer geometry (presence of relief or sedimentary base) or extreme thickness can result in amplification or increased duration of seismic motion. These special effects are not simply due to the properties of the upper layers of the soil (last 30 metres under the installation).

In cases where there are such site specific effects or where the average velocity of the shear waves in the first 30 metres of the soil is less than 300 m/s, *ad hoc* studies are necessary to allow for these particularities in estimating the seismic motion associated with Maximum Credible Earthquakes and Maximum Design Earthquakes. In such situations, the use of the response spectrum calculated with law (2) can well be supplemented with other seismic motion indicators specific to the site.

2.3.5. Allowance for active faults with surface rupture*

If the site is located in the immediate vicinity of an active fault with surface rupture, a study to determine the seismic motion associated with the earthquakes which could have occurred along the fault, and which might affect the site, needs to be made. Indications concerning the manner in which such studies are to be carried out are given in Appendix III.

2.4. Allowance for seismic motion

2.4.1. For the design of installations or parts of installations to be designed to resist earthquakes, the free-field motion defined in §2.3. is to be used as indicated below.

2.4.1.1 The installation must be designed for seismic loads englobing those resulting from the motion associated with Maximum Design Earthquakes. Its upper-bound nature is established on the basis of parameters describing ground motion associated with the Maximum Design Earthquakes. Comparison is to be made, with damping reduced to 5%, between the spectra used for design of the installation and the response spectra associated with the Maximum Design Earthquakes. It will be sufficient to verify that the spectra adopted for the design of the installation englobe the response spectra associated with the Maximum Design Earthquakes. The use of the data mentioned in §2.3.3. is not automatic but, depending on the case, varies with the type of site or structure in question.

2.4.1.2. Allowance for spectra corresponding to the earthquakes deduced from the study of active faults with surface rupture for the design basis of the facility shall depend on the case, varying with the recurrence interval* of the earthquakes, the degree of certainty associated with the knowledge of their characteristics and the comparison of the spectra obtained with the spectra associated with the Maximum Design Earthquake.

2.4.1.3. The spectrum adopted by the operator for the design basis of its facility must not be less than any minimum spectrum arbitrarily set as an acceleration of 0.1 g with an infinite frequency. Depending on the site conditions, the acceleration values of the spectrum are determined as follows:

Shear-wave velocity less than 800 m/s					
Frequency	0.25 Hz	2.5 Hz	8 Hz	30 Hz	33 Hz
Pseudo acceleration	0.02 g	0.21 g	0.23 g	0.1 g	0.1 g

Shear-wave velocity greater than 800 m/s					
Frequency	0.35 Hz	3.5 Hz	9 Hz	30 Hz	33 Hz
Pseudo acceleration	0.02 g	0.21 g	0.23 g	0.1 g	0.1 g

2.4.2. New data and methods that become available during construction or operation of the facility may lead the government to request reassessment of the seismic motion corresponding to a given site

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APPENDIX I

SEISMOTECTONIC ZONE DELIMITATION METHOD

Seismotectonic zones are sections of the earth's crust which have the same seismogenic potential. The objective is to characterise each zone by geometry and the seismicity occurring in it. A seismotectonic zone can consist of a number of separate sections with the same structural and seismotectonic characteristics. A fault or a set of faults can, as such, correspond to a zone.

Characterisation of zones includes all geological, geophysical and seismic data available.

1. Data to use

1.1. <u>Static condition</u>

To delimit seismotectonic zones, it is possible, for example, to consider:

- crust thickness;
- sedimentary cover thickness;
- lithological nature of the soil;
- crust structure in terms of the main tectonic episodes. The geometry of the structures is essential in delimiting zones. The directions of paleostresses and the different tectonic episodes can also be used to identify zones with the same tectonic history;
- geophysical data.

1.2. <u>Dynamic condition</u>

Each seismotectonic zone must deform uniformly (type and intensity of seismic and aseismic deformation). This is studied using data on seismicity, deformation and stresses.

1.2.1. <u>*Seismicity*</u>

Seismicity is a measure of current deformation, and plays a number of roles in delimiting seismotectonic zones. Its analysis contributes to knowledge of the deformation regime (type and intensity of seismic and aseismic deformation). It can also be used to highlight local features. Particular care needs to be paid to the following points:

- epicentre location,
- intensity at epicentre or the magnitude of the different earthquakes, and their quantitative distribution as a function of these parameters,
- the depths of their hypocentres,
- the geometry of the highest intensity areas of major earthquakes,

- the spatial and temporal distribution of instrumented earthquakes (mainly aftershocks after strong earthquakes) or historic epicentre swarms,
- the mechanisms of the epicentres of the earthquakes.

1.2.2. *Deformation*

All evidence of neotectonic* deformation, whether direct (ruptures in recent soil, folding, volcanic activity etc.) or indirect (morphological anomalies) must be identified and studied. In particular, active faults with surface rupture must be identified and the data relating to them must be quantified insofar as possible. If offsets are found in morphological markers, these need to be dated.

For the most recent period, i.e. within a hundred years or so, allowance needs to be made for successive level comparison data, as well as conventional geodesic data (triangulation) and spatial geodesic (Global Positioning System).

The following material contributes to delimiting zones of uniform deformation, characterised by type and intensity.

Type of deformation. Insofar as possible, it is required to determine the type of potential deformation for each fault, on the basis of data on recent deformation and the directions of stresses.

Deformation intensity. With the data currently available, the deformation intensity can only be determined qualitatively on the basis of deformation velocity, relief intensity etc. The seismicity study can therefore provide information on the seismic deformation rate.

1.2.3. *Stresses*

The current stress situation in the sector considered is examined on the basis of:

- *in situ* stress measurements,
- earthquake hypocentre mechanisms,
- macrotectonic measurement in recent soils and volcanic alignments.

2. Delimitation of seismotectonic zones

A review of the above material is made to delimit the seismotectonic zones consisting of sections of the earth's crust that are uniform in terms of their seismogenic potential. It is postulated that any earthquake that has occurred at any point in a seismotectonic zone can occur anywhere in it.

A seismotectonic zone can consist of a fault, or even a series of faults with the same geometrical and dynamic characteristics, and the same seismic potential. When a zone consists of one of more faults, its delimitation must allow for dipping of the structures.

In each zone, the static and dynamic characteristics need to be precisely established. In addition, for zones consisting of one or more discontinuities, it is necessary to establish the geometric characteristics, the chronology of the different cases of motion and the seismicity associated with them.

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APPENDIX II

METHOD FOR DETERMINING THE CHARACTERISTICS OF THE EARTHQUAKES REPRESENTATIVE OF THE SEISMICITY OF THE SITE

The characteristics used for determining the earthquakes representative of the seismicity of the site are:

- epicentre co-ordinates,
- epicentre intensity,
- isoseismals,
- focal depth,
- magnitude,
- regional intensity attenuation laws.

As a general rule, the co-ordinates of the epicentre, the focal depth and the magnitude are deduced from macroseismic data. However, for recent earthquakes, these characteristics calculated using experimental data may be available. The values are to be compared and their differences explained. If there is no firm basis for choosing one of the two values, that representing the worst case for the site is to be adopted.

1. Epicentre co-ordinates and intensity

The epicentre co-ordinates and intensity are deduced from the near-field distribution of local observations of intensity estimated in the localities. The location of the epicentre generally corresponds to the barycentre of the area of greatest intensity, but when it is not clearly established (for example in the case of offshore epicentres), the approximate location of the epicentre can be determined by appropriate methods (such as the intensity attenuation law).

The epicentre intensity does not necessarily correspond to the maximum intensity observed (site effect, offshore epicentre, mountainous region) and can be deduced from the local intensity distribution in the near field or the use of appropriate methods (intensity attenuation law for instance).

2. Isoseismals

Isoseismal contours may be plotted if the number of local intensities with the same value is sufficient and is sufficiently uniformly distributed. These curves, which average out the local effects, can provide a quick overall view of the effects (level and extent). When of known quality, isoseismal contours can be used, after seismotectonic analysis, to determine the intensity at the site of earthquakes representative of site seismicity.

3. Focal depth

Intensity, when estimated on the basis of a sufficient number of points, can show regular decay with distance from a point source that is explainable by an extremely simple energy model (such as the Sponheuer relationship). This hypothesis is justified for earthquakes of low and medium magnitude, representative of the moderate seismicity in France. Intensity distribution can then be used, after elimination of inconsistencies (site effects and associated phenomena), to estimate the depth of the hypocentre of the earthquake. Calculation should preferably be made using all the macroseismic data, rather than the radii of the isoseismal contours which are the result of interpretation. The depth measurement accuracy increases with the number of point intensities, and the uniformity of their distribution, particularly in the area close to the epicentre. In the absence of sufficient macroseismic data, the depth can be deduced from those obtained from well-documented historical or instrumented earthquakes, located in the same seismotectonic zone, or by using other methods. If there are found to be significant differences and there is no clear basis for choosing one value rather than another, the value representing the worst case for the site shall be adopted.

4. Magnitude

The magnitude of historical earthquakes must be determined by best available correlations in the French context, linking magnitude to intensity and focal distance, establishing the basis of sets of consistent macroseismic data. These correlations, readjusted to earthquakes for which instrumental magnitude (M) and macroseismic intensities (I) are available, are in the following general form:

$M = \alpha I + \beta \log R + \varepsilon$, where R is the focal distance (km).

Such correlations established only on the basis of a single epicentre intensity are to be avoided. At the epicentre, the focal distance is the depth of the hypocentre.

5. Regional attenuation laws

Insofar as possible, use should be made of regional attenuation laws based on a model in which intensity decreases with distance (for instance the Sponheuer relationship). These laws can be used to determine the intensity of an earthquake at the site, in the absence of isoseismal contours. Laws are established using all the macroseismic data of a sufficient number of earthquakes contained in the database used for assessment of the site risk, or derived from other data sets, provided it can be proved that these laws effectively apply to the regional context of the site.

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APPENDIX III

ALLOWANCE FOR ACTIVE FAULTS WITH SURFACE RUPTURE

As part of the study to determine the seismic motion associated with any earthquakes which may have occurred along an active fault with surface rupture, the following three-stage method can be used.

The first stage consists in determining what observations can be used to conclude that one or more surface ruptures of co-seismic* origin have occurred and determine the age of the ruptures and individual slip values. Allowance for paleoseismic indications is based on the following:

- direct observation of one or more surface ruptures (photograph, drawing, description of outcrop) or clear morphological evidence of offsets in geological markers that are dated and identified (river floodplanes, water courses, horizon marks etc.). Each surface rupture must be related to a fault whose dimensions (geometry, area and length) are compatible with the estimated magnitude of any paleoearthquakes;
- a study of the tectonic nature of the deformation. Other hypotheses can explain the deformations observed that must be examined (gravity-driven processes, diaphyrism, halokinesis, arglokinesis, glacial-tectonics, glacial, karstic, process associated with superficial deformation in the periglacial environment etc.);
- an assessment of the age of the last level affected (whatever the method used for dating) and, if possible, the value of the interval between two or more events.

The second stage consists in evaluating the paleoseismic event recurrence time on the basis of the average velocity of slip at the fault. The velocity is estimated using geological and geodesic data or the distribution, in frequency and magnitude, of earthquakes in the region. Paleoseismic indications of events separated by intervals of ten thousands of years or less must be taken into consideration.

The third stage consists in determining the magnitude range associated with the surface rupture by studying the length, segmentation and seismogenic depth of the fault. In the French context, these parameters are difficult to determine and, as appropriate, it could be necessary to resort to commonly-used published empirical relationships linking slip and magnitude.

The magnitude of paleoseismic events must be evaluated using a motion magnitude considered to be equal to magnitude Ms between Mw=6.5 and Mw=7.5. The seismic motion associated with each of the hypotheses relating to paleoseismic magnitude is to be calculated using equation (2) of §2.3.1.

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GLOSSARY

A/V: This parameter is expressed in s^{-1}, where A and V are acceleration and maximum signal velocity respectively, and provides information on the frequency content of the signal.

CAV: Combined absolute velocity, the quantity corresponding to:

$$CAV = \int |\gamma(t)|\, dt$$

It is the integral, for the duration of the earthquake, of the absolute value of acceleration $\gamma(t)$. It is expressed in m/s.

Co-seismic: qualifies the occurrence of an earthquake. A co-seismic rupture is created by instantaneous tectonic rupture of the fault generating the earthquake. It is distinguished from a rupture created by a different tectonic phenomenon (collapse, landslide etc.) or aseismic deformation (slow slip along a fault).

Focal distance: the distance between the hypocentre of an earthquake and a given point.

Macroseismic data: information derived from surface observation of the effects of an earthquake.

Main shock duration: a period during a seismic event generally defined as the period of time after the seismic signal has reached 5% of the Arias intensity and that which it has reached 95%.

Epicentre: the point on the surface of the ground virtually above the hypocentre of an earthquake.

Active fault with surface rupture: fault showing evidence of recurrent motion near the surface over a period of a number of tens of thousands of years.

Hypocentre: the point inside the earth considered to be where the origin of the energies dissipated by the earthquake is located.

Intensity: assessment, in a limited area on the surface of the ground, of the effects of an earthquake on a statistical basis, with reference to descriptive scale criteria.

In this document, reference is made to the MKS macroseismic intensity scale (Medvedev-Sponheuer-Karnik, 1964), used to assess the intensity of the earthquakes contained in the SIRENE database and, for recent earthquakes, the EMS 1998 scale (European Macroseismic Scale, 1998 version) which constitutes an extension of the MSK scale, better adapted to recent buildings. These scales have twelve degrees, and intensity can be expressed in half-degree increments.

Arias intensity: Arias intensity is defined as follows:

$$I = \frac{p}{2g} \int \gamma^2(t)dt$$

It is the integral, for the duration of the earthquake, of the square of acceleration $\gamma(t)$. It is expressed in m/s.

Isoseismal: a line joining points of equal intensity, separating two areas in which the observed intensities are different for the same earthquake.

Attenuation law: law describing the decay of a parameter as a function of distance. In this document, reference is made both to attenuation of intensity as a function of focal distance and of attenuation of the spectral ordinates of the response spectrum as a function of distance and magnitude.

Average law: the values of the response spectrum obtained from information in accordance with a lognormal distribution (the logarithms of the values are distributed normally). The two-stage least-square regression system used to deduce the attenuation law coefficients (2) is based on the logarithm of the acceleration values. The spectral acceleration logarithm average value is therefore equal to the median value as the distribution is normal. This means that the value given by law (2) represents a confidence interval of 50% and that predicted by law (2), increased by its standard deviation, represents a confidence interval of 84%.

Magnitude: quantity obtained by measuring the amplitude of waves recorded by a seismograph; the magnitude gives an estimate of the energy dissipated in the hypocentre in the form of seismic waves. There are a number of definitions of magnitude:

Local magnitude (Ml) is defined as the maximum amplitude of either P waves or S waves. The LDG uses the maximum amplitude of the S-phase measured along the vertical component of the velocity (Plantet, 1978). For an epicentre distance D:

$$ML(LDG) = \log(A/T) + B(D) + C$$

A: maximum amplitude of S-wave displacement,
T: associated period,
B(D): average attenuation coefficient,
C: station correction.

The magnitude of an earthquake gives the average of the values calculated in stations located between 100 and 1500 km from the epicentre.

The surface magnitude (Ms) is measured using Rayleigh surface waves. A general definition of surface magnitude Ms is:

$$Ms = \log10\ (A/T) + s\ (D,h) + s(Ms)$$

A: ground motion amplitude,
T: associated period,
s (D,h): empirical amplitude-distance calibration function,
s (Ms): correction term used to allow for site effects, journeys and hypocentre mechanisms (Wilmore, 1979).

The moment magnitude (Mw) is associated with the seismic moment Mo of the earthquake. Mo is simply expressed as a function of the area S of the fault that has moved, of average displacement (or dislocation) D in the fault and rigidity m of the material, by the relationship Mo = m S D. Magnitude Mw is associated with Mo by the expression:

$$Mw = 2/3\log Mo - 6.0$$

The values obtained for Mw, Ms and Ml are practically identical (Madariaga and Perrier, 1991), for magnitudes of less than 7.5.

Seismic motion: motion of a point on the free-field ground surface, i.e. in the absence of any installations.

Neotectonic: concerning current deformation of the earth crust.

Recurrence interval: average time interval between successive earthquakes, in a given magnitude range, occurring at the same fault or in a specific zone.

Seismogenic potential: capacity of a zone to produce earthquakes of given characteristics.

Focal depth: distance between the hypocentre and the epicentre of an earthquake.

Seismogenic depth: maximum depth reached by coseismic ruptures.

SISFRANCE: a historical seismicity database (BRGM/EDF/IPSN) formerly named SIRENE. This macroseismic database contains information (date, epicentre positions, point intensity values etc.) concerning historical and contemporary earthquakes in France.

Seismic records: set of accelerometer recordings obtained at the ground surface in earthquakes.

Response spectrum: curve corresponding to maximum amplitude, as a function of frequency, of simple oscillator response with given damping, when excited by ground motion.

Average velocity of shear waves: average velocity of propagation of shear waves in the case of low deformation.

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