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Support to the implementation, harmonization and further development of the Eurocodes

G. Solomos, A. Pinto, S. Dimova

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Executive Summary

The Eurocodes are envisaged to form the basis for structural design in the European Union and they should enable engineering services to be used across borders for the design of construction works. At the phase of the national implementation, National Annexes with the Nationally Determined Parameters will complement them, and it is very likely that parameter values will differ. It is, thus, desirable at a later stage to work towards eliminating such differences, if relevant, and aim at achieving maximum level of harmonization.

Eurocode 8, or EN 1998, applies to the design and construction of buildings and civil engineering works in seismic regions. One of the crucial aspects in determining the design seismic action is the assignment of the seismic hazard level at a site. In this direction, a review of the provisions regarding seismic zonation in the current National Seismic Codes has been undertaken. It is preceded by an explanatory exposition of the relevant recommendations of Eurocode 8, especially in what concerns the definition of the reference peak ground acceleration. The principles of the methodology of the Probabilistic Seismic Hazard Assessment, used for arriving at hazard estimates, are outlined. Most of the codes in EU are next reviewed, in particular those in the more earthquake prone areas. This work was performed in 2006 and clearly reflects the situation at that time. The codes are found to be at a transition stage in view of the entry in force of the Eurocodes. Differences in the way of presenting the seismic hazard (either as ground acceleration or intensity, constant value zones, contours etc.) are identified, as well as some cross-border inconsistencies. However, an overall tendency towards progressively adhering to EC8 recommendations emerges, especially for the codes which have been revised in the last five years.

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1 INTRODUCTION

The Member States of the EU and of the European Free Trade Association (EFTA) recognise that EN Eurocodes serve as reference documents for the following purposes:

- as a means to prove compliance of building and civil engineering works with the essential requirements of the Construction Products Directive [1], particularly Essential Requirement 1 "Mechanical resistance and stability" and Essential Requirement 2 "Safety in case of fire";
- as a basis for specifying contracts for construction works and related engineering services;
- as a framework for drawing up harmonised technical specifications for construction products in accordance with Guidance Paper L [2].

At the phase of the national implementation of the Eurocodes, National Annexes with the Nationally Determined Parameters (NDP) will complement them. It is very likely that parameter values of some NDPs will differ and it is, thus, desirable at a later stage to work towards eliminating such differences, if relevant, and aim at achieving maximum level of harmonization in accordance with the Commission Recommendation 2003/887/EC [3].

Within the suite of Eurocodes, EUROCODE 8 or EN 1998 [4], applies to the design and construction of buildings and civil engineering works in seismic regions. Its purpose is to ensure, that in the event of earthquakes human lives are protected, damage is limited, and structures important for civil protection remain operational.

This is achieved through satisfying the following two fundamental requirements:

- No-collapse requirement: The structure should withstand the design seismic action without local or global collapse.
- Damage limitation requirement: The structure should withstand a seismic action with larger probability of occurrence than that of the design seismic action, without the occurrence of excessive damage.

The above-mentioned design seismic action is expressed in terms of the reference seismic action associated with a reference probability of exceedance, P_{NCR}, in 50 years, and the importance factor γ_I, which reflects reliability differentiation. The value P_{NCR}=0.10 is recommended.

Analogously, the seismic action for the “damage limitation requirement” is defined by its probability of exceedance, P_{DLR}, in 10 years, and the value P_{DLR}=0.10 is recommended.

As recognized in the EN 1998 document, the random nature of the seismic events and the limited resources available to counter their effects are such as to make the attainment of the above goals only partially possible and best measurable in probabilistic terms. Thus the competent authorities, the structure owner and the designer, professionally responsible for the seismic design of a project, make a fundamental trade-off between costly higher resistances and higher risks of economic loss. The extent of the seismic protection that can be provided to different categories of buildings is a matter of optimal allocation of resources and is therefore expected to vary from country to country, depending on the relative importance of the seismic risk with respect to risks of other origin and on the global economic resources.

Clearly the concept of risk entails those of hazard and vulnerability, and, of course, the value of the assets to be protected. In this case, the former depends on the ground motion input due to an earthquake, and the latter deals with the identification of the weaknesses and potential damage of a structure. Commonly considered seismic action parameters at a site are the maximum intensity, the duration of the shock, the peak ground acceleration (PGA), the peak ground velocity (PGV), the peak ground displacement (PGD), and several spectral accelerations. For structural engineering applications, the most widely used among them is the peak ground acceleration (PGA), as it is traditionally and immediately related to the induced seismic forces, which form the basis of the current structural seismic design procedures.

In order to take stock of the current situation, a review of the seismic zoning provisions with respect to construction of most of the European countries is conducted and presented below. The main work on reviewing the national seismic maps was performed in 2006 and, thus, reflects the state-of-the-art at that time. A methodology for assessing the seismic hazard and for determining in a rational manner the level of the seismic input to be taken into consideration is also outlined.

2 THE SEISMIC ACTION

2.1 Seismic zones

For most of the applications of EN 1998, the hazard is described in terms of a single parameter, i.e. the value of the reference peak ground acceleration, a_{gR}, on type A ground (ground type A corresponds to rock or other rock-like geological formation, including at most 5m of weaker material at the surface).

This information is to be included in the National Annex. Thus national territories are subdivided by the National Authorities into seismic zones, in the interior of which the hazard is assumed to be constant.

For each seismic zone the reference peak ground acceleration, a_{gR}, corresponds to the reference probability of exceedance in 50 years, P_{NCR}, of the seismic action for the no-collapse requirement.

To this reference ground motion an importance factor γ_I =1.0 is assigned and the design ground acceleration a_{gd} is expressed as $a_{gd} = \gamma_I \, a_{gR}$. for ground of type A.

Further, depending upon the value of the design ground acceleration and the ground type, it is possible in the National Annex to define cases of low or very low seismicity, where reduced/simplified or no seismic design procedures for certain types or categories of structures may be followed.

2.2 Representation of the seismic action

Within the scope of EN 1998 the earthquake motion at a given point of the surface is represented by an elastic ground acceleration response spectrum. The horizontal seismic action is described by two orthogonal components assumed as being independent and represented by the same response spectrum.

The selection of the values of the parameters defining the shape of this elastic response spectrum in a Country may be found in its National Annex. However, EN 1998 also stipulates that time-history representations of the earthquake motion may be used, too. In either case, as briefly described below, the peak ground acceleration plays a dominant role in defining the design seismic input.

2.2.1 Elastic response spectrum

For the horizontal components of the seismic action, the elastic response spectrum *Se(T)* is defined by the following expressions (see Fig. 2.1):

$$
\begin{aligned}
0 \le T \le T_B: &\quad S_e(T) = a_{gd}\ S\left[1 + \frac{T}{T_B}(\eta\ 2.5 - 1)\right] \\
T_B \le T \le T_C: &\quad S_e(T) = a_{gd}\ S\ \eta\ 2.5 \\
T_C \le T \le T_D: &\quad S_e(T) = a_{gd}\ S\ \eta\ 2.5\left[\frac{T_C}{T}\right]
\end{aligned}
\tag{2.1}
$$

$$T_D \le T \le 4s: \qquad S_e(T) = a_{gd}\ S\ \eta\ 2.5\left[\frac{T_C T_D}{T^2}\right]$$

where:

$S_e\ (T)$ = elastic response spectrum;

T = vibration period of a linear single-degree-of-freedom system;

a_{gd} = design ground acceleration on type A ground, $a_{gd} = \gamma_I\ a_{gR}$;

T_B, T_C = limits of the constant spectral acceleration branch;

T_D = value defining the beginning of the constant displacement response range of the spectrum;

S = soil factor;

η = damping correction factor; its reference value is η = 1 for 5% viscous damping.

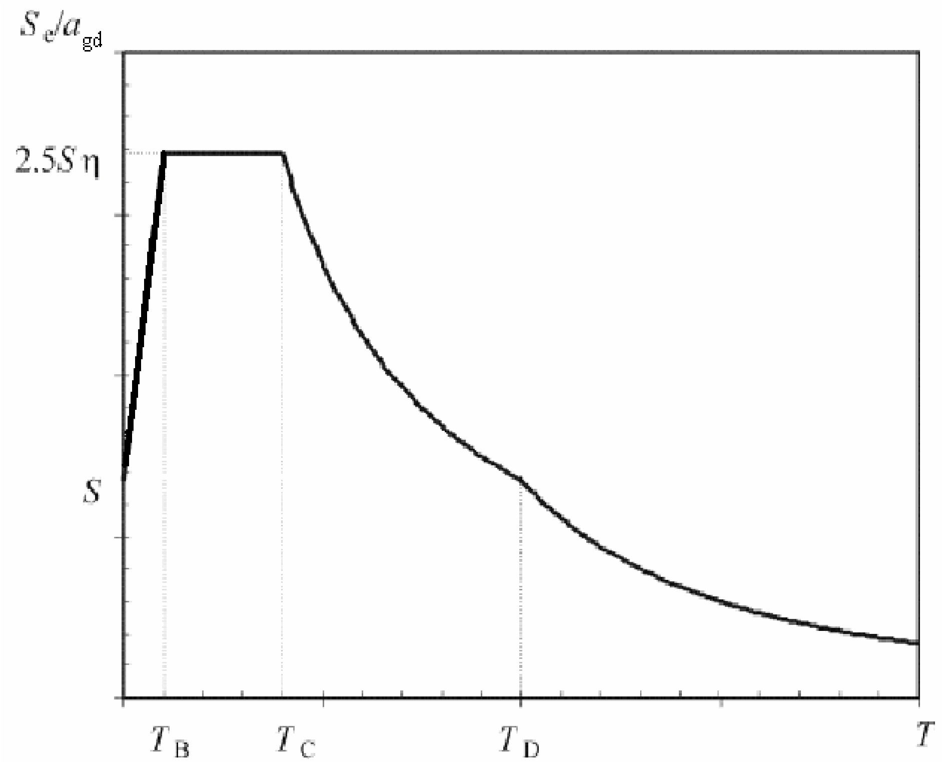


Figure 2.1. Shape of elastic response spectrum.

The values of the parameters S, T_B, T_C and T_D, may be specified in the National Annex for the several local ground conditions (ground types A, B, C, D, and E, are described in EN 1998). In the absence of any geological investigation, two types of spectra, Type 1 and Type 2, are also proposed. The use of Type 2 spectrum is recommended if the earthquakes that contribute most to the seismic hazard have a surface-wave magnitude not greater than 5.5. Suggested values for the parameters, in the case of ground type A, are quoted in Table 2.1.

Table 2.1. Values of the parameters describing the recommended elastic response spectrum for ground type A.

Spectrum	S	T_B (sec)	T_C (sec)	T_D (sec)
Type 1	1.0	0.15	0.4	2.0
Type 2	1.0	0.05	0.25	1.2

2.2.2 Design spectrum for elastic analysis

The capacity of structural systems to resist seismic actions in the non-linear range generally permits their design for forces smaller than those corresponding to a linear elastic response. According to EN 1998, in order to avoid explicit inelastic structural analysis in design, the capacity of the structure to dissipate energy, through mainly ductile behaviour of its elements and/or other mechanisms, is taken into account by performing an elastic analysis based on a response spectrum, "design spectrum", reduced with respect to the elastic one. This reduction is accomplished by introducing the behaviour factor q. The values of the behaviour factor q, which also accounts for the influence of the viscous damping being different from 5%, are given for the various materials and structural systems and according to the relevant ductility classes in the various Parts of EN 1998.

For the horizontal components of the seismic action the design spectrum, $S_d(T)$, is defined by the following expressions:

$$
\begin{aligned}
&0 \le T \le T_B: && S_d(T) = a_{gd}\ S\left[\frac{2}{3}+\frac{T}{T_B}\left(\frac{2.5}{q}-\frac{2}{3}\right)\right]\\
&T_B \le T \le T_C: && S_d(T) = a_{gd}\ S\ \frac{2.5}{q}\\
&T_C \le T \le T_D: && S_d(T)\ \begin{cases} = a_{gd}\ S\ \dfrac{2.5}{q}\left[\dfrac{T_C}{T}\right]\\ \ge \beta\, a_{gd}\end{cases}\\
&T_D \le T: && S_d(T)\ \begin{cases} = a_{gd}\ S\ \dfrac{2.5}{q}\left[\dfrac{T_C T_D}{T^2}\right]\\ \ge \beta\, a_{gd}\end{cases}
\end{aligned}
\tag{2.2}
$$

where:

$S_d(T)$ = design spectrum;

a_{gd}, S, T_C and T_D: as defined for the elastic spectrum;

q = behaviour factor;

β = lower bound factor for the horizontal design spectrum; the β value in a Country may be found in its National Annex; a recommended value of β = 0.2 is provided.

For the vertical component of the seismic action the corresponding response spectrum is given by expressions similar to those for the horizontal component, with the design ground acceleration in the vertical direction, a_{vg} replacing a_{gd}. The recommended values for a_{vg} are: a_{vg} / a_{gd} = 0.45÷0.90.

2.2.3 Time-history representation of the seismic action

Depending on the nature of the application and on the information actually available, the description of the seismic motion may be made by using artificial accelerograms and actually recorded or simulated accelerograms. In EN 1998, among other recommendations for the representativity of such time histories, it is required that their duration is consistent with the magnitude and the other relevant features of the seismic event underlying the establishment of a_{gd}, and that their values are scaled to the value of $a_{gd}S$ for the zone under consideration.

3 EXCEEDANCE PROBABILITIES AND RETURN PERIODS

As mentioned above, the random nature of the seismic events and the many uncertainties entering in the determination of the seismic hazard at a site, render a probabilistic approach to the subject very appropriate. In the ensuing analysis the underlying fundamental probabilistic model is that of a stationary Poisson process [5]. That is, the occurrence of a ground motion parameter at a site in excess of a specified level is a Poisson process, if it is assumed that the occurrences of the causing earthquake events follow a Poisson arrival process, too. Clearly this implies that any seismic event is independent of the occurrence of all others, and this could be approximately true for major earthquakes, excluding associated foreshocks, aftershocks etc.

In the discussion below the ground motion parameter considered is the peak ground acceleration (PGA), denoted for short as the random variable "A_g" which takes on the values "a_g" (not to be confused with the ground type A). The same analysis would be equally applicable to other ground motion parameters.

The **annual rate of exceedance** $w=w(a_g)$, is first defined as the number of exceedances per year of the ground motion level a_g at the site under consideration. The determination and calculation of this rate will be presented in the next section.

The mean or average **return period,** T_R, of this ground motion level a_g at this site is next defined as simply the inverse of the above annual probability of exceedance, i.e.

$$T_R = 1 / w \tag{3.1}$$

It is customary to describe ground motion levels in these terms. For example, one can interchangeably talk of the 500-year return-period peak ground acceleration at a site, or, of the peak ground acceleration having an exceedance rate of 1/500 per year.

One may also seek to determine the probability of exceedance of the T_R return period ground motion (say the peak ground acceleration a_{gR}) in the next T_L years (in general $T_L \neq T_R$). This can be accomplished, based on the Poisson modeling, as follows.

If the rate of exceedance per year is $w = 1/T_R$, the rate of exceedance in T_L years will be $wT_L = T_L / T_R$. According to the Poisson model the following probabilities can be established for the specific site:

P[n events in T_L with PGA in excess of a_{gR}] : ……. $P(n) = \dfrac{e^{-wT_L}(wT_L)^n}{n!}$

P[n=0 events in T_L with PGA in excess of a_{gR}] : ……. $P(n=0) = e^{-wT_L}$

P[one or more events in T_L with PGA in excess of a_{gR}] :…….. $P_R = 1 - P(n=0)$

$$P_R = 1 - e^{-wT_L} = 1 - e^{-T_L/T_R} \tag{3.2}$$

This equation reveals that, for a given T_L, the seismic motion level may equivalently be specified either via its mean return period T_R or its probability of exceedance P_R.

- Applying the last expression for T_L =1 year

$$P_{R,1} = 1 - e^{-1/T_R} \tag{3.3}$$

and considering that $1/T_R$ is small for realistic return periods ($T_R \geq 20$ years)

$$P_{R,1} = 1 - [1 - (1/T_R) + ...] \cong 1/T_R = w \tag{3.4}$$

This shows that the probability of exceedance of the T_R return-period ground motion in 1 year is practically equal to the corresponding annual exceedance rate.

- Applying the exceedance probability expression for $T_L = T_R$ years

$$P_{R,T_R} = 1 - e^{-T_R/T_R} = 1 - e^{-1} = 0.632 \tag{3.5}$$

that is, the probability of exceedance of the T_R return-period ground motion in T_R years is equal to 0.632 (and not 1.0, as is a common misconception).

- Rewriting the exceedance probability expression, it is easily found that the probability of exceedance, P_R, in T_L years of a specific level of the seismic motion is related to the mean return period, T_R, of this level of the seismic motion as

$$T_R = -\frac{T_L}{\ln(1 - P_R)} \tag{3.6}$$

The seismic action provisions of EN 1998, mentioned above, can be now readily understood. For the non-collapse requirement the time T_L, commensurate with the average life span of a building, is taken equal to T_L=50 years, and P_R is set equal to the *reference probability of exceedance* P_{NCR}. Utilizing the recommended value of $P_R = P_{NCR} = 0.10$, a return period of 474.5years is derived, i.e., $T_{NCR} \approx 475$ years.

That is, in EN 1998 it is recommended that the **reference peak ground acceleration** on type A ground, a_{gR}, for the purpose of seismic zonation, corresponds to a *reference probability of exceedance* P_{NCR}=0.10 in T_L=50 years, or equivalently to a *reference return period* of $T_{NCR} \approx 475$ years.

For the seismic action level of the damage limitation requirement a time horizon of T_L=10 years is considered, and the probability of exceedance is chosen equal to $P_R = P_{DLR} = 0.10$. The above expression now produces a mean return period of $T_{DLR} \approx 95$ years.

Clearly for the design of critical structures, such as nuclear power plants, dams, bridges etc., smaller values of the reference probability of exceedance, or longer reference return periods would be selected. It is instructive to observe the inter-relation of these two parameters in the Table 3.1 below.

Table 3.1. Typical values and relationships of reference probabilities of exceedance and corresponding return periods for a specific site.

Probability of exceedance **P_R**	**Time span** **T_L**	**Mean return period** **T_R**
20%	10 years	45 years
10%	10 years	95 years
20%	50 years	224 years
10%	**50 years**	**475 years**
5%	50 years	975 years
10%	100 years	949 years
5%	100 years	1950 years

- Triggered from the above Table, one more question can be readily handled. Specifically, sometimes it is desired for a certain ground motion, which has a P_R probability of exceedance in T_L years, to determine the probability, P_Q, that the same ground motion is exceeded in Q years. Since the level of ground motion (defined by its annual exceedance rate, or return period) remains constant, working with the above equations it can be easily derived that the sought probability is

$$P_Q = 1 - (1 - P_R)^{Q/T_L} \tag{3.7}$$

Table 3.2 Relationships among several exceedance probabilities and associated time spans for a certain level of ground motion at a specific site.

If a ground motion has a probability of exceedance in **50 years**	in 10 years this ground motion will have a probability of exceedance	in 100 years this ground motion will have a probability of exceedance	in 250 years this ground motion will have a probability of exceedance
0.20	0.04	0.36	0.67
0.10	0.02	0.19	0.41
0.05	0.01	0.10	0.23
0.02	0.004	0.04	0.10

According to the EN 1998 recommendations, the probability of exceedance of the zonal reference peak ground acceleration in 50 years is set to P_{NCR}=0.10. It is interesting to note that the probability of exceeding this reference peak ground acceleration is reduced five times for a 10-year span, it is almost doubled for 100 years, and it becomes four times higher for 250 years.

4 EVALUATION OF SEISMIC HAZARD

Even though deterministic techniques are still encountered, due to the many inherent uncertainties involved (size, location, and time of occurrence of future earthquakes, and propagation of seismic waves), a more rational framework for arriving at estimates of the seismic hazard at a site is by employing probabilistic approaches. They come under the general term "Probabilistic Seismic Hazard Analysis" or "…Assessment", shortly PSHA. The two most commonly used approaches are based either on the Poisson model or on extreme value (Gumbel) distributions [6,7]. Only the former is outlined below as, due to its merits, it seems to enjoy a wider acceptance [8]. The goal of such a PSHA is to quantify the probability of exceeding various ground motion levels at the site (or a grid of sites) in a certain time interval given all possible earthquakes.

As mentioned earlier, several ground motion parameters can be considered: the maximum intensity at a site, the duration of the shock, the peak ground acceleration (PGA), the peak ground velocity (PGV), spectral accelerations (at structural periods of 0.2sec, 1.0sec, 2.0sec, etc.). The methodology of PSHA remains essentially the same in all cases [9]. For the reasons explained before, the peak ground acceleration parameter is essentially treated below.

The PSHA entails three fundamental steps: 1) the specification of the models for the seismic sources responsible for the seismic-hazard; 2) the specification of the ground motion models, i.e., the attenuation relationships; and 3) the actual calculation of the sought exceedance probabilities.

1) The models for the seismogenic sources in the region are basically derived from the earthquake catalogues of historical and instrumental seismicity. This statistics is inevitably based on geologically short periods, and thus, it may be supplemented by additional data, such as, the results from seismic monitoring, geodetic monitoring, deep geologic investigation etc. All this information is used to formulate the seismic source zones on the earth's surface, which in general are given the shape of a polygon or of a line, Fig.4.1. A line source would represent earthquakes generated along a fault, whereas an area source would correspond to dispersed seismic activity, not directly associated with known faults. Further to its shape, each idealized source zone should be characterized by an upper and lower bound for magnitude, m_o and m_u, respectively, the Gutenberg-Richter earthquake recurrence b-parameter (see below), an annual activity rate (shocks per year greater than m_o), and an average hypocentral depth.

One of the most popular models to describe earthquake magnitude recurrence of seismic sources is the well-known Gutenberg-Richter model, which is derived assuming a linear relation between the logarithm (base 10) of the frequency and the magnitude

$$\log N(m) = a - b\ m \quad \text{or} \quad N(m) = \exp(\alpha - \beta m) \tag{4.1}$$

where *N(m)* represents the number of earthquakes with magnitude greater than *m* and $\alpha \approx 2.3a$, and $\beta \approx 2.3b$ are parameters to be fitted to the catalogue data.

That task is carried out by the statistical analysis of earthquake catalogues for the region of interest (containing all idealised seismic source zones). Furthermore, only a given time window of the catalogues are taken into account, which implies that a stationary process is assumed.

If events with magnitude greater than or equal to m_u and less than or equal to m_o are discarded, the cumulative distribution of magnitudes for earthquakes with epicentres inside source *i* can be derived as follows:

$$F_M(m) = P[M \le m | m_o \le M \le m_u] = \frac{P[(M \le m) \cap (m_o \le M \le m_u)]}{P[m_o \le M \le m_u]} = \frac{P[m_o \le M \le m]}{P[m_o \le M \le m_u]}$$

(4.2)

and using the annual exceedance rates for the magnitude from the Gutenberg-Richter formula:

$$F_M(m) = \frac{N(m_o) - N(m)}{N(m_o) - N(m_u)} = \frac{1 - \exp[-\beta(m - m_o)]}{1 - \exp[-\beta(m_u - m_o)]} \tag{4.3}$$

By differentiating this expression with respect to *m*, the probability density function is obtained

$$f_M(m) = \frac{\beta \exp[-\beta(m - m_o)]}{1 - \exp[-\beta(m_u - m_o)]} \tag{4.4}$$

The above linear relation between the logarithm of the frequency and magnitude, has proved to fit well the data if seismic source areas are very large and the lower and upper limits are conveniently chosen. However, it sometimes may be more efficient to use a quadratic frequency-magnitude relation, which allows better adjustment to the recorded data [10].

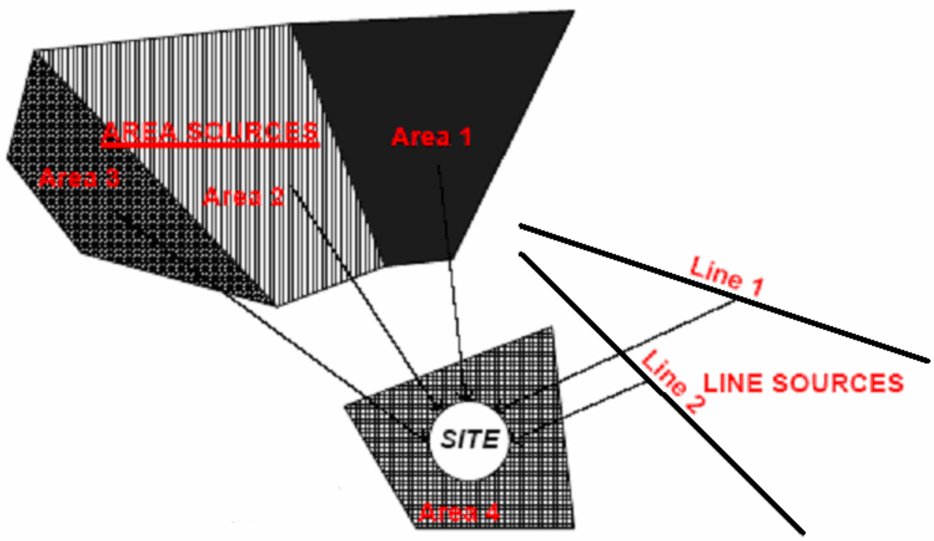


Fig. 4.1. Schematic representation of the Seismic Hazard Analysis procedure for derivation of site seismicity from seismic sources, idealised as area or line zones.

2) The attenuation relationships provide the value of a ground motion parameter (peak ground acceleration, spectral ordinates…) at a certain distance from an earthquake of a given magnitude. They are usually empirically determined equations, and they try to take into account path effects on the wave propagation to a specific site and possibly its local soil dynamic behaviour. Several researchers have proposed and used empirical laws for the attenuation of seismic ground motion. For example, concerning peak ground acceleration, $PGA \equiv a_g$, an attenuation model which includes magnitude and distance as independent variables has been employed. This widely used model provides predictions a_g^* of the PGA, as follows [11]:

$$\log(a_g^*) = C_1' + C_2'm + C_3'r + C_4'\log(r) \tag{4.5a}$$

$$\ln(a_g^*) = C_1 + C_2m + C_3r + C_4\ln(r) \tag{4.5b}$$

The peak ground acceleration is usually expressed in g (=9.81m/sec^2), m is magnitude (usually, surface wave magnitude M_s), $r=(d^2+h_o^2)^{1/2}$, where d is an "epicentral distance" (shortest distance from the site to the surface projection of the fault rupture) in km, and h_o is a constant to be determined together with the constants C_i, and C_i' i=1,4 (log and ln denote, respectively, the base 10 and the natural logarithm functions). Such a relationship is a linear function of magnitude, and contains two distance dependent terms, of which the first represents anelastic losses and the second geometric losses due to the spherical spreading from a point seismic source. The constants are determined by fitting the analytical expressions to observations.

It has, however, been noted that the observations scatter significantly about the predicted values. This uncertainty is currently being handled in a statistical manner, as it has been noticed that the ratios ε of the recorded (observed) to the corresponding predicted PGAs, $\varepsilon=a_g/a_g^*$, exhibit a characteristic trend, which can be satisfactorily fitted by a log-normal distribution, i.e., $\ln(\varepsilon)$ would be normally distributed. It is also found that the order of magnitude of the values of the mean and standard deviation are, respectively, $<\ln\varepsilon>\approx 0$, and $\sigma_{\ln\varepsilon}\approx 0.5$.

A few examples of such relationships for stiff type soil or rock (class A soil) are presented below. Ambraseys and Bommer [12] have proposed for the horizontal PGA in the European area

$$\log(a_g^*) = -1.09 + 0.238m - 0.0005\,r - \log(r) \tag{4.6}$$

with h_o=6km and $\sigma_{\log\varepsilon}$=0.28. In the same work, these researchers propose for the peak vertical ground acceleration in the European area the formula

$$\log(a_{gv}^*) = -1.34 + 0.230m - \log(r) \tag{4.7}$$

with h_o=6km and $\sigma_{\log\varepsilon}$=0.27. Ambraseys, Simpson and Bommer [13,14], in their work for the derivation of attenuation relationships for the spectral ordinates, have also proposed a revised formula for the European area

$$\log(a_g^*) = -1.39 + 0.266m - 0.922\log(r) \tag{4.8}$$

with h_o=3.5km and $\sigma_{\log\varepsilon}$=0.25. The form of this attenuation relationship is shown in Figures 4.2 and 4.3. For the Western North America Spudich et al. [15] have proposed

$$\log(a_g^*) = 0.299 + 0.229(m-6) - 1.052\log(r) \tag{4.9}$$

with h_o=7.27km and $\sigma_{\log\varepsilon}$=0.22.

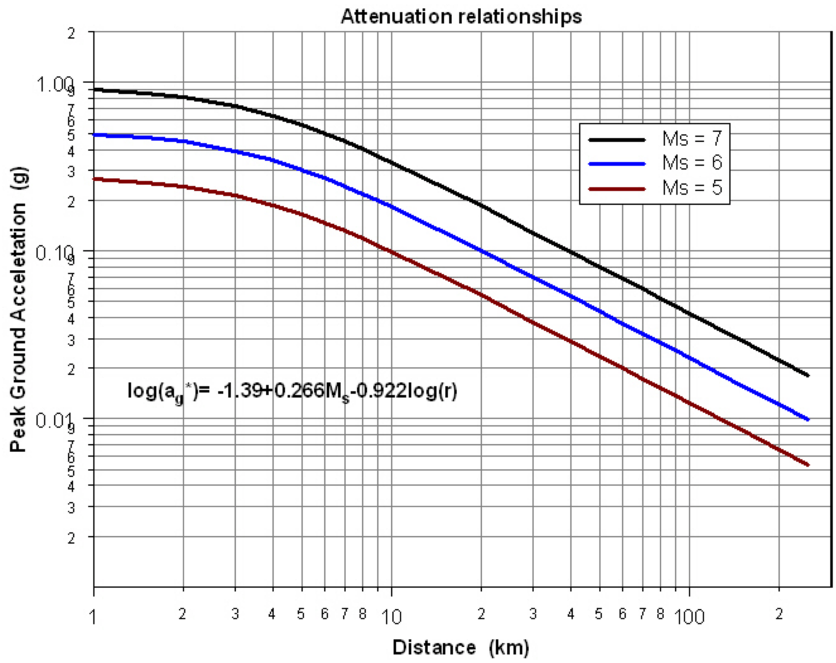


Fig. 4.2. Peak ground acceleration attenuation relationships for the European area proposed by Ambraseys et al.[13-14].

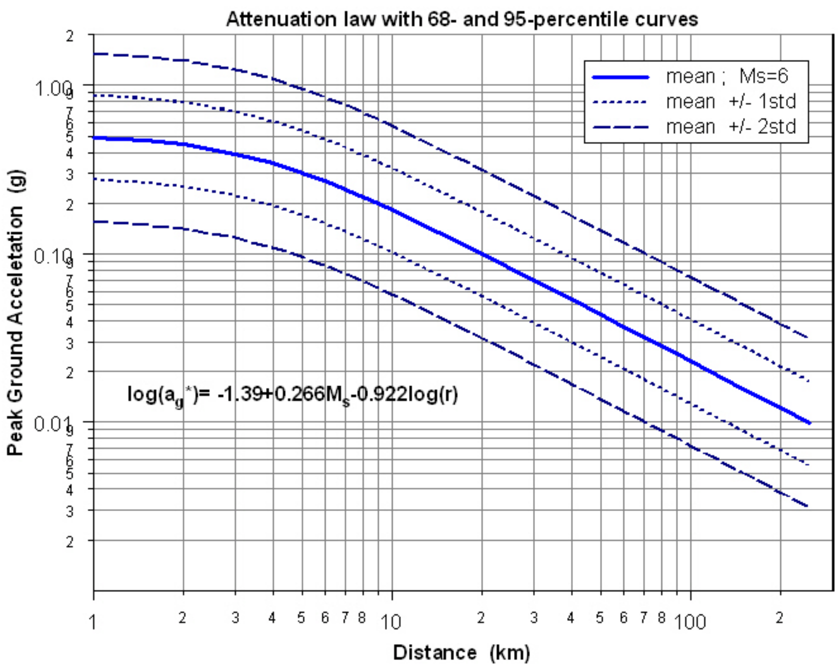


Fig. 4.3. Scatter of the predicted values of the peak ground acceleration for the attenuation relationship for the European area proposed by Ambraseys et al.[13-14].

Clearly the above empirical findings imply that

$$a_g = \varepsilon \; a_g^* \tag{4.10}$$

and this equation shows that the actually occurring PGA at a site can also be modelled as a random variable lognormally distributed (a_g* is a deterministic term), or that

$$\ln(a_g) = \ln(a_g{*}) + \ln(\varepsilon) \tag{4.11}$$

will have a normal (Gaussian) distribution [5]. The mean and standard deviation of $\ln(a_g)$ will be, respectively: $<\ln a_g>=\ln(a_g{*})$ and $\sigma_{\ln ag} = \sigma_{\ln\varepsilon}$, and its *pdf* can be easily written as

$$f_1(\ln a_g) = \frac{1}{\sigma_{\ln\varepsilon}\sqrt{2\pi}} \exp[-(\ln a_g - \ln a_g^*)^2 / 2\sigma_{\ln\varepsilon}^2] \tag{4.12}$$

The *pdf* of the lognormal variable a_g can also be written as:

$$f_2(a_g) = \frac{1}{a_g \sigma_{\ln\varepsilon}\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\frac{1}{\sigma_{\ln\varepsilon}} \ln(\frac{a_g}{a_g^*})\right]^2\right\} \tag{4.13}$$

Fig. 4.4 shows the form of the above two distributions. The case of a shock of magnitude M_s=6 at a distance d=10km has been considered, for which eq.(4.8) predicts the value: a_g*=0.182 (in g), or, $\ln a_g$*=-1.703. The value of $\sigma_{\ln\varepsilon}=\ln(10)\,\sigma_{\log\varepsilon}\approx 0.62$ has been applied.

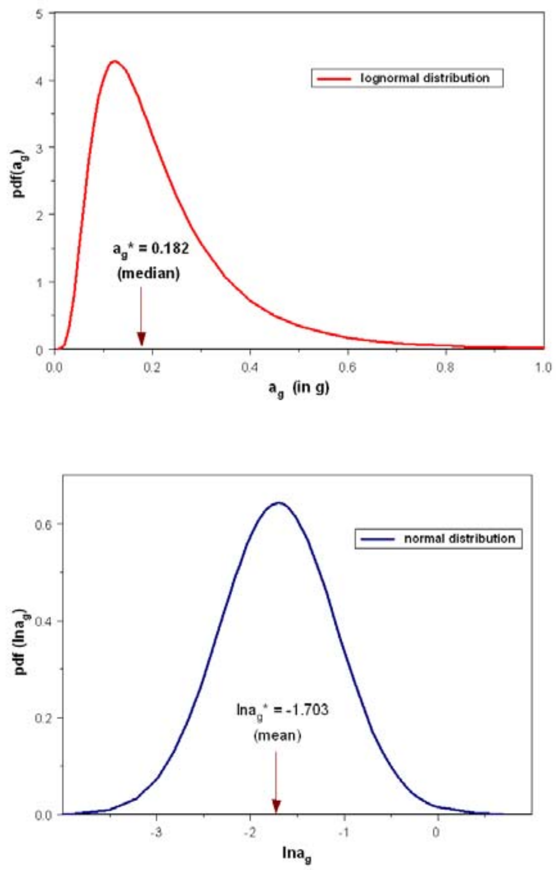


Figure 4.4. Form of the pdf of the random variables a_g and $\ln(a_g)$, respectively, at a site distant 10km from the epicenter of a M_s=6 seismic shock, according to eq.(4.8).

Thus, it is seen that according to the above modeling, the value $\ln(a_g^*)$ produced by the attenuation laws (4.5b) is the mean value of the normally distributed $\ln(a_g)$, or equivalently, the value a_g^* is the median of the lognormally distributed a_g. It should also be observed that the expression of eq.(4.13) is also the conditional pdf of a_g, given that an earthquake of magnitude m has occurred at distance r from the site under consideration, i.e, $f_2(a_g)=f_2(a_g|m,r)$.

Finally, if the exceedance probability of a certain PGA level is desired at the site, then through (numerical) integration one can obtain

$$P(A_g > a_g \mid m,r) = P(\ln A_g > \ln a_g \mid m,r) = \frac{1}{\sigma_{\ln\varepsilon}\sqrt{2\pi}} \int_{\ln a_g}^{\infty} \exp[-\frac{(z-\ln a_g^*)^2}{2\sigma_{\ln\varepsilon}^2}]\, dz \qquad (4.14)$$

This last expression is fundamental for the analysis below.

3) The basic steps in the procedure for the calculation of the seismic hazard in a PSHA are outlined below [8], without indulging on subtleties or controversial modeling issues. From a mathematical point of view, the PSHA can be formulated as follows. Let the site seismic parameter Y (peak ground acceleration, spectral ordinates etc.) be a random variable depending on a set of random variables given by the vector x. The unconditional probability

$P(Y>y)$ that the value of Y at the site exceeds a certain level y can be computed by applying the total probability theorem, expressed by

$$P(Y > y) = \int P(Y > y \mid x)\, f_x(x)\, dx \tag{4.15}$$

where $P(Y>y \mid x)$ indicates the conditional probability of having a parameter value greater than a certain level y, given that a sample vector x has occurred, and $f_x(x)$ is the joint probability density function associated with the random variables x. If it is considered that the site seismic motion is reasonably described by n uncorrelated variables with pdf's $f_j(x_j)$, j=1…n, the integral above can be re-written as

$$P(Y > y) = \int \ldots \int P(Y > y \mid x_1, x_2, \ldots x_n)\, f_1(x_1)\, f_2(x_2) \ldots f_n(x_n)\, dx_1 dx_2 \ldots dx_n \tag{4.16}$$

Uncertainties in the PSHA are customarily concentrated to the size and place of an earthquake, and to the wave propagation patterns. The source uncertainties are modelled by the random variable M, which represents magnitude, and by the location of the events within each idealised source zone. This latter can be expressed as the random variable R, the distance from source to site. Randomness of the wave propagation is also properly incorporated in the functional descriptions of the attenuation laws.

As is generally assumed, magnitude and spatial distribution are considered statistically independent. Then, computation of $P(Y>y)$, taking into account each seismic source i separately, is given via the above equations in the form

$$P(Y > y)_i = \int_R \int_M P(Y > y \mid m, r)\, f_M(m)_i\, f_R(r)_i\, dm dr \tag{4.17}$$

In this particular case, $P(Y>y|m,r)$ stands for the probability of exceeding a site parameter value y given that an earthquake of magnitude m and distance r has occurred inside a given seismic source zone i. The function $f_M(m)_i$, eq.(4,4), is the probability density function (*pdf*) associated with the relative frequency of the magnitude of the events that may occur in the zone i, and $f_R(r)_i$ is the *pdf* used to reflect the randomness of the epicentral location of earthquakes inside source i. For the numerics of eq.(4.17) and the limits of integration, it is recalled that within each seismic source i the magnitude takes on values in the range $m_{oi}<m<m_{ui}$, and it is assumed that $f_R(r)_i$ is uniformly distributed [16-17].

If the parameter Y of concern is the peak ground acceleration, then expression (4.14) represents the conditional probability $P(Y>y|m,r)$ to be substituted into eq.(4.17), i.e.

$$P(A_g > a_g)_i = \int_R \int_{m_{oi}}^{m_{ui}} P(A_g > a_g \mid m, r)\, f_M(m)_i\, f_R(r)_i\, dm dr \tag{4.18}$$

Using the Gutenberg-Richter formula, eq.(4.1), the annual rate of the occurrence ν_i of earthquakes with magnitude greater then m_{oi} in the seismic source i can be determined, and the annual rate of occurrence of a ground motion greater than a_g at the site, denoted as w_i, will be

$$w_i = \nu_i\, P(A_g > a_g)_i \tag{4.19}$$

Consequently, the rate of occurrence of a ground motion greater than a_g in a specified time interval T_L due to the seismic source i will be $w_i T_L$. According to the Poisson process setting, as shown in Chapter 3, the probability of exceeding the ground motion *a_g,* at a site due to the occurrence of earthquakes in seismic source *i,* will be given as

$P_{TL}(A_g>a_g)_i$ = P[one or more events in T_L with PGA in excess of a_g] = 1-P[n=0 events]

$$P_{TL}(A_g > a_g)_i = 1 - e^{-w_i T_L} \tag{4.20}$$

Estimates of seismic hazard at a given site, due to the occurrence of magnitudes greater than m_{oi} in any of the seismic source zones can now be determined by summing up all potential contributions. Thus, considering *n* seismic sources, the annual exceedance rate of a ground motion a_g at the site, defined as *w*, will be

$$w = \sum_{i=1}^{n} w_i \tag{4.21}$$

and, consequently, arguing on the same basis of the Poisson model, the probability of exceedance of a ground motion a_g in the next T_L years at the site will be

$$P_{TL}(A_g > a_g) = 1 - e^{-wT_L} \tag{4.22}$$

Clearly, these are exactly the expressions derived also in the previous chapter, when dealing with the definition of return periods.

An example of the typical result of the above analysis is depicted in Fig.4.5. Shown there are two hazard curves for a hypothetical site, due to all potential seismic sources around it, for time spans of T_L=1 year and T_L=50 years, respectively.

From such a graph, it can, for instance, be read that for this site the peak ground acceleration (PGA) with 10% probability of exceedance in 50 years is ~0.16g. Similarly, it is readily seen that the level 0.10g PGA will be exceeded with probability ~0.004 in 1 year and with probability ~0.20 in 50 years, etc.

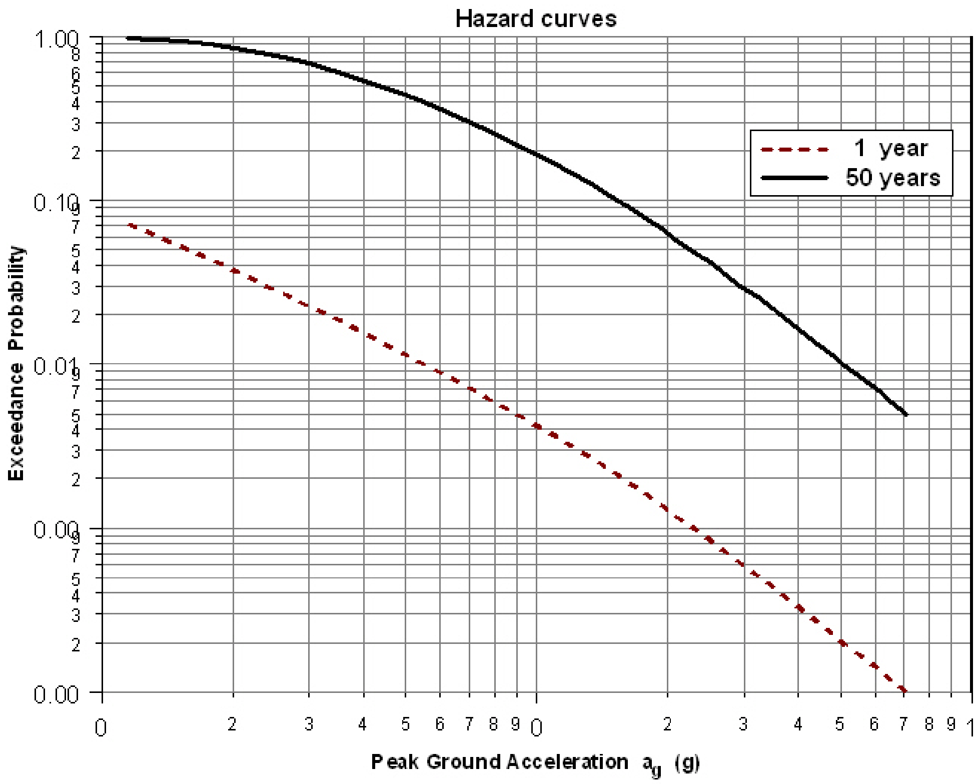


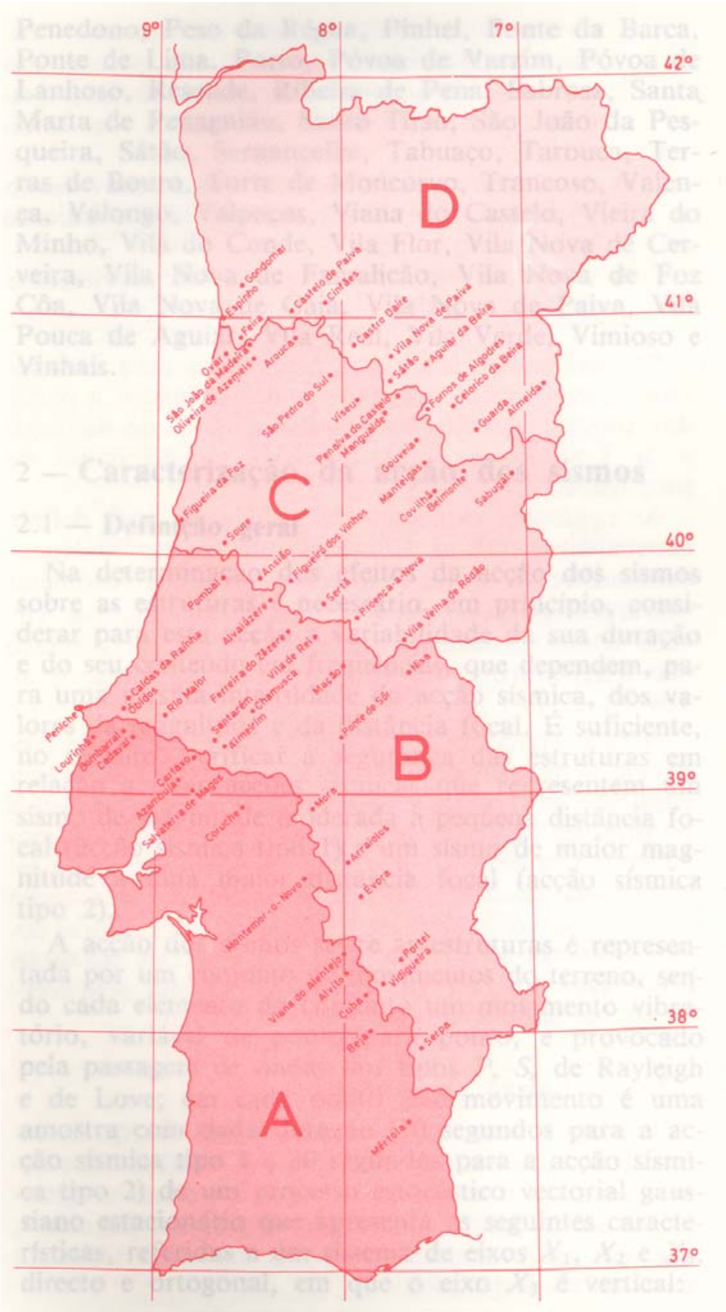
Figure 4.5. Example of typical hazard curves for a site for time spans of T_L=1 year and T_L=50 years, respectively.

No further details of this methodology are presented [18]. It can only be mentioned that issues, such as the incorporation of uncertainties can be done in a systematic and rational way, using the "logic tree" formulation, where various alternatives for the input parameters can be used, and each assigned different weights, based on expert judgment, etc.

5 NATIONAL SEISMIC ZONATION

A review of the provisions of the national building codes with respect to seismic hazard and zonation is undertaken in the following pages.

5.1 Portugal



The seismic provisions foresee:

- Four seismic zones A, B, C, D, and three soil types: I (stiff soil, rock), II, III

- Coefficient of seismicity α:

Seismic zone	α
A	1.0
B	0.7
C	0.5
D	0.3

- Two types of seismic actions: type 1 (moderate magnitude earthquake at close distance), type 2 (greater magnitude earthquake at longer distance).
- The following values of the PGA for zone A (derived to within graphical accuracy from plots of acceleration response spectra for percentage of critical damping ζ=0.05 and natural frequency $f \rightarrow \infty$):

Peak Ground Acceleration for soil type I

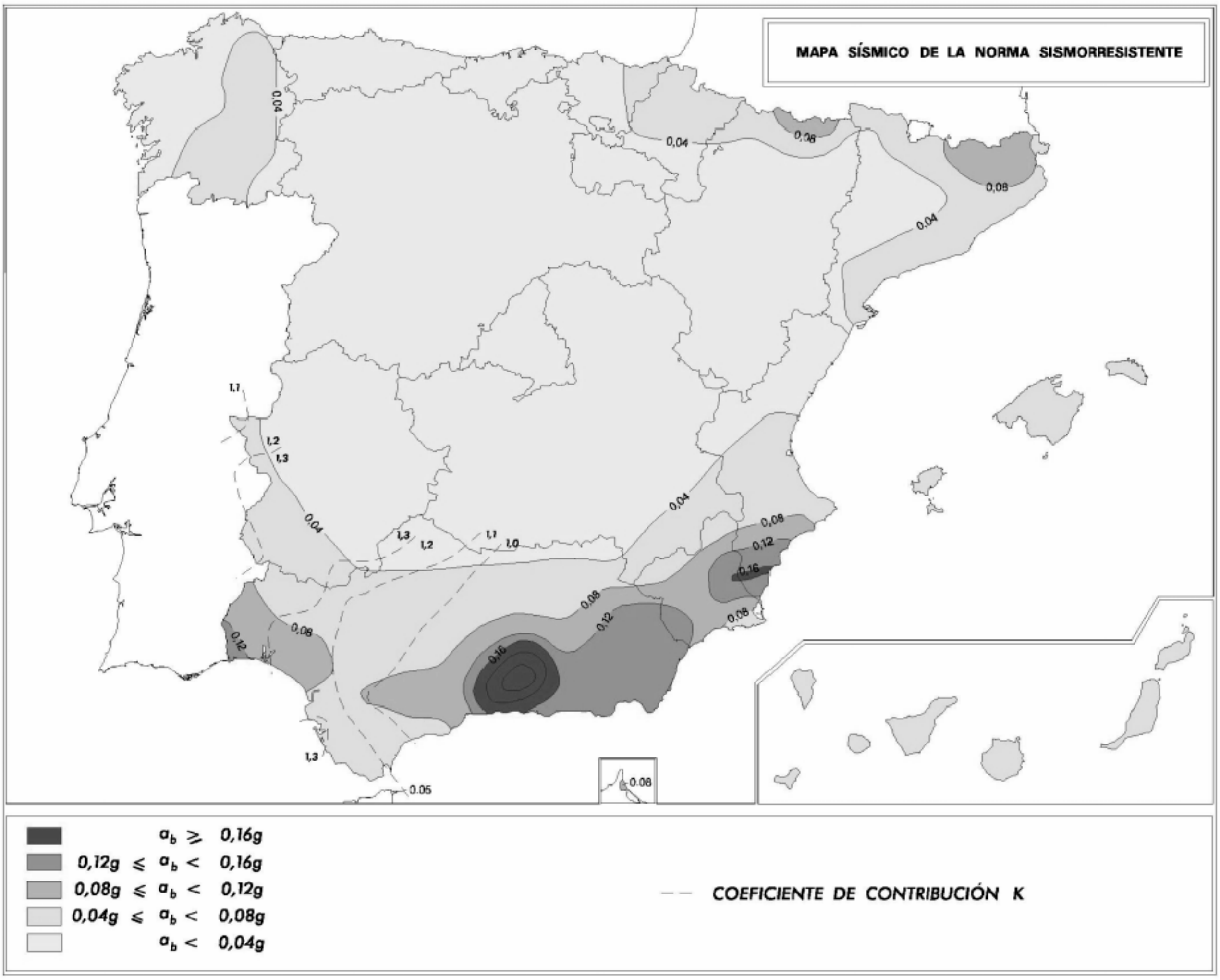
Seismic zone	**Action type 1**	**Action type 2**
A	0.48g	0.26g
B	0.34g	0.18g
C	0.24g	0.13g
D	0.14g	0.08g

Values for zones B, C and D are calculated by multiplying the values of zone A by the corresponding coefficients of seismicity α.

Sources

- Regulamento de Segurança e Acções para Estruturas de Edificios e Pontes, Decreto-Lei N.º 235/83, de 31 de Maio.

5.2 **Spain**



Four soil types are defined, I (stiff soil, rock), II, III, IV, and five seismic zones delimited by contours. As shown in the above map, the corresponding base ground accelerations (500-year return period, 10% exceedance probability in 50 years) a_b, are as follows:

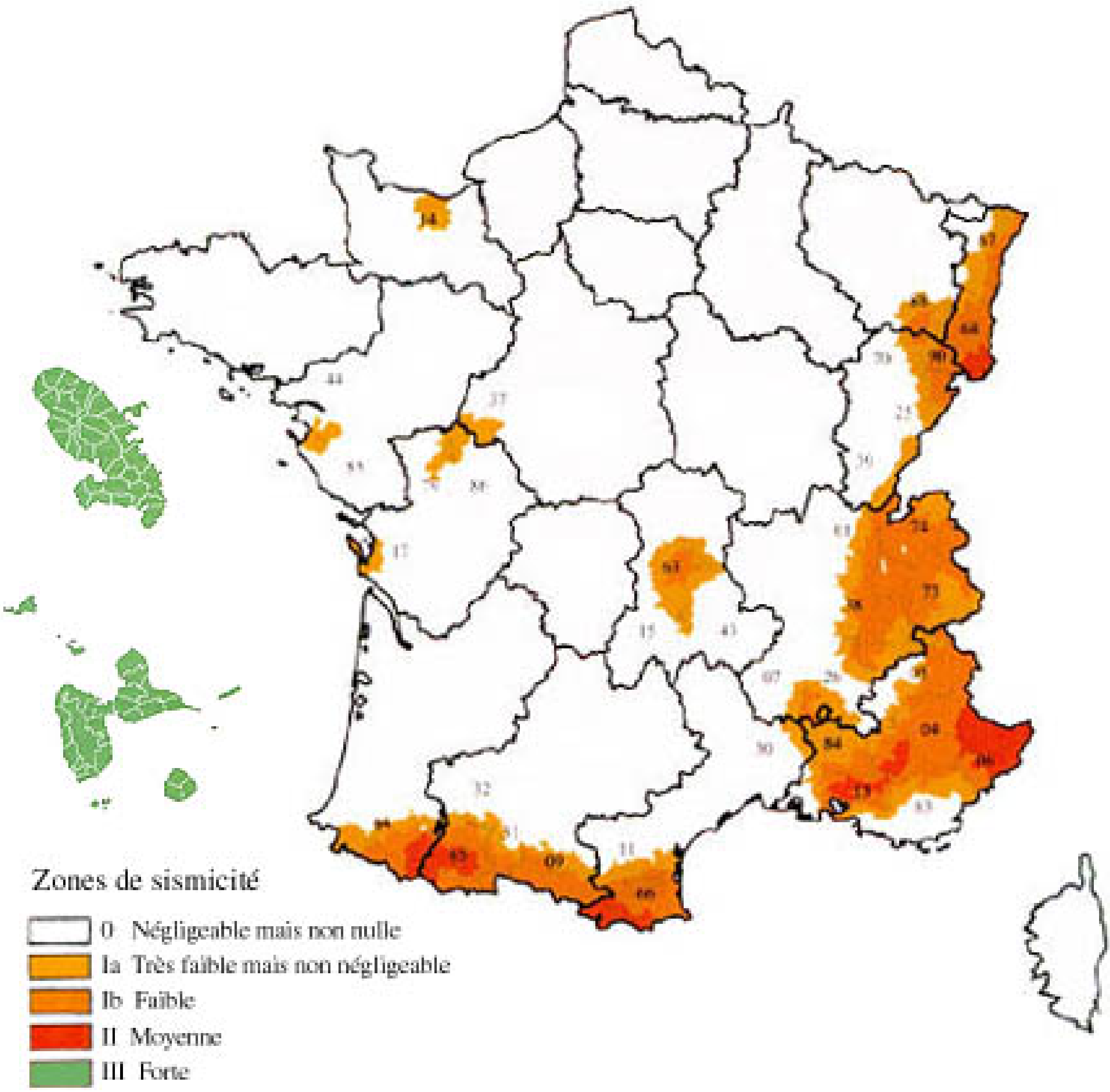
Ground Acceleration a_b for soil type I

Seismic zone	**Ground Acceleration a_b**
1	$0.16g \leq a_b$
2	$0.12g \leq a_b < 0.16g$
3	$0.08g \leq a_b < 0.12g$
4	$0.04g \leq a_b < 0.08g$
5	$a_b < 0.04g$

Sources

- MINISTERIO DE FOMENTO, 19687 REAL DECRETO 997/2002, de 27 de septiembre, por el que se aprueba la norma de construcción sismorresistente: parte general y edificación (NCSR-02). ANEXO: NORMA DE CONSTRUCCIÓN SISMORESISTENTE NCSE-02 PARTE GENERAL Y EDIFICACIÓN

5.3 **France**



Five zones of increasing seismicity are defined:

1. zone 0 of "negligible but not zero seismicity" with no particular seismic provisions to be respected; no shocks of intensity higher than VIII have been historically observed.

2. four zones Ia, Ib, II et III, where observance of seismic provisions in the construction is justified. These zones are defined as follows:

- zone I of "weak seismicity" where :

- no shocks of intensity greater than or equal to IX has been historically observed.
- the return period of a shock of intensity greater than VIII exceeds 250 years,
- the return period of a shock of intensity greater than VII exceeds 75 years,

- This zone is subdivided into two zones:

  - the zone Ia of "very weak but not negligible seismicity " where: no shocks of intensity higher than VIII have been historically observed;

  - the zone Ib of " weak seismicity " which comprises the rest of zone I ;

- zone II of " moderate seismicity ", where:

  - either a shock of intensity greater than IX has been historically observed.
  - or the return periods of a shock of intensity greater than or equal to VIII and of a shock of intensity greater than or equal to VII are smaller than 250 and 75 years, respectively;

- zone III of "strong seismicity", only assigned to the regions of Guadeloupe and Martinique

Buildings of the so-called normal risk category, are divided into four classes, A, B, C, D, in terms of increasing importance. Class B comprises the normal importance buildings.

A nominal acceleration a_N is assigned to each seismic zone and for each class of buildings, as in the Table below:

	Nominal Acceleration in m/sec^2 (and in g**)**		
SEISMIC ZONES	**CLASS B**	CLASS C	CLASS D
Ia	1.0 (0.10g)	1.5	2.0
Ib	1.5 (0.15g)	2.0	2.5
II	2.5 (0.25g)	3.0	3.5
III	3.5 (0.36g)	4.0	4.5

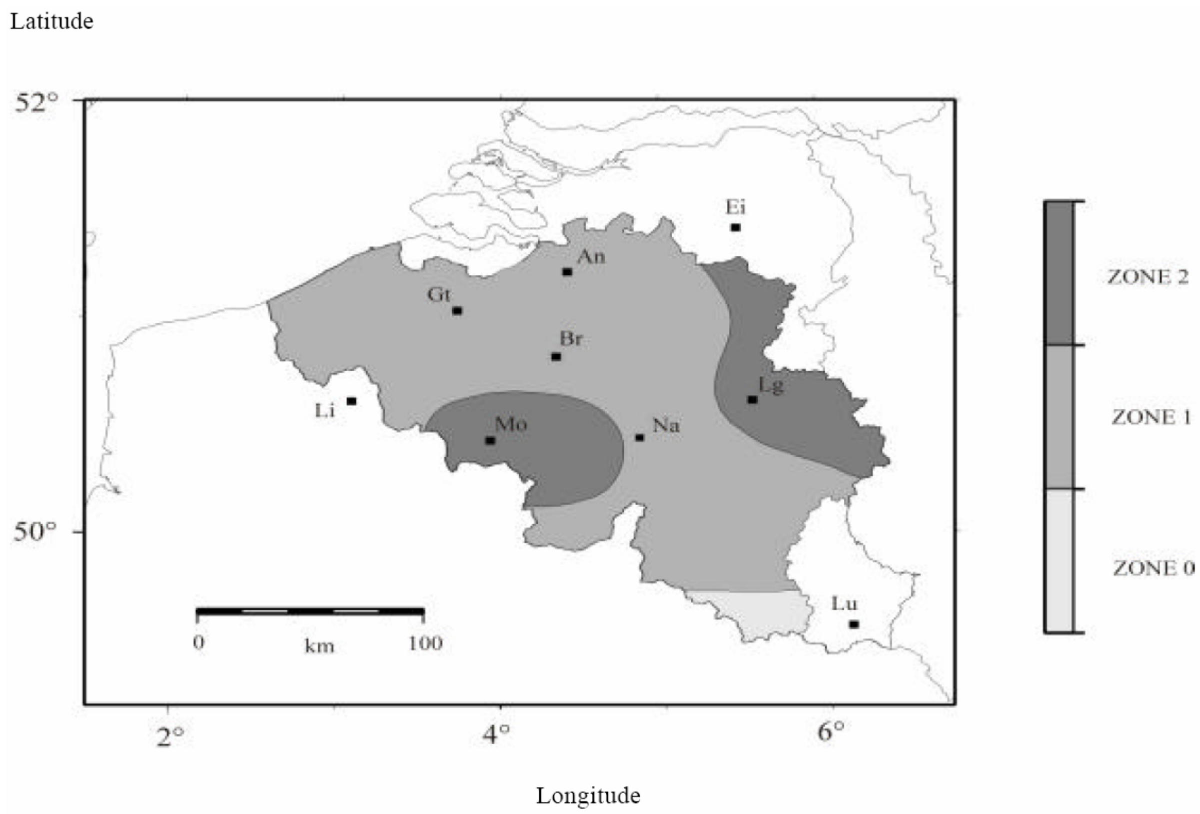
Sources

- Décret n°91-461 du 14 mai 1991 relatif à la prévention du risque sismique (J.O. du 17 mai 1991).

- Arrêté du 29 mai 1997 relatif à la classification et aux règles de construction parasismique applicables aux bâtiments de la catégorie dite "à risque normal" (J.O. du 3 juin 1997) (1).

- Décret n°2000-892 du 13 septembre 2000 portant modification du code de la construction.

5.4 **Belgium**



The seismic zonation map is based on a seismic hazard study with a 90% probability of no exceedance over 50 years (return period 475 years).

Further, the NAD for Belgium foresees three soil types: A (firm soil, rock), B, C. As seen in the above map, 3 zones are defined, where for soil type A the design ground accelerations at the bedrock level (PGA or Peak Ground Acceleration) are, respectively:

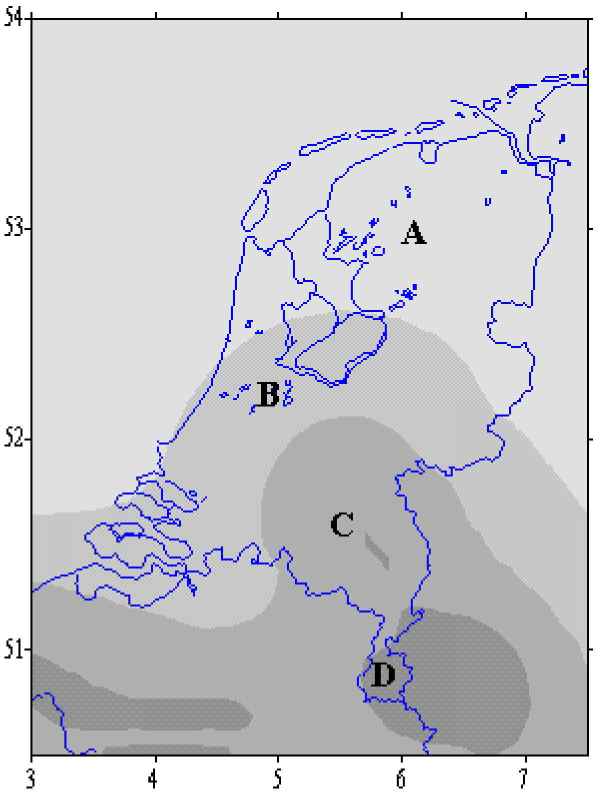
Seismic Zone 0:	No significant acceleration
Seismic Zone 1:	PGA = 0.05 g (0.50 m/sec^2)
Seismic Zone 2:	PGA = 0.10 g (1.00 m/sec^2)

Sources

- NBN-ENV 1998-1-1: 2002 NAD-E/N/FEurocode 8: Conception et dimensionnement des structures pour la résistance au séisme - Partie 1-1: Régles générales – Actions sismiques et exigences générales pour les structures. Document d'application belge, Institut Belge de Normalisation (IBN), avril 2002.

- Seismic Risk Assessment and Mitigation for Belgium in the frame of EUROCODE 8, Final Report, 2001, A. Plumier1, C. Doneux, T. Camelbeeck, G. van Rompaey, D. Jongmans, M. Wathelet, H. Teerlynck, F. Nguyen

5.5 Netherlands



The seismic zonation map is based on a seismic hazard study with a 10% probability of exceedance in 50 years (return period 475 years).

As seen in the above map, four zones are defined, where for stiff soil type the peak ground accelerations (PGA or Peak Ground Acceleration) are, respectively:

Seismic Zone A : PGA = 0.10 m/sec^2 (0.010 g)

Seismic Zone B : PGA = 0.22 m/sec^2 (0.022 g)

Seismic Zone C : PGA = 0.50 m/sec^2 (0.050 g)

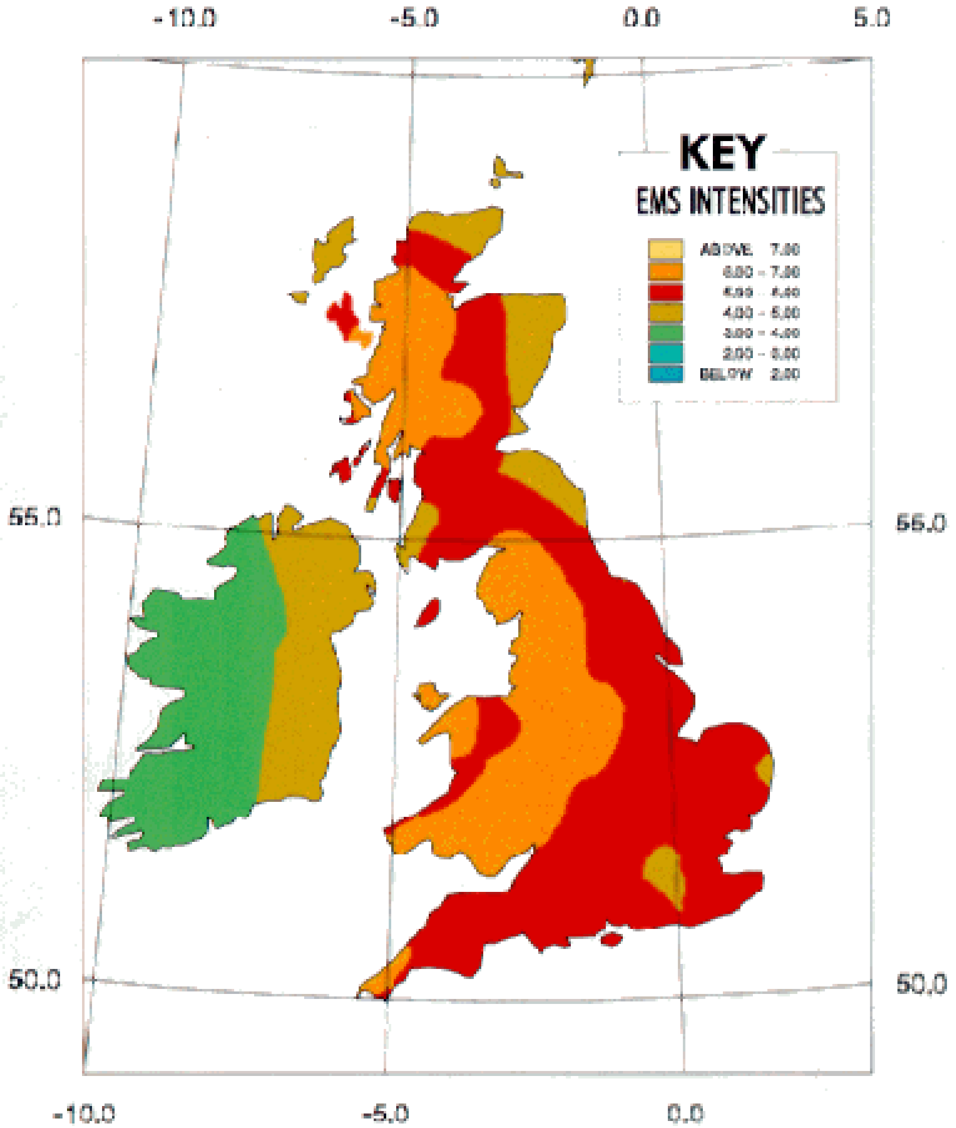
Seismic Zone D : PGA = 1.00 m/sec^2 (0.100 g)

Sources

- Het Koninklijk Nederlands Meteorologisch Instituut; http://www.knmi.nl/onderzk/seismo/

- Crook, Th. de, 1996, A seismic zoning map conforming to Eurocode 8, and practical earthquake parameter relations for the Netherlands, Geologie en Mijnbouw, 75, pp 11-18.

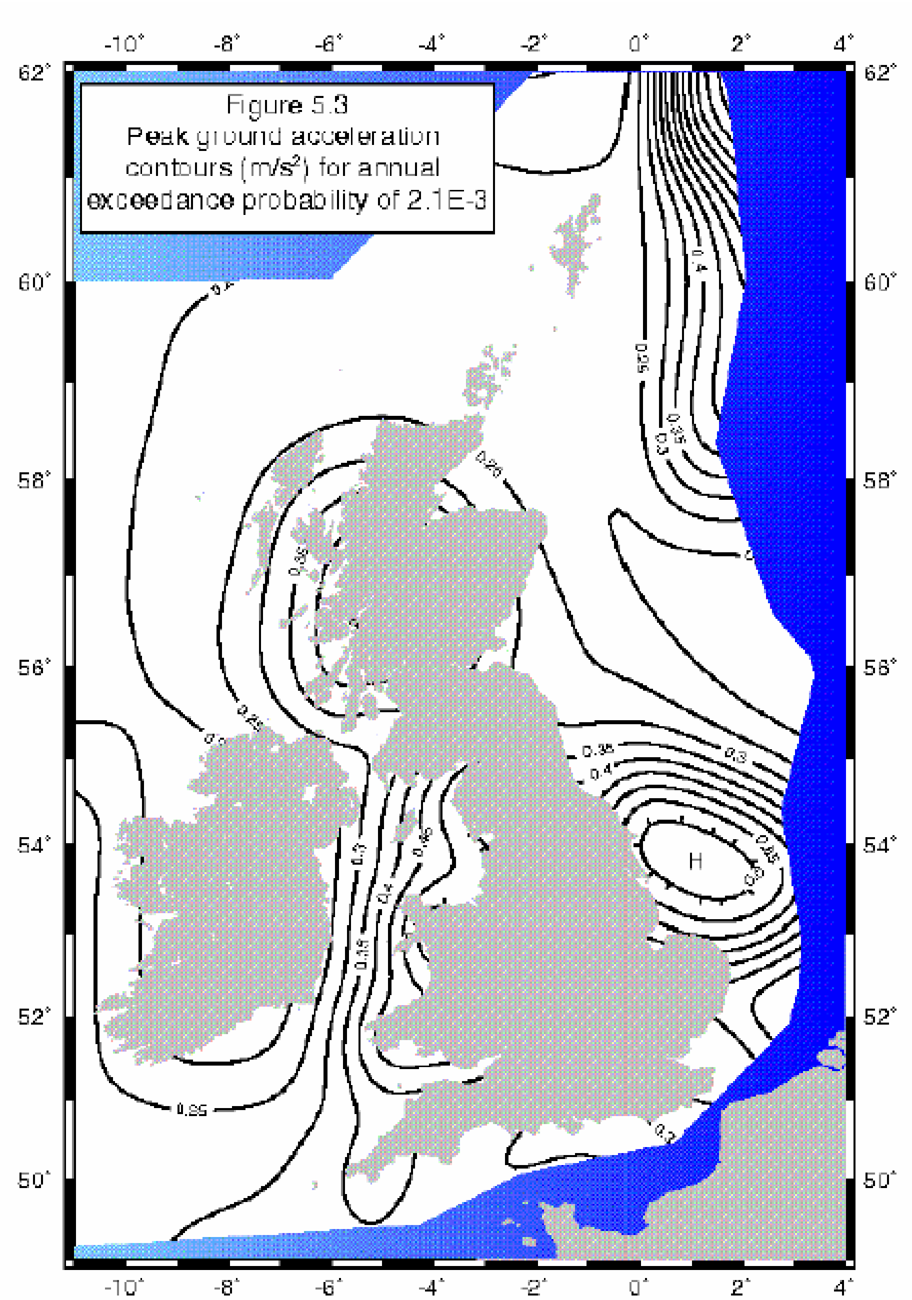
5.6 **United Kingdom and Ireland**



No onshore seismic zonation map with peak ground accelerations is currently available. In the context of EN 1998 the countries lie overall in the “very low seismicity” and in the “low seismicity” regions.

Recently a map of seismic intensity (EMS scale) for 475years mean return period has been published (shown above), which enjoys wide consensus. Although the correlation between intensity and ground acceleration is rather weak, in areas with intensities of 6 or 7 the 475-year return period PGA could be exceeding the 0.04g level.

Interestingly, a seismic hazard mapping of offshore Britain has been carried out through a coordination and synchronization of relevant British and Norwegian projects. Thus a high degree of harmonization has been achieved, and this study has provided an internationally consistent basis for defining offshore seismic loadings.



Sources

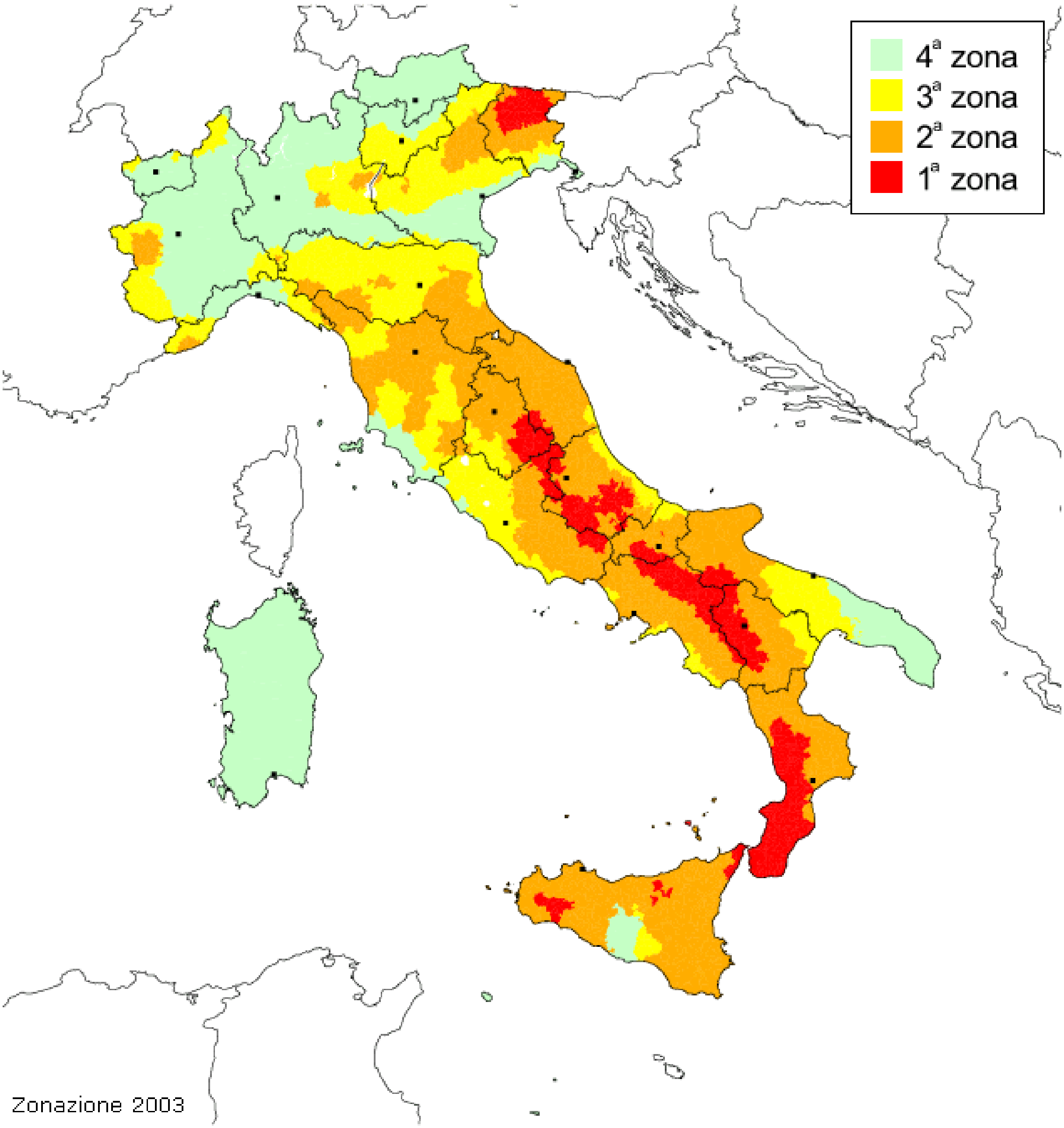
- Musson, R., Seismicity and Earthquake Hazard in the UK, British Geological Survey, http://www.quakes.bgs.ac.uk/hazard/hazuk.

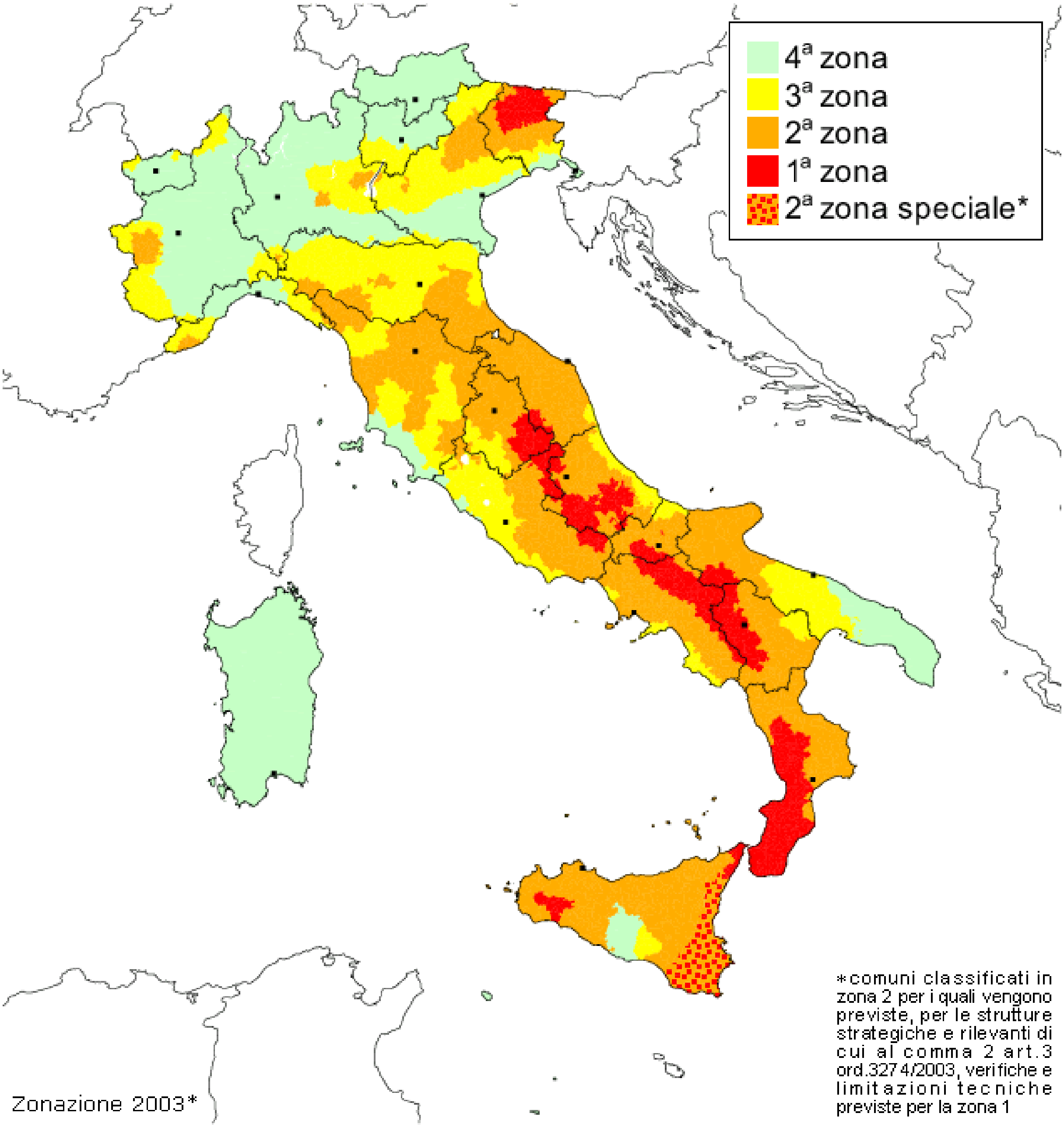
- Musson, R., and Winter, P., 1994, Seismic hazard of the UK, AEA Technology Report No AEA/CS/16422000/ZJ745/005.

- Booth, E., and Skipp, B., Eurocode 8 and its implications for UK-based structural engineers, The Structural Engineer, 3 Feb. 2004.

- Seismic hazard: UK continental shelf, Prepared by EQE International Ltd for the Health and Safety Executive, Offshore Technology Report 2002/005.

5.7 Italy





4ª zona
3ª zona
2ª zona
1ª zona
2ª zona speciale*
*comuni classificati in zona 2 per i quali vengono previste, per le strutture strategiche e rilevanti di cui al comma 2 art.3 ord.3274/2003, verifiche e limitazioni tecniche previste per la zona 1
Zonazione 2003*

Four seismic zones are defined according to the value of the maximum ground acceleration a_g, whose probability of exceedance is 10% in 50 years.

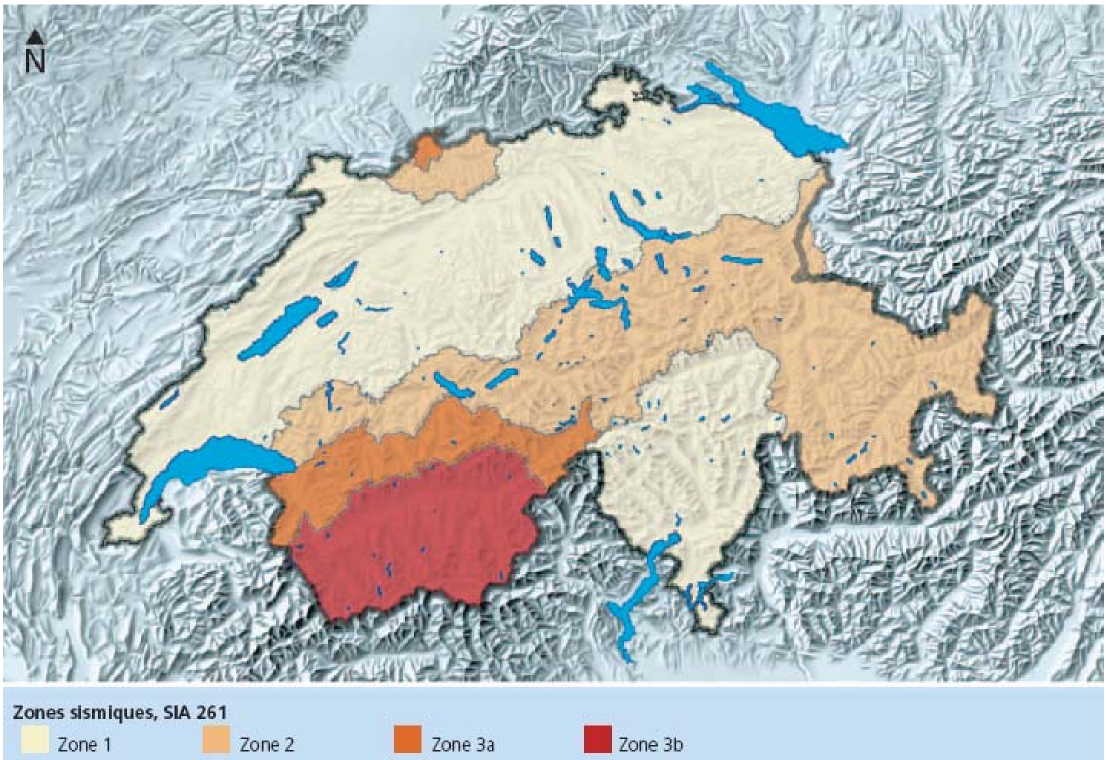
Seismic zone	**Ground acceleration with probability of exceedance equal to 10% in 50 years** **(a_g)**	**Acceleration of anchorage of the elastic response spectrum** **(Technical norms)** **(a_g)**
1	> 0.25g	**0.35g**
2	0.15g – 0.25g	**0.25g**
3	0.05g – 0.15g	**0.15g**
4	< 0.05g	**0.05g**

Sources

- Ordinanza del Presidente del Consiglio dei Ministri n. 3274 del 20 marzo 2003, Gazzetta Ufficiale della Repubblica italiana n.105 dell'8 maggio 2003, «Primi elementi in materia di criteri generali per la classificazione sismica del territorio nazionale e di normative tecniche per le costruzioni in zona sismica».

- Ordinanza del Presidente del Consiglio dei Ministri n. 3316 del 2 ottobre 2003, Gazzetta Ufficiale della Rebubblica Italiana, n.236 del 10-10-2003, «Modifiche ed integrazioni all'ordinanza del Presidente del Consiglio dei Ministri n.3274 del 20 marzo 2003, recante «Primi elementi in materia di criteri generali per la classificazione sismica del territorio nazionale e di normative tecniche per le costruzioni in zona sismica».

5.8 Switzerland



In the recently introduced (2003) national seismic building code SIA 261, seismic zonation has been based on ground motion values with 10% probability of exceedance in 50 years, i.e., 475years mean return period. Four seismic zones (Z1, Z2, Z3a and Z3b) have been proposed. Similar to EN 1998, five soil types are also defined, and the PGA values quoted in the Table below refer to soil type A (stiff soil, rock). For other ground types SIA 261 specifies a simplified scaling factor.

Peak Ground Acceleration for soil type A

Seismic zone	a_g in **m/sec^2**
Z1	0.6
Z2	1.0
Z3a	1.3
Z3b	1.6

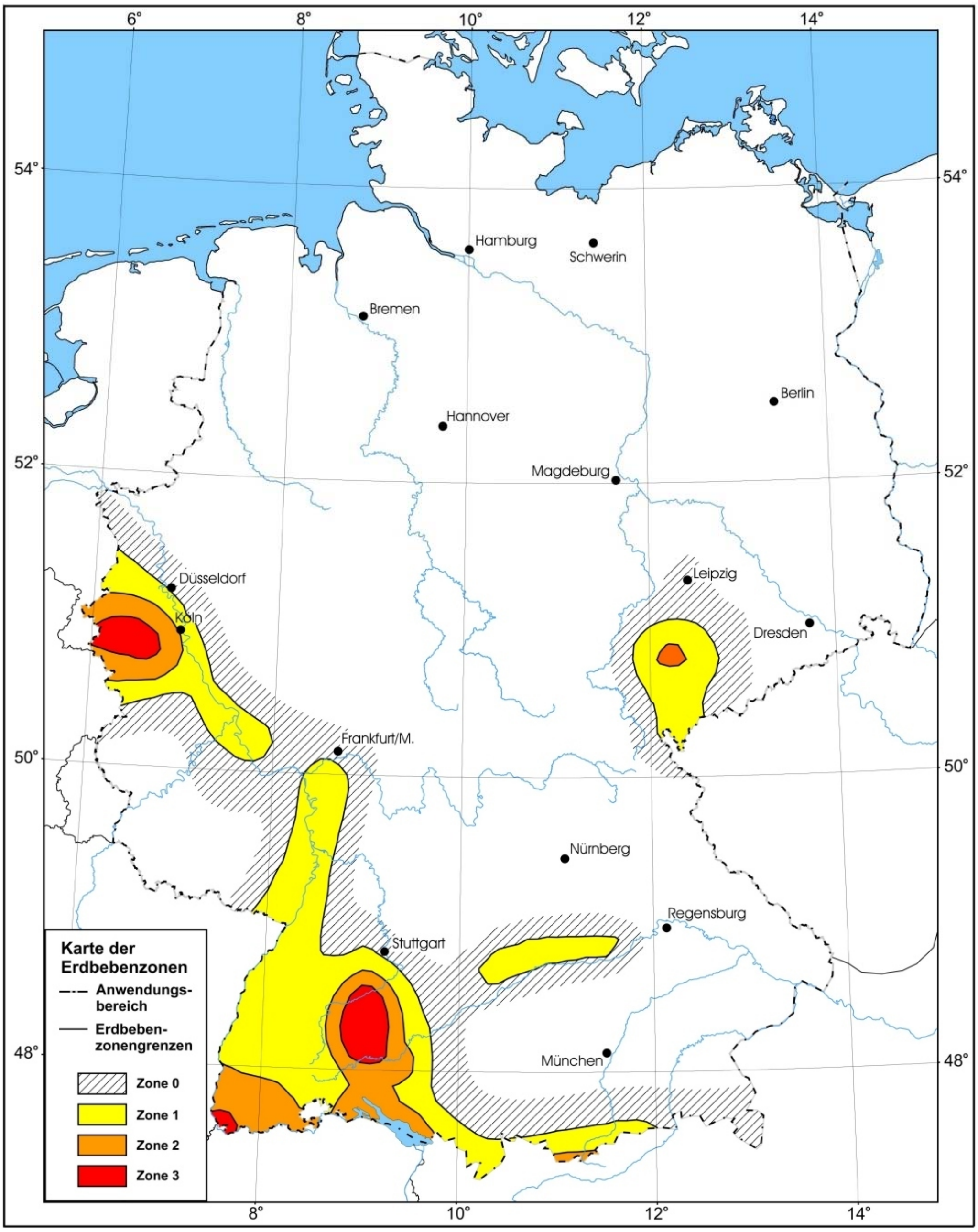
Sources

- Principe pour l'établissement et l'utilisation d'études de microzonage en Suisse, Directives de l'OFEG (Office fédéral des eaux et de la géologie), Berne, 2004.

- Seismic Hazard Assessment of Switzerland, 2004, Giardini, D., Wiemer, S., Fäh, D, and Deichmann, N., Version 1.1 – Nov. 25, 2004 Swiss Seismological Service, ETH Zurich.

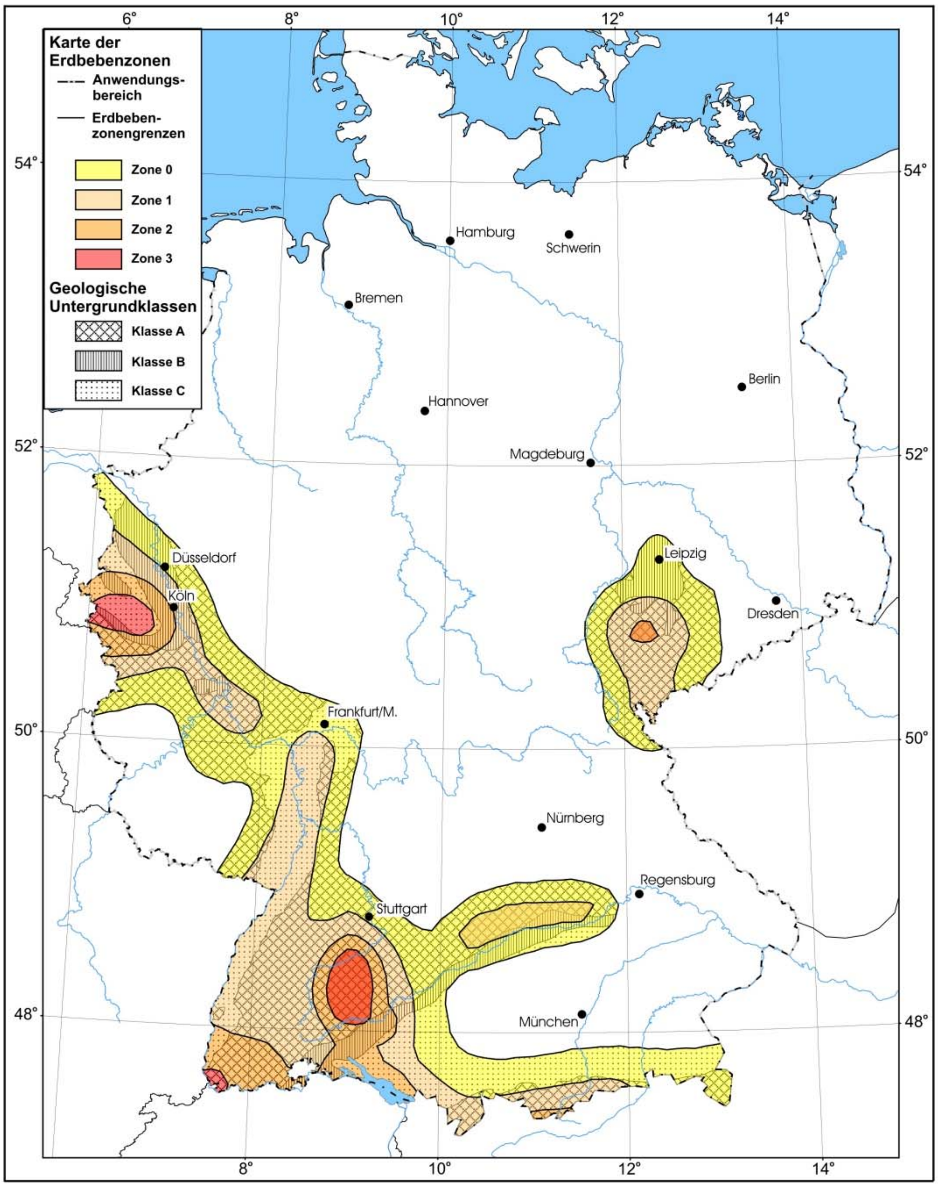
5.9 Germany

Karte der Erdbebenzonen
für die erdbebengerechte Baunorm E-DIN 4149
(in Analogie zum Eurocode 8)



GFZ POTSDAM

Karte der Erdbebenzonen und geologische Untergrundklassen (unkorrigiert)



According to the new DIN 4149 T1, four seismic zones with three associated soil classes (A, B. C) are defined. The horizontal PGA for soil class A assigned to each zone, corresponding to a 10% probability of exceedance in 50 years, is as follows:

Peak Ground Acceleration a_o for ground class A

Seismic zone	**Acceleration a_o in m/sec^2**
0	0.25 (0.025g)
1	0.40 (0.041g)
2	0.65 (0.066g)
3	1.00 (0.102g)

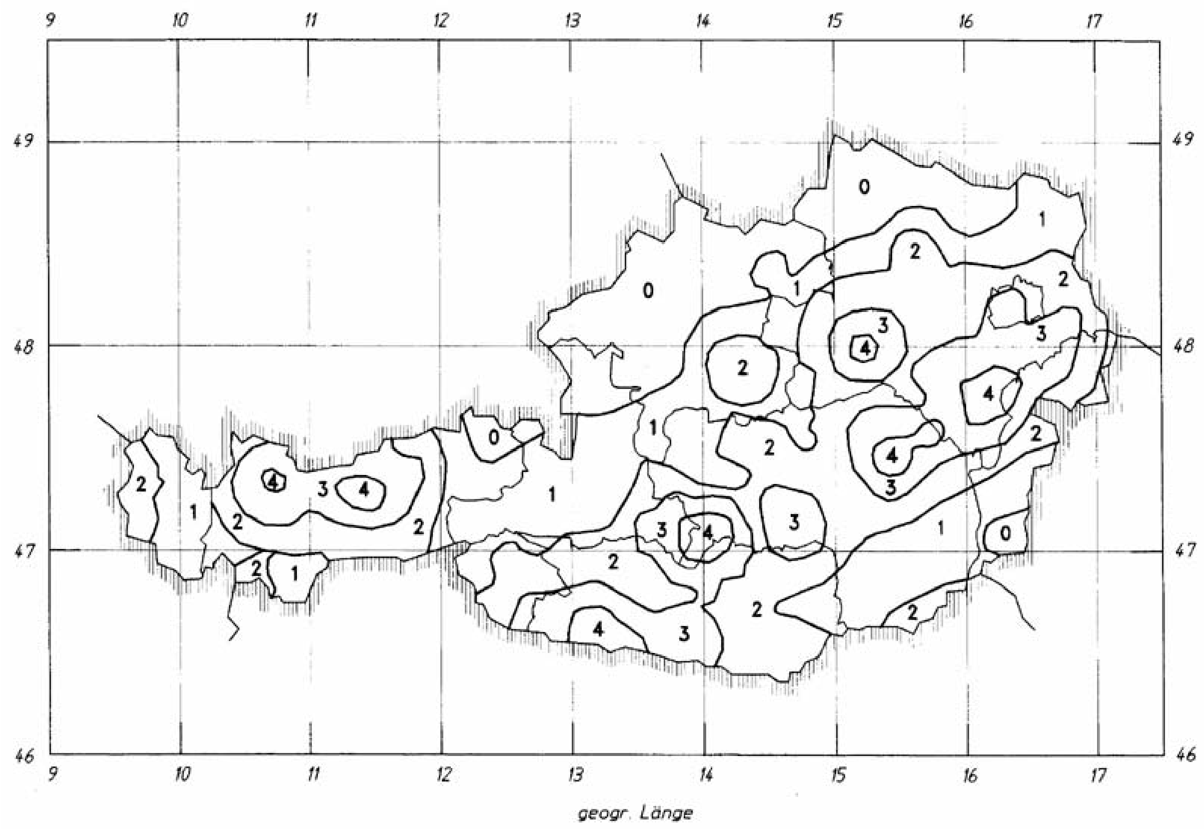
Sources

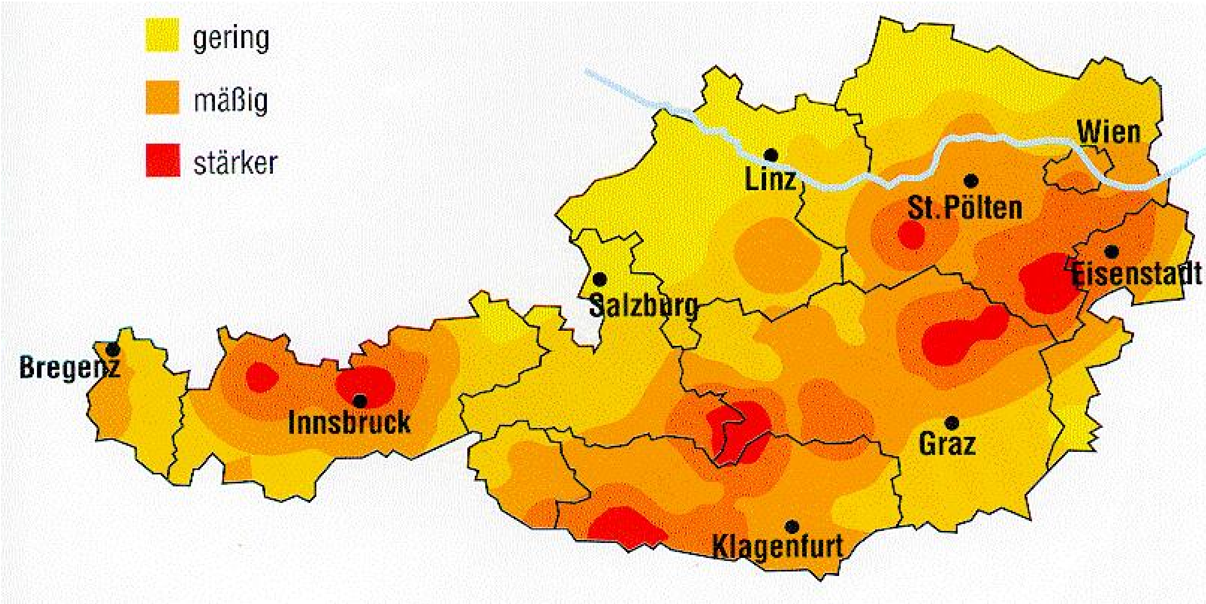
- DIN 4149 “Bauten in deutschen Erdbebengebieten”, 2002.

- GeoForschungsZentrum Potsdam (GFZ), http://seismohazard.gfz-potsdam.de.

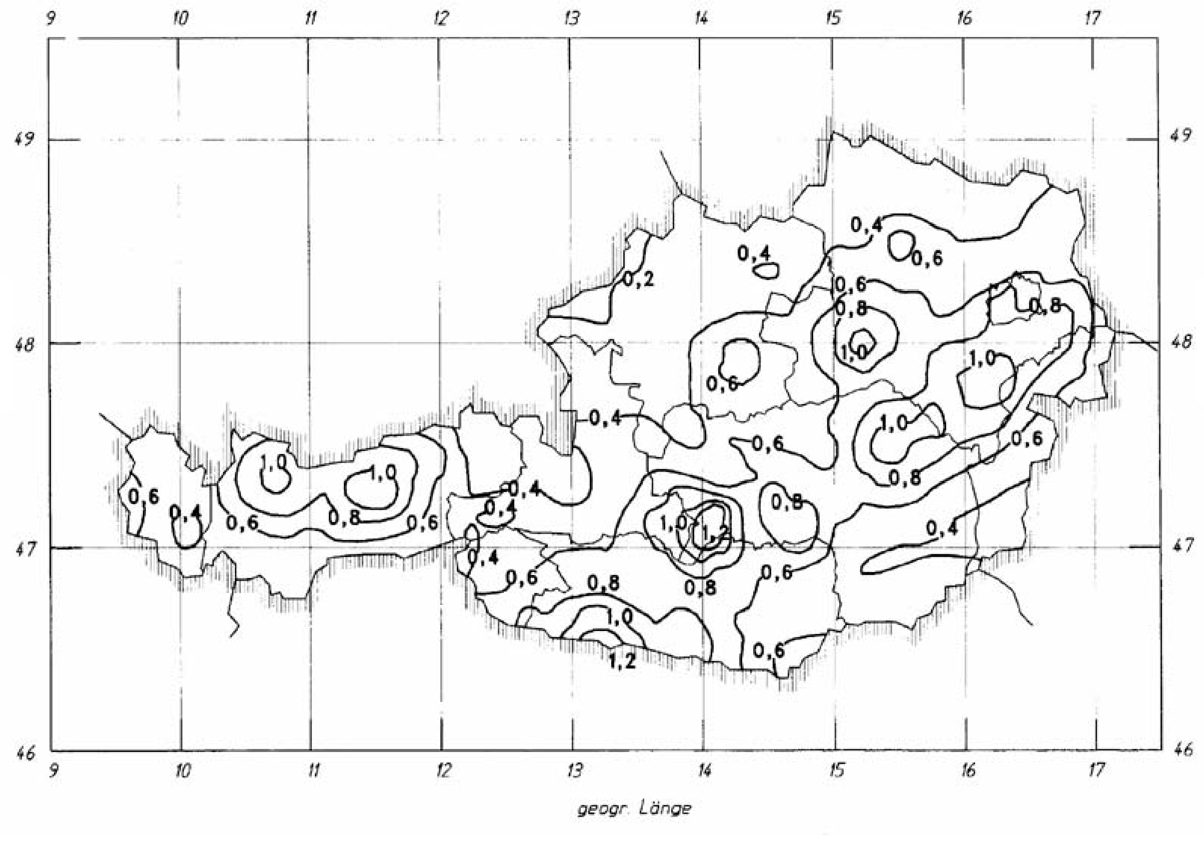
5.10 **Austria**

Übersichtskarte Zoneneinteilung in Österreich





Isolinien der effektiven Bodenbeschleunigung a_h in m/s^2



Seismic zonation is based on ground acceleration values with 10% probability of exceedance in 50 years. Five seismic zones (0 - 4) are defined, along with three soil types.

Two maps are provided: the first map outlines the seismic zones, and the second shows associated iso-value contours of the “effective” ground acceleration in m/sec^2 (which is considered to be 70% of the maximum ground acceleration). From this second map, shown above, the following Table has been drawn.

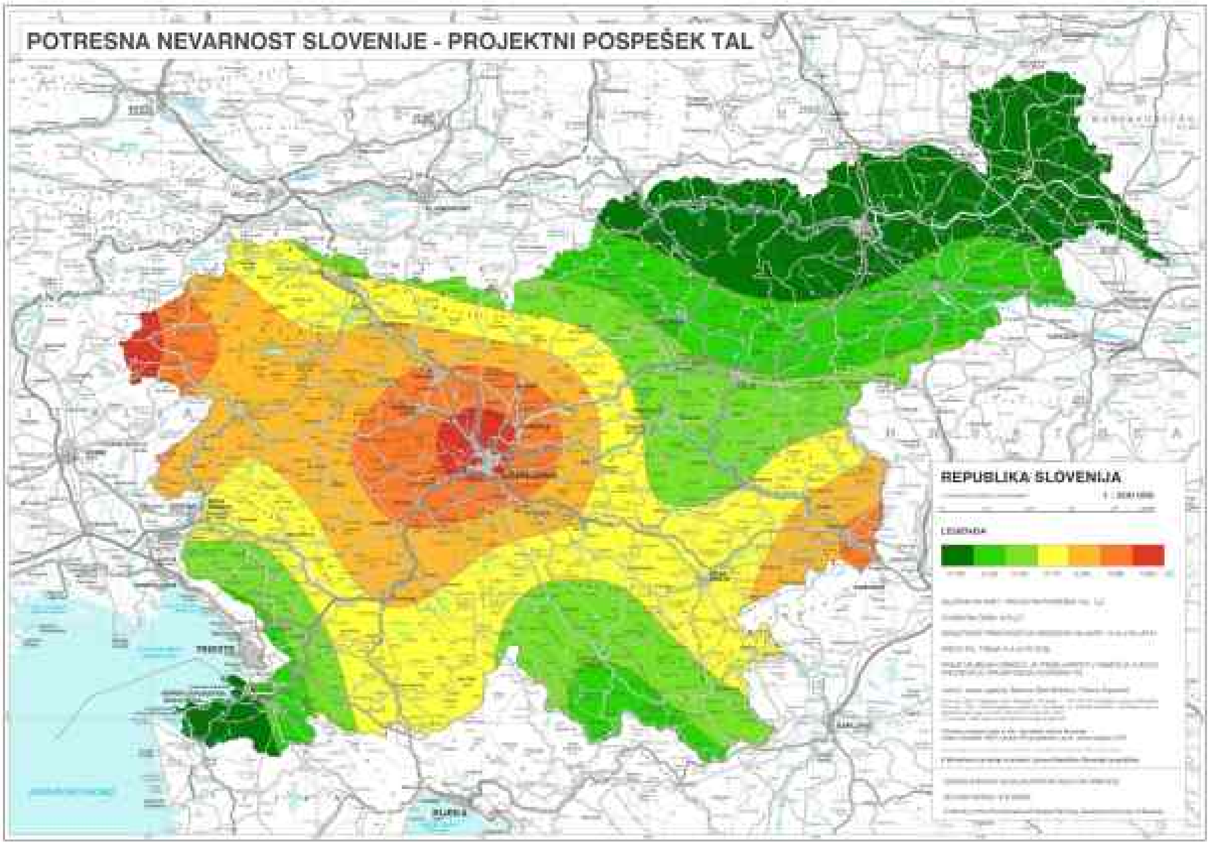
Effective Ground Acceleration a_h for stiff soil type

Seismic zone	a_b in **m/sec^2**
0	$0.4 \geq a_h$
1	$0.6 \geq a_h \geq 0.4$
2	$0.8 \geq a_h \geq 0.6$
3	$0.8 \geq a_h \geq 1.0$
4	$a_h \geq 1.0$

Sources

- ÖNORM B 4015, Österreichische Gesellschaft für Erdbebeningenieurwesen und Baudynamik, 2002, W. A. Lenhardt, http://www.oge.or.at/.

5.11 **Slovenia**



A new seismic hazard map has been introduced (2002) as part of the national seismic building code, which is in accordance with Eurocode 8. Seismic zonation has been based on ground acceleration values with 10% probability of exceedance in 50 years, i.e., 475-year mean return period. Shown in colors above, seven seismic zones have been proposed with their associated PGAs for stiff soil or rock, which are as follows.

Peak Ground Acceleration for soil type A

Seismic zone	a_g
red	0.250g
orange	0.225g
light orange	0.200g
yellow	0.175g
light green	0.150g
green	0.125g
dark green	0.100g

Sources

- Ministry of the Environment and Spatial Planning, Geophysical Survey of Slovenia, “Tolmač karte potresne nevarnosti Slovenije”, Janez Lapajne, Barbara Šket Motnikar, Polona Zupančič, MOP - Agencija RS za okolje, Urad za seizmologijo, Dunajska 47/VII, 1000 Ljubljana, www.arso.gov.si/podro~cja/potresi/podatki/projektni_pospesek_tal.html.

5.12 **Hungary**

In the current code four seismic zones were defined in terms of the MKS intensity. For the determination of the equivalent lateral forces a seismic zone factor was used, whose values per zone are as follows:

Seismic Zone Factor (K_s)

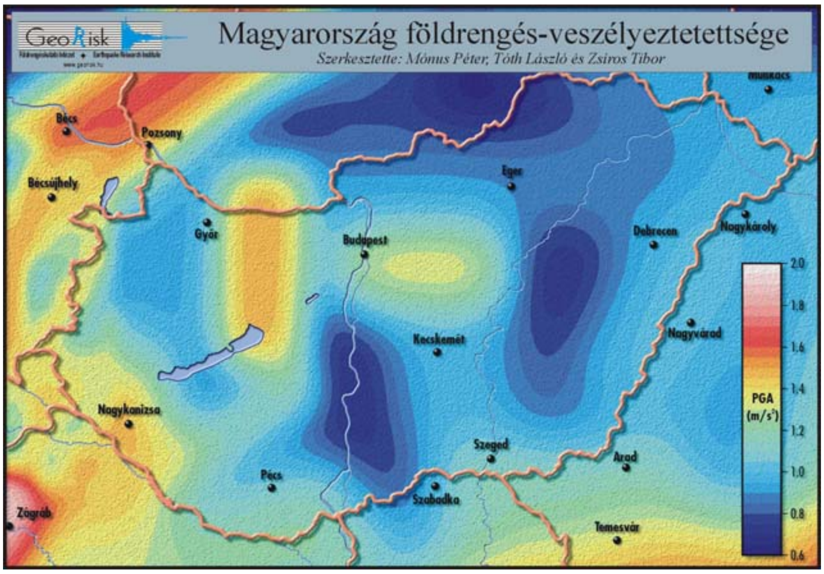
Seismic zones	$\mathbf{K_s}$
6	0.15
7	0.22
8	0.26
9	0.32

It has not been possible to retrieve the corresponding seismic hazard map.

For the Eurocode 8, the NAD under preparation foresees four seismic zones to be based on the seismic hazard mapping of the country portrayed below. This map has been produced by the *GeoRisk* - Earthquake Research Institute Ltd., Budapest. It shows PGA in m/sec^2 with 10% probability of excedance in 50 years, that is, with a return period of 475 years.

Peak Ground Acceleration a_g for stiff soil

Seismic zone	$\mathbf{a_g}$
1	0.04g
2	0.06g
3	0.08g
4	0.10g



Sources

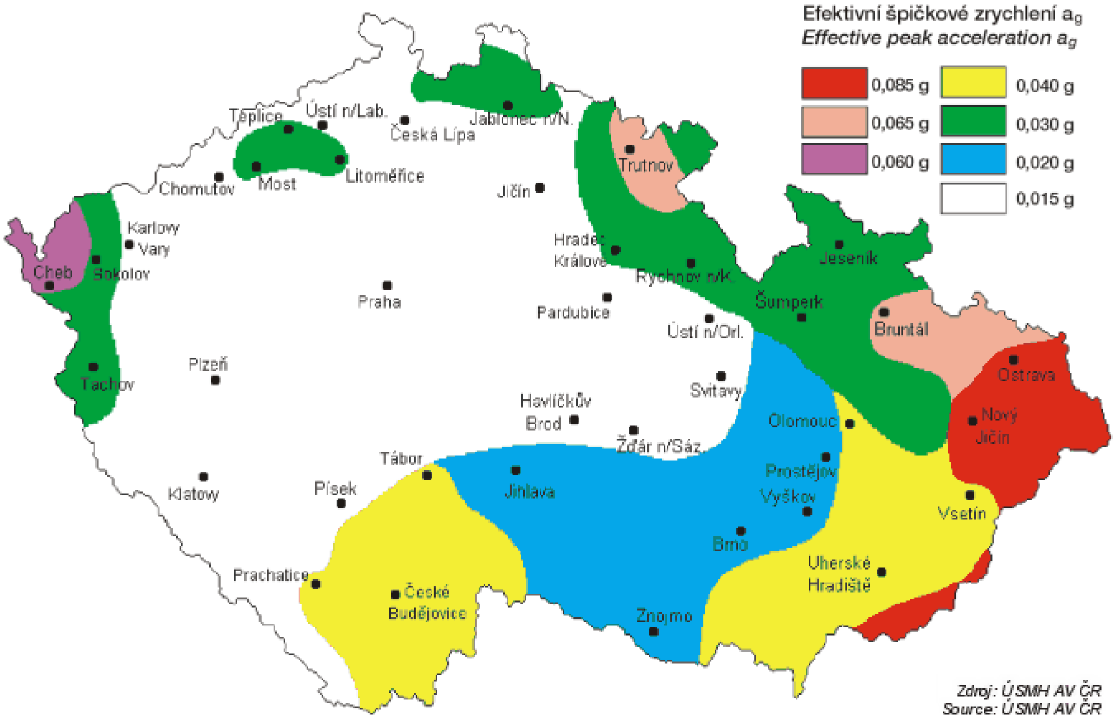
- International Institute of Seismology and Earthquake Engineering, http://iisee.kenken.go.jp /net/seismic_design_code/index.htm.

- *GeoRisk* Earthquake Research Institute Ltd., http://www.georisk.hu/.

5.13 **Czech Republic**

A seismic zonation map was included in the building code standards (ČSN 73 0036). Recently a new map was completed on the basis of earthquake catalogues for Central European countries delimiting seismogenic areas and maximum possible earthquake intensities, as well as information on suppression of macroseismic intensities. In this map, values of seismic loading are expressed in terms of the macroseismic intensities (MSK scale) with 10% probability of excedance in 50 years. Related values employed for seismic zone delineation for the National Application Document of EUROCODE 8 (CR-CSN P ENV 1998-1-1) are expressed in terms of the effective peak acceleration as shown below.

Obr. B3.1.6 Seizmické oblasti ČR – ČSN P ENV 1998-1-1, národní aplikační dokument – EUROKÓD 8
Seismic zones in the CR – CSN P ENV 1998-1-1, National Application Document – EUROCODE 8



Effective peak acceleration a_g for stiff soil

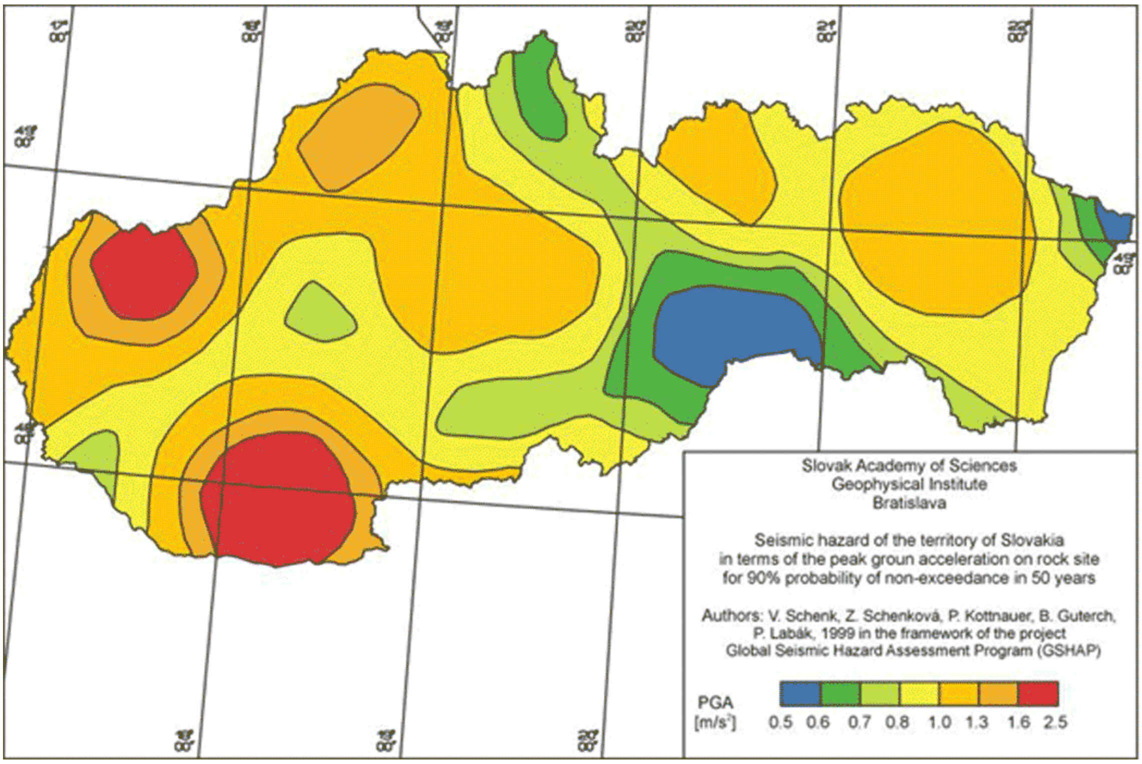
Seismic Zone	$\mathbf{a_g}$
white	0.015g
blue	0.020g
green	0.030g
yellow	0.040g
violet	0.060g
tan	0.065g
red	0.085g

Sources

- Statistical environmental yearbook of the Czech Republic. - Praha, The Ministry of Environment of the Czech Republic 2003; Schenk, V. - Schenkovα, Z., "Geological environment and soil. Seismic areas in CR-CSN P ENV 1998-1-1. National application document - Eurocode 8", http://www.env.cz/rocenka2003/b3.htm.

5.14 **Slovakia**

As for the Czech Republic, a seismic zonation map was included in the building code standards (ČSN 73 0036). Recently a new seismic hazard assessment was completed in terms of macroseismic intensities (MSK scale) and peak ground accelerations with 10% probability of excedance in 50 years. Seven PGA zones can be possibly distinguished, as shown below.



Peak Ground Acceleration a_g for rock

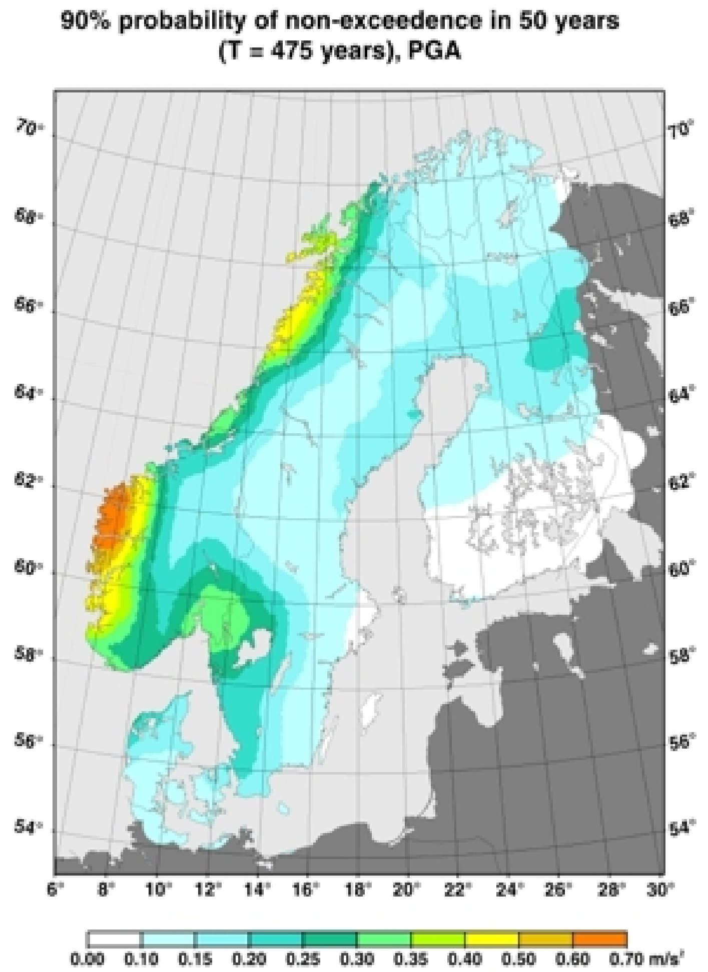
Seismic Zone	**a_g (m/sec^2)**
blue	$0.5 \leq a_g \leq 0.6$
green	$0.6 \leq a_g \leq 0.7$
light green	$0.7 \leq a_g \leq 0.8$
yellow	$0.8 \leq a_g \leq 1.0$
light orange	$1.0 \leq a_g \leq 1.3$
orange	$1.3 \leq a_g \leq 1.6$
red	$1.6 \leq a_g \leq 2.5$

Sources

- Geophysical institute, Slovak Academy of Sciences (GPI SAS), http://www.seismology.sk/Maps/maps.html.

5.15 **Scandinavian countries**

Unfortunately it has not been possible to retrieve seismic zoning maps from the respective building codes. However, in order to have an idea of the associated seismic hazard of the Fennoscandia region the map below is included. It depicts the seismic hazard for Sweden, Finland, Denmark and Norway, in terms of PGA (m/sec^2) with 10% probability of exceedance in 50 years, based on a combined regionalization model from Wahlström and Grünthal. The maximum PGA value (orange colour) is approximately 0.7m/sec^2 = 0.07g.



Sources

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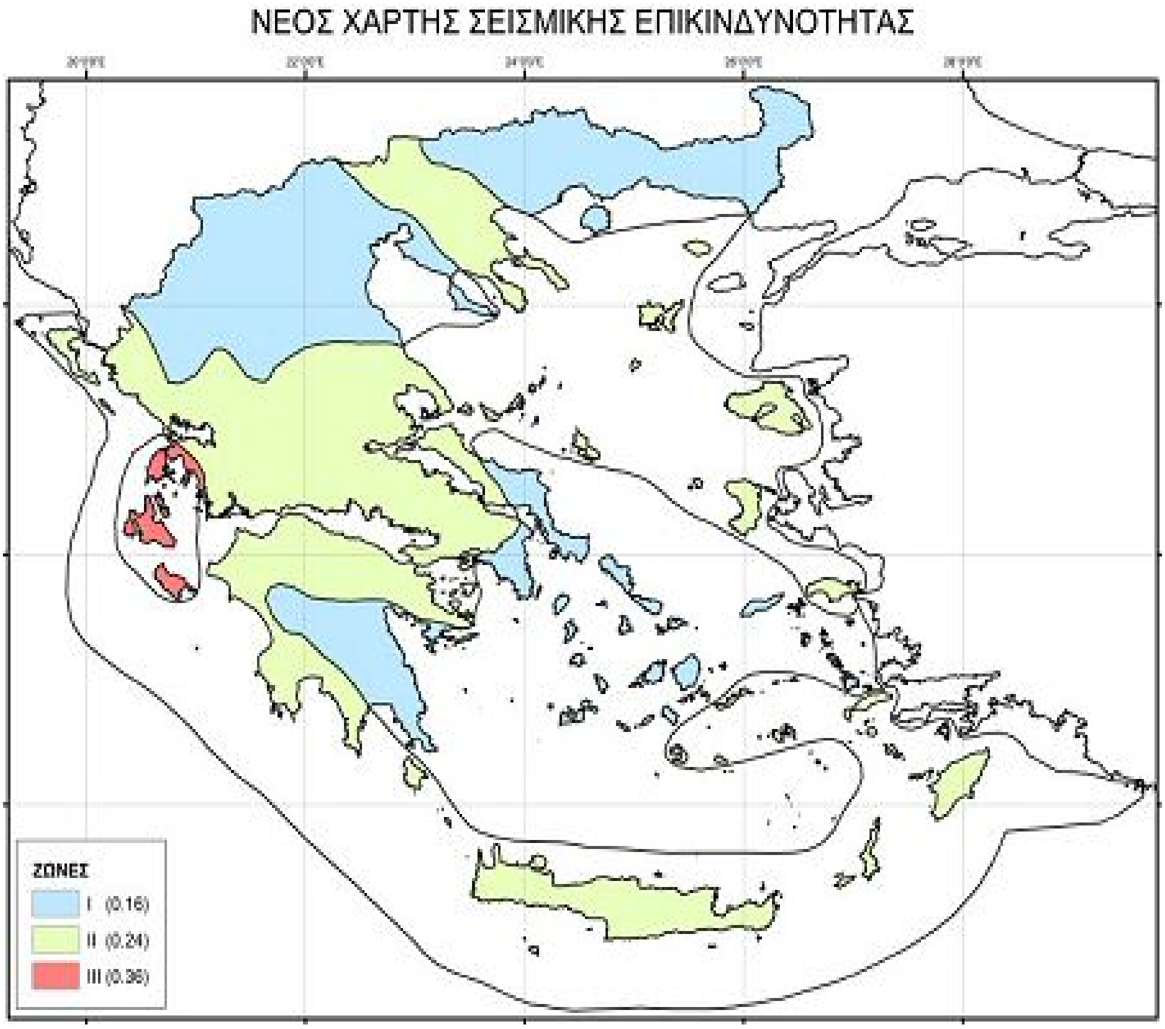
5.16 **Greece**



The Greek seismic building code “EAK-2000” has been revised in 2003 to incorporate, inter alia, the new seismic hazard map of the country.

Seismic zonation has been based on ground acceleration values with 10% probability of exceedance in 50 years, i.e., 475years mean return period. Three seismic zones (I, II, III) have been introduced, and five soil types are defined. The PGA values assigned to each zone refer to soil type A (stiff soil, rock).

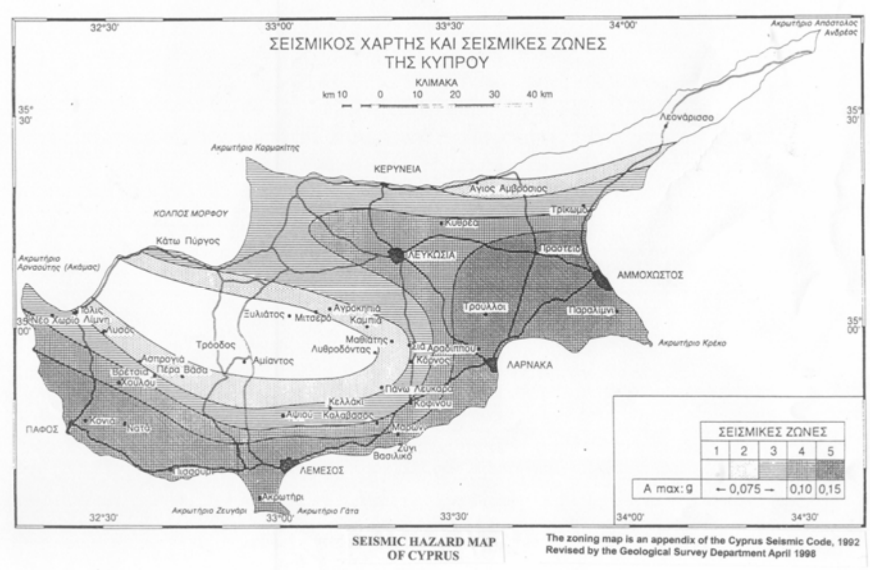
Peak Ground Acceleration for soil type A

Seismic zone	a_g
I	0.16g
II	0.24g
III	0.36g

Sources

- Τροποποίηση διατάξεων του «Ελληνικού Αντισεισμικού Κανονισμού ΕΑΚ-2000» λόγω αναθεώρησης του Χάρτη Σεισμικής Επικινδυνότητας (Φ.Ε.Κ. Β΄ 1154/12-8-2003, Απόφαση Αριθ. Δ17α/115/9/ΦΝ275).

5.17 **Cyprus**



The seismic building code of Cyprus includes seismic zonation based on ground acceleration values with 10% probability of exceedance in 50 years, i.e., 475years mean return period. Five zones (1-5) are defined with PGA ranging from 0.075g to 0.15g. In a recent revision of the code (2004), three seismic zones are defined; the PGA values assigned to each zone (for stiff soil, rock) are as follows.

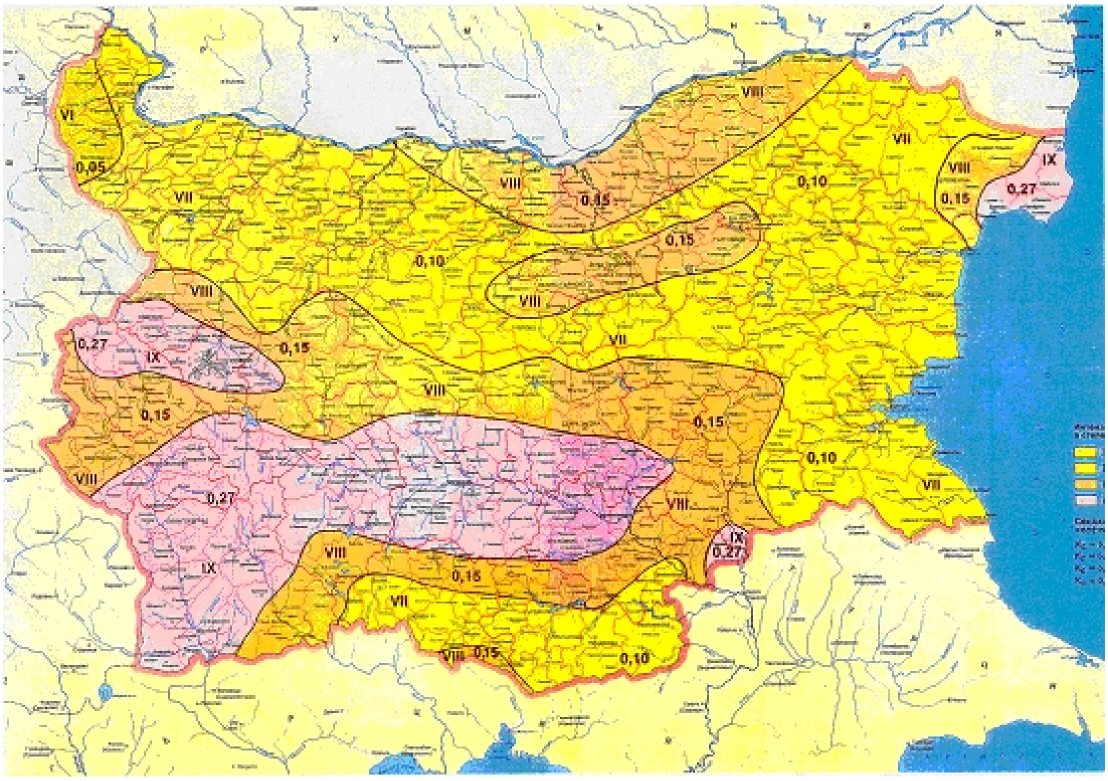
Peak Ground Acceleration

Seismic zone	a_g
1	0.15g
2	0.20g
3	0.25g

Sources

- Prof. C. Chrysostomou, personal communication, Higher Technical Institute, Nicosia, Cyprus.

5.18 **Bulgaria**



In the ad-hock Bulgarian Codes (1987) three seismic zones are defined, characterized by their site intensity for a 1000-year mean return period. The associated, correspondingly, seismic coefficient (ground accelerations) are shown in the Table below. It is, however, contended that more realistic levels of Kc for zones VIII and IX should be higher (0.20 and 0.40, respectively).

Values of seismic coefficient K_c

Seismic zones	K_c
VI	0.05
VII	0.10
VIII	0.15
IX	0.27

Sources

- Regulations for Design of Buildings and Structures in Seismic Regions, Sofia, 1987 (in Bulgarian).

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5.19 **Romania**

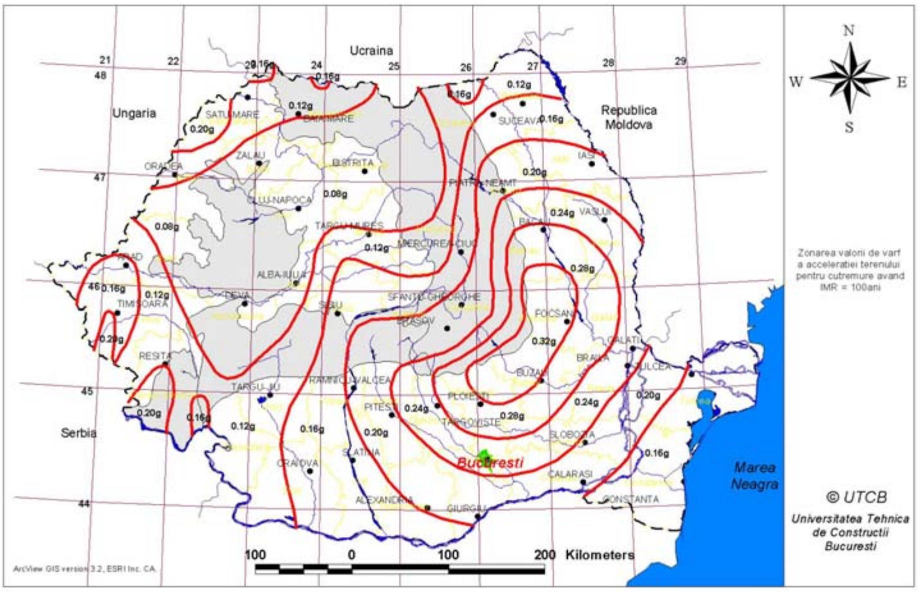
Current legislation for earthquake protection (Law no. 575/2001, Building Code P 100-92 and seismic standard SR 11100/1-93) provides maps for seismic intensity areas, recurrence period and the classification of all urban localities according to possible seismic intensity on MSK scale. The maps indicate the expected intensity of an earthquake in a certain area from VI to IX on the MSK-64 scale, the average recurrence period (20, 50 and 100 years), peak ground accelerations and control periods of the response spectra.

The seismic zonation included in the building code P100-92 defines six zones with peak ground acceleration values as shown in the table below (unfortunately no map is available). The associated average return period is considered to be 50 years.

The seismic zone coefficient K_s (in g)

Seismic Zones	K_s
A	0.32
B	0.25
C	0.20
D	0.16
E	0.12
F	0.08

The draft of the new seismic code P100/2004, which follows Eurocode 8, is foreseeing to include a revised seismic zonation map. As shown below, it will indicate PGAs (0.08g, 0.12g, 0.16g, 0.20g, 0.24g, 0.28g, 0.32g) corresponding to an average return period of 100 years, i.e., to a 40% probability of exceedance in 50 years.



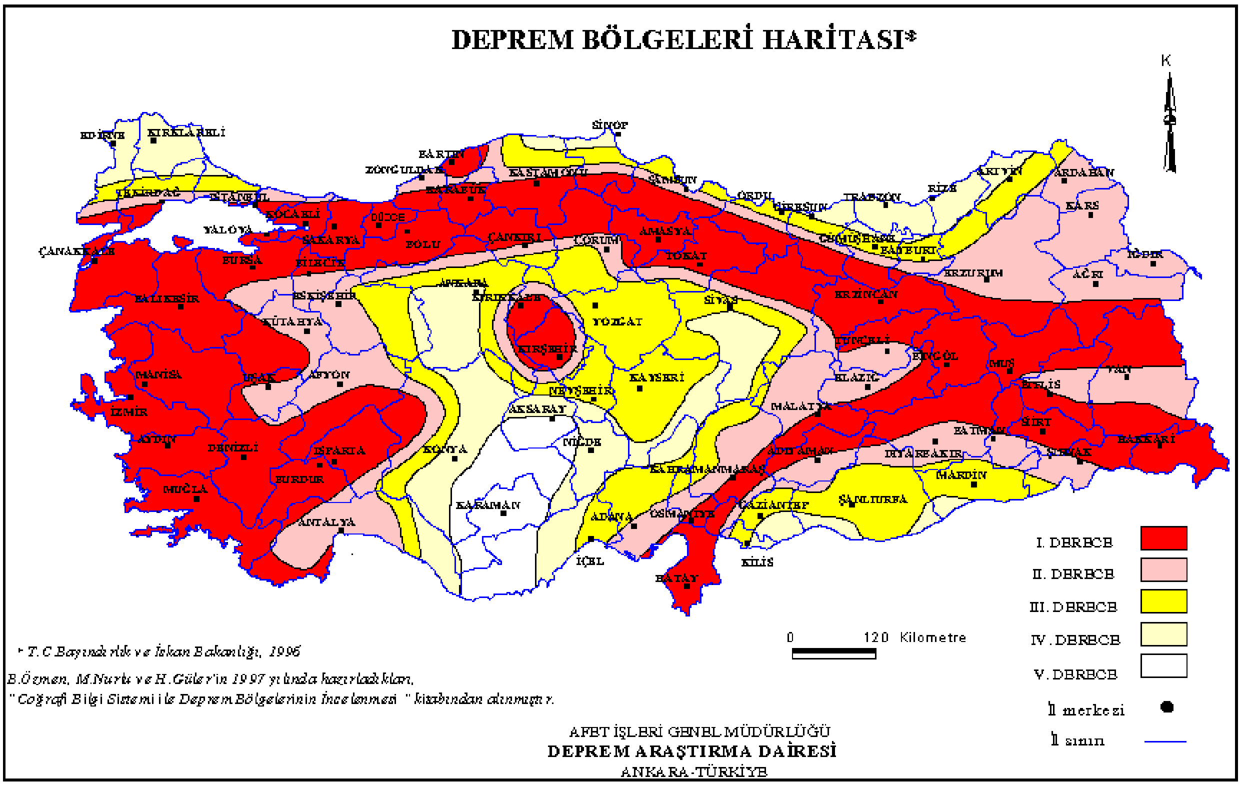
Sources

- International Institute of Seismology and Earthquake Engineering, http://iisee.kenken.go.jp

/net/seismic_design_code/index.htm.

- Dr. R. Zaharia, Personal Communications, Politehcnica Univ. of Timisoara, Romania.

5.20 **Turkey**



Seismic zonation is based on ground acceleration values with 10% probability of exceedance in 50 years, i.e., 475years mean return period. Five seismic zones (I, II, III, IV, V)) are defined, as shown in the Table below.

Peak Ground Acceleration for stiff soil

Seismic zone	**A_o**
I	0.40g
II	0.30g
III	0.20g
IV	0.10g
V	no seismic provisions

Sources

- Ministry of Public Works and Settlement, “Specification for Structures to be Built in Disaster Areas / PART III - EARTHQUAKE DISASTER PREVENTION”, Issued on: 2.9.1997, Official Gazette No.23098, Effective from: 1.1.1998, Amended on: 2.7.1998, Official Gazette No.23390.

6 CONCLUDING REMARKS

A review of the current situation regarding the seismic zonation in most of the EU and neighbouring countries with respect to seismic provisions in the respective building codes has been conducted. According to EN 1998, the seismic zonation will remain in the competence of the national authorities. However, for the widest acceptance of the Eurocodes, harmonization of procedures and/or parameter values is highly desirable, and this is the next objective for CEN/TC250 after the official launch of the Eurocodes. For the purposes of EN 1998, harmonization of the seismic zoning at European level should be addressed. Thus, at a first stage it is important to identify differences and similarities in the national codes in the definition of the seismic input.

As exposed in the previous Chapter, there are still a lot of differences, especially when the national seismic provisions are more than five years old [19]. Newer codes tend to comply closely with the recommendations of EN 1998. Clearly, the manner of seismic hazard depiction is gradually migrating from intensity to peak ground acceleration. Mainly constant value PGA zones are used but some PGA contour maps are also encountered. What is to be avoided are the still existing different seismic hazard zones on the two sides of a national border. Of course, this does not exclude that the same seismic design may finally be used for similar types of structures in the two sides of the border, since the design seismic action depends on several other parameters (form of response spectrum and especially the importance factor, Chapter 2), which are nationally defined and, appropriately chosen, can compensate for differences in the PGAs. However, such facts strike the eye of the observer, as it is not expected that measures of natural phenomena exhibit discontinuities at border lines.

It is to be stated that the main work on reviewing the national seismic maps was performed in 2006 and reflects the state-of-the-art at that time. It is possible that some of the Member States have in the meantime changed their maps and/or the related legislative framework.

Two essential elements towards homogenization and higher credibility in seismic hazard and zoning would be the adoption of the ground motion level corresponding to a 475-year mean return period, and its expression in terms of peak ground acceleration (not MSK intensity). Along with the ongoing national studies, a great aid in this direction can be provided by the results of the work conducted in the last ten years within three major project frameworks [20,21], which are:

- GSHAP (Global Seismic Hazard Assessment Program; 1992-1998),
- IGCP-382 project SESAME (International Geological Correlation Program - Seismotectonics and Seismic Hazard Assessment of the Mediterranean Basin; 1996-2000), and
- ESC WG-SHA (European Seismological Commission, Working Group on Seismic Hazard Assessment; 1996-2002).

Coordinated actions within these activities have allowed the development of a unified seismic hazard model for the european-mediterranean region. Seismogenic areas have been established according to tectonic, geophysical, geological and seismological data. This unified source model consists of 463 seismic sources, Fig. 6.1, each of which is characterized by the corresponding seismicity parameters: the minimum and maximum magnitude and the earthquake occurrence rates. Further, each source zone is supplemented with an associated sub-catalogue, which stems from the corresponding regional catalogue. The appropriate ground motion attenuation relationships [12-14], and a homogeneous hazard calculation procedure have been employed [22] in order to finally arrive at estimates of the seismic hazard in terms of PGA and spectral accelerations.

For the European-Mediterranean region, these estimates for the peak ground acceleration at a 10% probability of exceedance in 50 years for stiff soil conditions are shown in Fig. 6.2 This map has been published in 2003 under the auspices of the European Seismological Commission (ESC) in 5000 copies. Ground motion values for other mean return periods could also be readily established, and uniform response acceleration spectra (with a specified probability of exceedance in T_L years) can be determined, too. Such an example is shown in Fig.6.3 for the spectral acceleration at 0.3sec structural period.

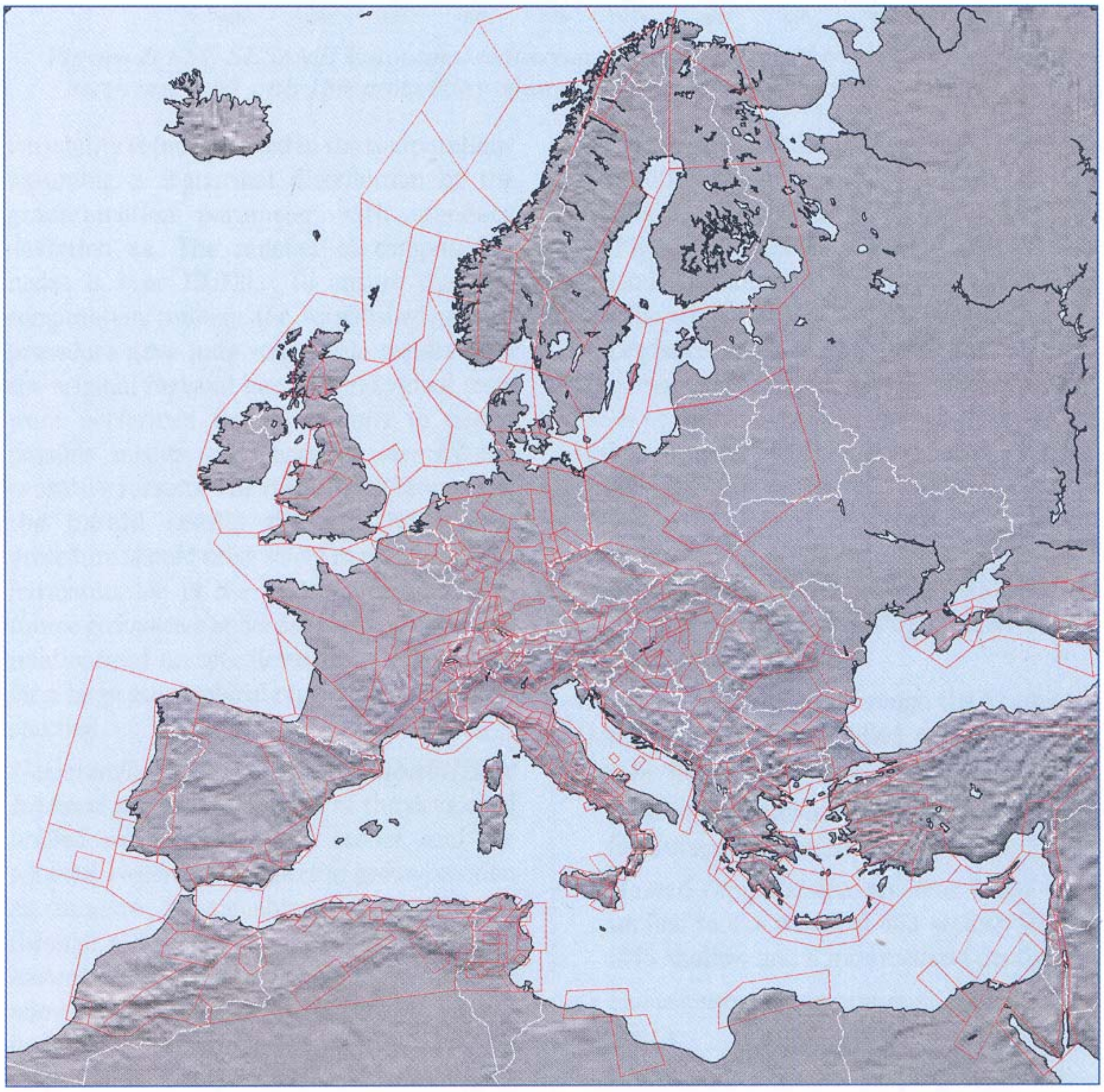


Figure 6.1. The unified source model with its 463 seismic sources *for the european-mediterranean region [20,21].*

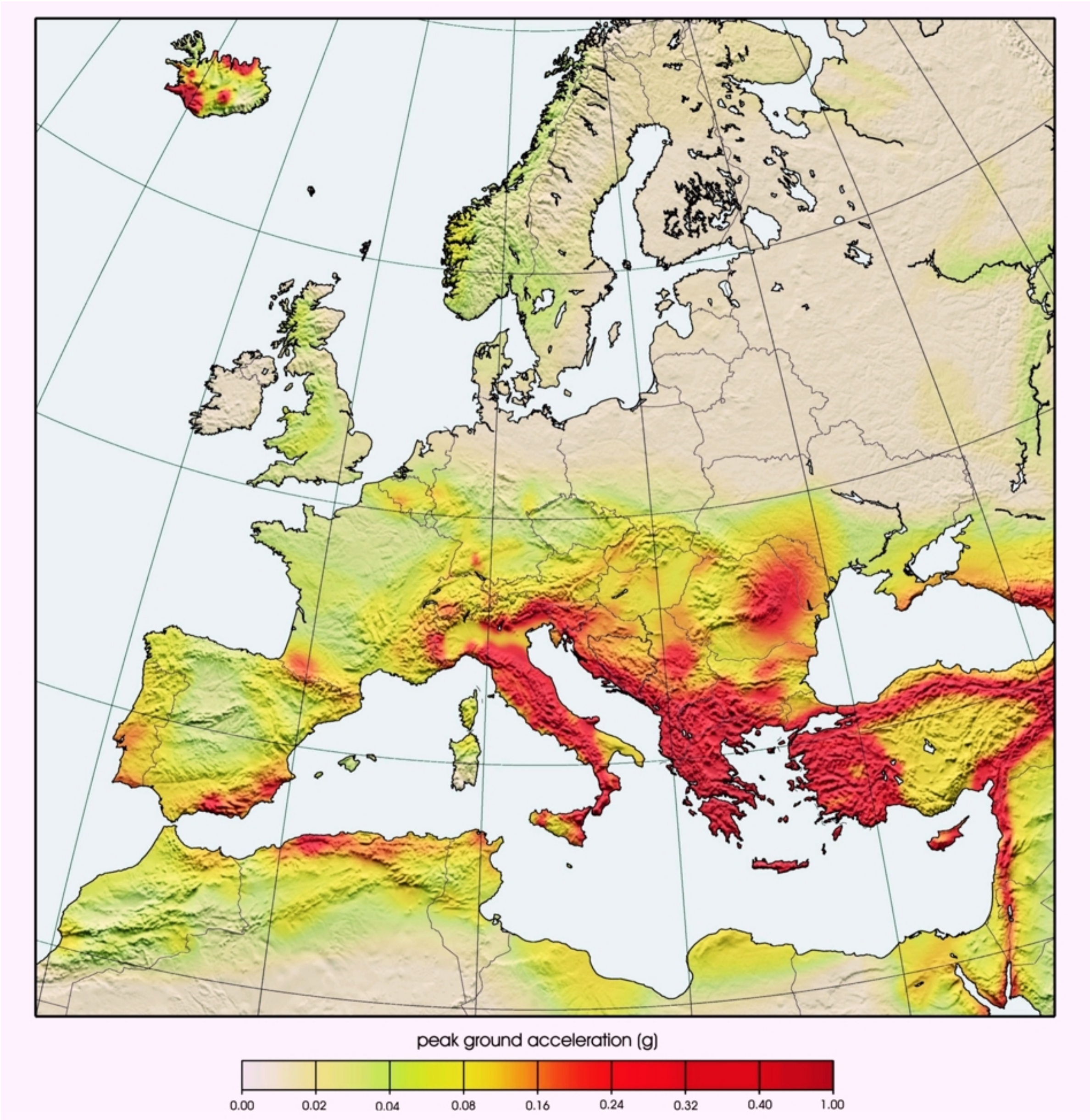


Figure 6.2. The ESC-SESAME European-Mediterranean seismic hazard map for the peak ground acceleration with 10% probability of exceedance in 50 years for stiff soil condition [20,21].

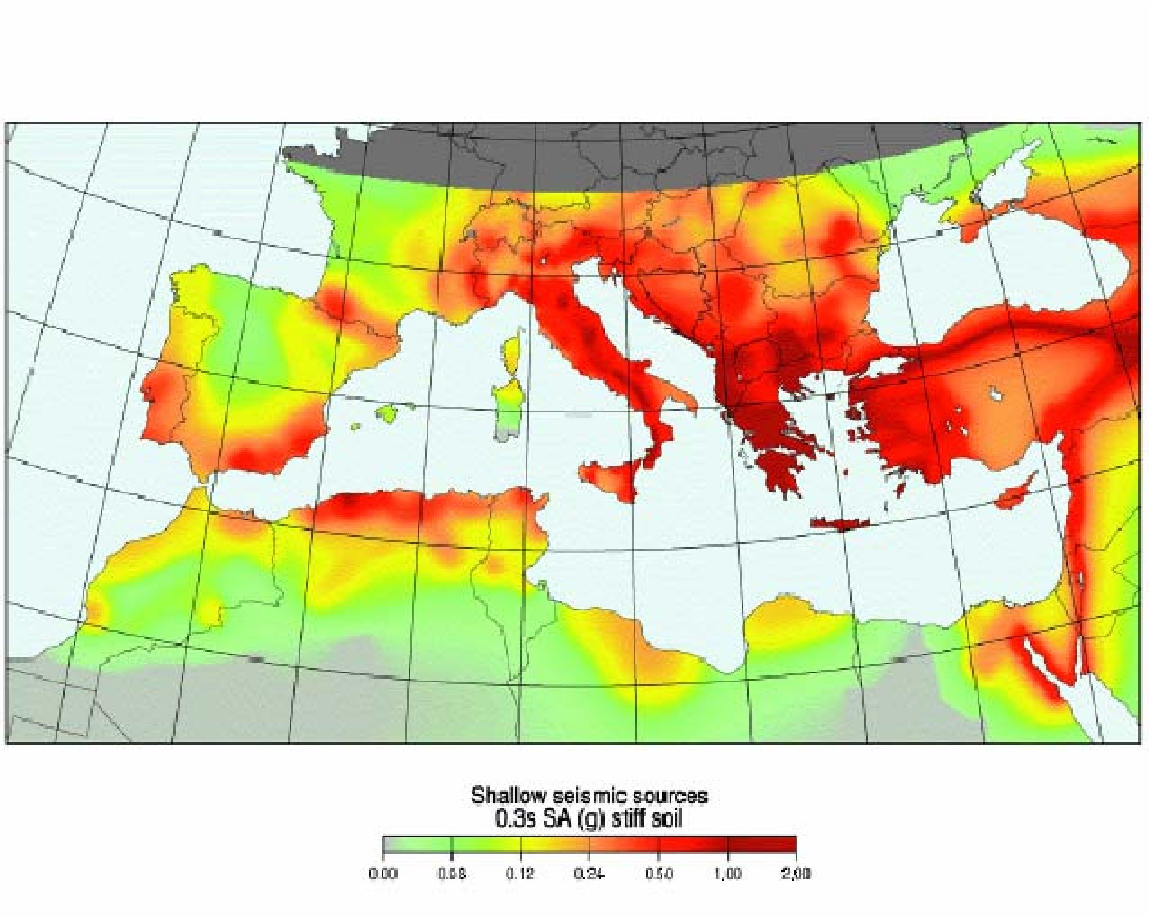


Figure 6.3. The ESC-SESAME European-Mediterranean seismic hazard map for the spectral acceleration at structural period of 0.3sec, with 10% probability of exceedance in 50 years for stiff soil conditions [20,21].

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Title: **A Review of the Seismic Hazard Zonation in National Building Codes in the Context of Eurocode 8**

Author(s):G. Solomos, A. Pinto, S. Dimova

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Abstract

The Eurocodes, accompanied by their National Annexes with the Nationally Determined Parameters (NDP), are envisaged to form the basis for structural design in the European Union. Convergence of the NDP values, where relevant, is a desirable objective, as this will lead to better harmonization. In this direction, for Eurocode 8 a review of the provisions regarding seismic zonation in the current National Seismic Codes has been undertaken. Differences in the way of presenting the seismic hazard (ground acceleration or intensity, constant value zones, contours, etc.) are identified, as well as cross-border inconsistencies. However, an overall tendency emerges towards progressively adhering to EC8 recommendations.

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