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Proposal for harmonized rules for the determination of seismic input data according to Eurocode 8

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ABSTRACT: A procedure for the determination of seismic input data according to Eurocode 8 is proposed and subsequently demonstrated by the example of the Federal Republic of Germany. Seismic intensity zones are established by considering a design seismic intensity, defined as seismic intensity for rock and firm soil sites. The peak ground acceleration, corresponding to a seismic zone, as well as the parameters of the normalized elastic response spectra are determined comparatively in two ways: by a statistical analysis of freefield response spectra and also by the analysis of synthetic spectra. In the determination of response spectra three underground classes - rock, medium and alluvium - are considered. In the analysis of the influences of the geological underground the thicknesses of layers are also taken into consideration. Strong motion durations and absolute ground displacements are deduced by seismic source and wave propagation simulations.

1 INTRODUCTION

In Eurocode 8 (EC 8) - Structures in Seismic Regions, Design (Commission of the European Communities 1989) a set of common rules is established as a basis for the design and construction of structures in seismic regions of the member countries of European Community. Seismic input data are not given in the code and shall be defined by the National Authorities. So the next step towards the harmonization of seismic design purposes is the establishment of harmonized rules for the determination of seismic input data, to be applied in each country by the respective authorities.

For a first approach to such a more extensive harmonization, the authors of this paper have been charged by the EC 8 Editing Panel to coordinate the elaboration of a study, containing proposals for harmonized rules for the determination of seismic input data, demonstrated by the example of Germany. A preliminary report on this study, drafted with the collaboration of D. Hosser (determination of seismic input data by statistical analysis of strong motion records), G. Schneider (seismic zones, determination of syntetic spectra, depending on seismotectonic and site conditions) and E. Keintzel (representation of seismic input data according to EC 8) is given in the Background Documents for EC 8 (Hosser et al. 1989). The recommendations of the final report (Hosser et al. 1991) are presented in the following.

2 SEISMIC ZONES

According to Eurocode 8 the seismic zonation of each country is made in such a way, that within each zone the peak ground acceleration in rock or firm soil, to be considered for design purpose, is constant. However, for practical purposes of seismic zonation, using informations on historical seismic events, it is useful to relate a nominal intensity to a given seismic zone, although this is not provided explicitly in EC 8. In this case, in order to be consistent with the provision of the peak ground acceleration in rock or firm soil as the only characteristic parameter of a seismic zone, this nominal intensity should be defined as intensity at sites on rock or firm soil. So it is a reference intensity, which will be in general lower than the maximum effective macroseismic intensity, stated in the respective zone at sites with unfavourable underground conditions.

Applying these considerations to German sites, two seismic zones may be established, represented in Fig. 1: zone 1 with the MSK reference intensity of 6 to 7 and zone 2 with the MSK reference intensity of 7 to 8. For sites with loose sediments in the

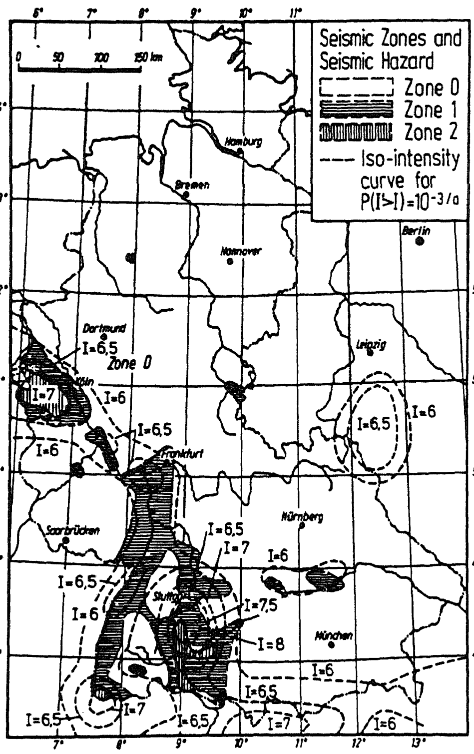


Figure 1. Proposed seismic zones and seismic hazard for the F.R. of Germany.

underground the site dependent macroseismic MSK intensity may be 7, respectively 8.

According to Eurocode 8, in addition to the seismic activity in the past and to general tectonic features of the region, also seismic hazard maps may be used for the establishment of a seismic zonation. However, even leaving out some theoretical problems in connection with a probabilistic description of the seismic activity, the use of seismic hazard maps for this purpose encounters a few practical problems, which must be resolved to a great extent by judgement:

- the choice of the annual probability of exceedance, admitted for the construction of the maps;
- the choice of an upper limit for the quantity - peak ground acceleration or intensity - represented in the map.

For illustration in Fig. 1 in addition to the proposed seismic zones, corresponding to the reference intensities I=6.5 and I=7.5, iso-intensity curves are represented, taken from a seismic hazard map proposed by Ahorner et al. 1986, and corresponding for the probability of exceedance of 10^{-3}/a to reference intensities from I=6 on. Generally a relative good agreement is stated. Some deviations of the seismic zone contours from the iso-intensity curves, especially in the region of Swabian Jura, are explained by the seismotectonic particularities of the region.

As reference intensities up to I=8 are calculated for the mentioned probability of exceedance, the extreme iso-intensity curve in Fig. 1 corresponds to this level. However, the consideration of a reference intensity I=8 would lead for unfavourable soil conditions to extrapolated design intensities, exceeding the maximum really observed intensity of I=8. For further considerations the scope of EC 8 may be remembered, that is the fact that this Eurocode is concerned with buildings and normal civil engineering structures. Special structures, associated with increased risks for the population, are outside of its scope. In this situation it is proposed to limit the characteristic parameter (in our case the reference intensity) for design purposes within the scope of EC 8 in such a way, that the really observed maximum value ist not exceeded. This means that, if the represented iso-intensity curves would be used for the establishment of a seismic zoning map, to be applied within the scope of EC 8, a limitation of the considered reference intensity to I=7.5 would have to be introduced and the iso-intensity curve for I=8 would have to be neglected.

3 NORMALIZED ELASTIC RESPONSE SPECTRA

In the mentioned study (Hosser et al. 1989 resp. Hosser et al. 1991) it is proposed to determine as well the peak ground acceleration a_g, corresponding to a seismic zone, as the parameters of the elastic response spectrum, normalized with respect to a_g, comparatively in two ways: by statistical analysis of freefield response spectra and by the analysis of synthetic spectra.

For the example of Germany the statistical analysis of freefield response spectra is performed according to Hosser et al. 1986, Hosser 1988 by considering strong motion records of earthquakes in the magnitude range of M_s=4.0-6.5 with hypocentral distances inferior to 60 km (zone 1) resp. to 40 km (zone 2). The synthetic spectra, used in the study, are derived according to Schneider et al. 1986, Kunze et al. 1988 by adopting in calculations focal parameters and site conditions typical for the two seismic zones. So for zone 1 magnitudes M_s=3.8-4.9 and for zone 2 magnitudes M_s=5.0-5.6 are considered, with focal depths h_0=5-15 km. As well in the statistical analysis of freefield response spectra, as in the determination of synthetic spectra by source and wave propagation calculations, three underground classes, defined by shear wave velocity and propagation quality caracteris-

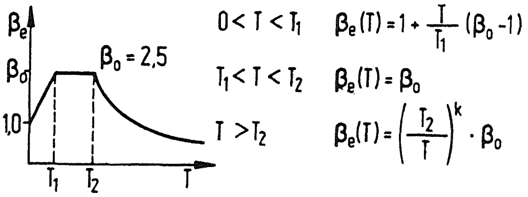


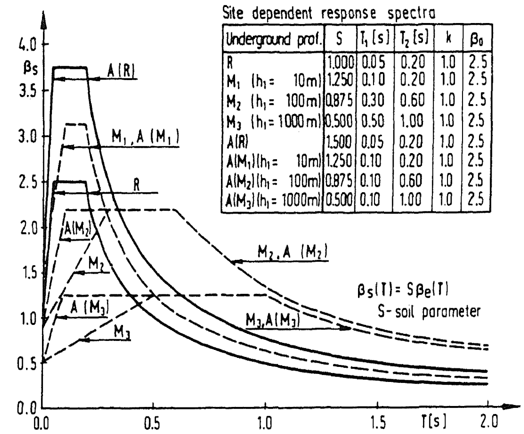
Figure 2. General shape of the elastic response spectrum in Eurocode 8, normalized with respect to the peak ground acceleration.

tics, are considered:class R, rock, class M, medium dense, coarse sediments, and class A, alluvium, loose, finely grained sediments.

In EC 8 the shape of the normalized elastic response spectrum, represented in Fig. 2, is defined by the amplification factor β_0, set in the study for a damping ratio of D = 0.05 to $\beta_0 = 2.5$, by the limits T_1 and T_2 of the maximum, constant acceleration branch and by the exponent k, met in the formula for the descending branch of the spectrum. The influence of the geological site conditions is introduced by the periods T_1, T_2 and by the soil parameter S, multiplying the spectrum as a whole. In the study the parameters T_1, T_2 and k are determined by both of the proposed approaches, but the influence of geological profiles with different layer thicknesses is evaluated by the synthetic spectrum approach.

In the investigation of the influence of geological profiles on synthetic spectra the following values of the shear wave velocity c_s, the density ρ and the propagation quality for shear waves Q_s are considered for the three underground classes:

- class R (rock), halfspace of cristalline rocks (R_C) with $c_s \cong 3300$m/s, $\rho \cong 2700$ kg/m³, Q_s=200 and layers of solid sediments (R_s) with $c_s \cong 2000$ m/s, ρ=2500 kg/m³, $Q_s \cong 50$.
- class M (medium), coarse, unconsilidated sediments with $c_s \cong 600$ m/s, $\rho \cong 2000$kg/m³, Q_s=20. As for this kind of underground the thickness of the layer is of major importance for the spectral parameters, three variants fo layer M - M_1, M_2, M_3 - with the thicknesses h_1=10 m, h_1=100 m and h_1=1000 m are considered.
- class A (alluvium), unconsolidated, loose surface layers with $c_s \cong 300$ m/s, $\rho \cong 1800$ kg/m³, Q_s=10. Corresponding to the situation in South-Western Germany, in the valleys of the Swabian Jura, this kind of layer is assumed with a thickness of about 10 m and covering stiffer layers of class R or M. Since not only the characteristics of the loose, uppermost layer, but also these of the underlaying geological structures influence the spectral parameters, the deeper layers are taken into account by considering underground profiles A(R) and A(M), that is underground profiles consisting of layers of type A, covering layers of type R or M. In case of the underground profile A (M) the influence of the thickness of the layer M is also taken into account.



Underground prof.	S	T_1 [s]	T_2 [s]	k	β_0
R	1.000	0.05	0.20	1.0	2.5
M_1 (h_1 = 10m)	1.250	0.10	0.20	1.0	2.5
M_2 (h_1 = 100m)	0.875	0.30	0.60	1.0	2.5
M_3 (h_1 = 1000m)	0.500	0.50	1.00	1.0	2.5
A(R)	1.500	0.05	0.20	1.0	2.5
A(M_1)(h_1 = 10m)	1.250	0.10	0.20	1.0	2.5
A(M_2)(h_1 = 100m)	0.875	0.10	0.60	1.0	2.5
A(M_3)(h_1 = 1000m)	0.500	0.10	1.00	1.0	2.5

Figure 3. Normalized site dependent elastic response spectra

In Fig. 3 normalized site dependent elastic response spectra are represented, proposed as a common conclusion of the investigations performed comparatively by statistical analysis of freefield spectra and by source and wave propagation considerations. Attention is called to the curves $M_{1,2,3}$ resp. A ($M_{1,2,3}$), showing the influence of the layer thickness in the case of unconsolidated sediments. Three kinds of effects may be distinguished:

- the shifting of the maximum spectral values towards higher periods and the enlargement of the plateau with increasing thickness,
- the amplification effect for certain frequency intervals,
- the absorption effect.

It is observed that for thin layers of unconsolidated sediments - profile A(R), M_1 or A(M_1) - the amplification effect is prevailing, whereas for thick layers - profile M_3 or A(M_3) - the absorbtion effect is prevailing. So as a conclusion it is proposed to provide in EC 8 for thick layers of unconsolidated sediments a soil parameter S=0.8-0.9, as done in several codes, but for thin layers values up to S = 1.5. Similar proposals are given in Mohraz et al. 1989, Fig. 2.47.

In Fig. 4 interpolation functions are presented for the evaluation of the limit periods T_1, T_2 and of the soil parameter S for different thicknesses of layers class M. It is evident that for seismic zones with characteristic earthquakes of higher magnitudes

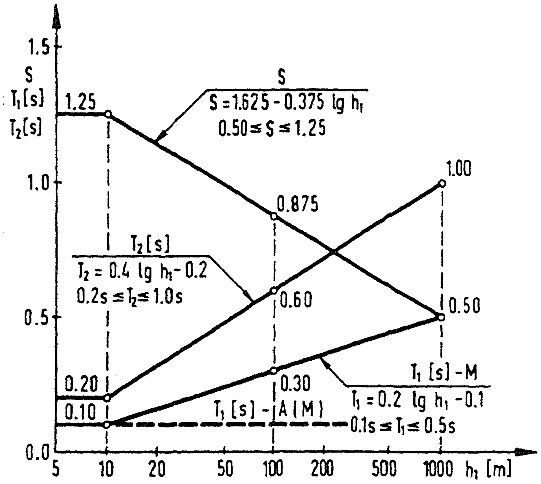


Figure 4. Interpolation functions for the parameters S, T_1 and T_2, underground class M and A(M).

and/or higher focal distances, higher periods T_2 will be obtained.

In order to determine a value of the exponent k, leading to realistic spectral values on the descending branch, this exponent is proposed to be evaluated from the condition that the spectral curve passes through two points with the abscissas T_2 and $T > T_2$, where T may be chosen arbitrarily, as shown in Fig. 5. Applying this condition to the mean value curves as well of the considered freefield spectra as of the synthetic spectra for T=1.0 s, respectively, for underground profile M_3 for T=1.5 s, values between k=0.8 and k=1.3 are obtained. The standard value k=1 is proposed.

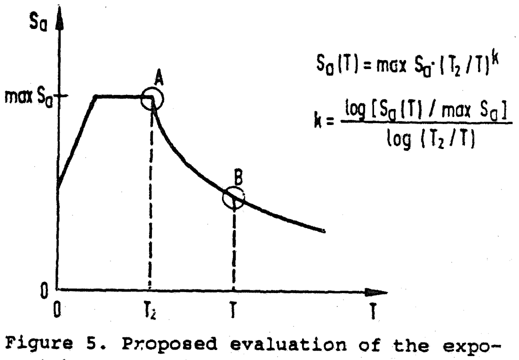


Figure 5. Proposed evaluation of the exponent k.

4 PEAK GROUND ACCELERATIONS

Elastic design spectra are obtained by multiplying the normalized elastic response spectra, defined in chapter 3, by the peak ground acceleration a_g. As mentioned, it is proposed to determine design values of the peak ground acceleration comparatively by statistical analysis of freefield response spectra and by the analysis of synthetic spectra. In the following the derivation of design values a_g by the former approach is presented.

Statistical response spectra - mean values and, with dashed lines, mean values plus or minus one standard deviation - are represented in Fig. 6 for zone 2, underground class R, and in Fig. 7 for zone 2, underground class M. By smoothing the mean value curve, a proposed elastic design spectrum curve is obtained. It is considered that the chosen confidence level - mean values, thus probability of non-exceedance of only 50% - is adequate within the scope of EC 8, that is for the design of buildings and normal civil engineering structures. Conforming to the same philosophy, in a study concerning seismic input data for the design of special structures associated with increased risks for the population, such as nuclear power plants (Hosser et. al. 1983), spectral values with a probability of non-exceedance of

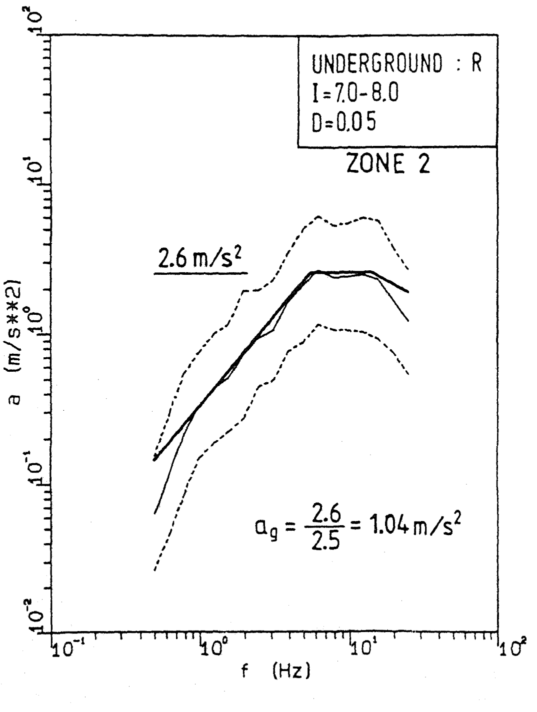


Figure 6. Statistical freefield acceleration response spectrum for zone 2, underground class R.

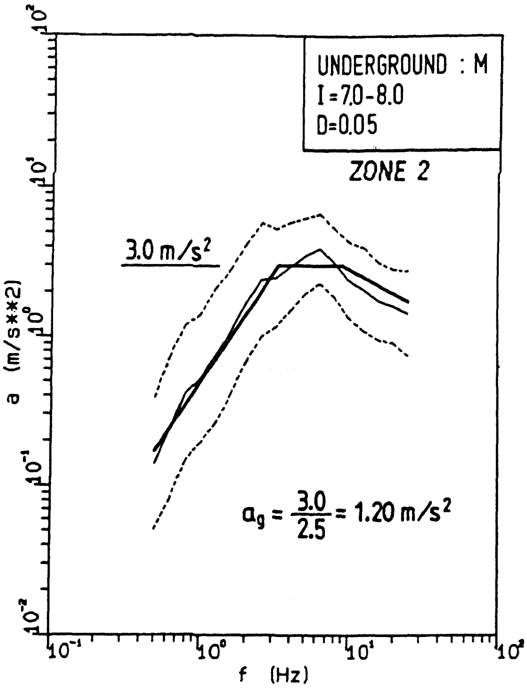


Figure 7. Statistical freefield acceleration response spectrum for zone 2, underground class M.

84% have been deduced. It is considered that in this way a rational correspondence between confidence level and scope is established.

It is remembered that for design purposes the peak ground acceleration is not a quantity important in itself; it is rather an intermediary value, used in the determination of spectral ordinates. Therefore it is appropriate to determine it as a design value, deduced from the smoothed design spectrum curve. So in the study a conventional design peak acceleration is determined by deviding the plateau value of the smoothed design spectrum by the conventional amplification factor β_0=2.5, as shown in Figs. 6 and 7. If the underground class M is interpreted as firm soil, a_g=1.20 m/s² is obtained in this way for zone 2; if the underground class R is considered, a_g=1.04 m/s² is found. Comparative investigations, using synthetic spectra and considering likewise β_0=2.5, lead for zone 2 to a_g=0.80 m/s². Finally on the basis of all the investigations on this subject, performed in the study, the *design values a_g=0.5 m/s² for zone 1 and* a_g=1,0 m/s² for zone 2 are proposed.

5 STRONG MOTION DURATIONS AND ABSOLUTE GROUND DISPLACEMENTS

The seismic input data, assigned in EC 8, include also strong motion durations t_0 and absolute ground displacements d, needed for the generation of artificial accelerograms, respectively for the calibration of design response spectra in the long period range.

For German sites, where only earthquakes with very short focal distances are of practical interest, the strong motion duration is nearly identical with the duration of the focal process, that is with the focal length, divided by the average fracture velocity in the fault surface. Considering for the largest events of zone 2 a focal length of about 6 km and assuming average focal fracture velocities of 2-3 km/s, the maximum strong motion duration reaches values of about t_0 = 3s. For zone 1 the value t_0=1,5 s is deduced.

In EC 8 absolute ground displacements are expressed by the relation d = α d_0, where α represents the ratio between the peak ground acceleration and the acceleration of gravity. For the evaluation of strong motion displacements the displacement-time function at the earths surface is determined, by analysing the propagation of a source signal, corresponding to the considered magnitude level, through a layered medium. In this way the values d_0=20 cm for the underground profiles R_C and $A(R_C)$ and d_0=40 cm for all other profiles are deduced. Due to the increase of displacements with magnitudes, much more accentuated than that of accelerations, for seismic zones with higher characteristic magnitudes, higher values d_0 will be obtained.

6 CONCLUSIONS

Evaluating in the study seismic input data for the application of Eurocode 8 in the seismic regions of the F.R. of Germany, an attempt is made to base their determination on rational principles, which may be applied also in other countries and which may lead to harmonized rules in the member states of the European Community. The most important of these principles may be listed as follows:

- definition of the seismic zones on the basis of reference intensities;
- determination of underground- and intensity dependent spectrum parameters by statistical analysis of freefield response spectra;
- comparative determination of the abovementioned spectrum parameters by the analysis of synthetic spectra;
- introduction of spectrum parameters which depend not only on the physical parameters, but also on the thickness of layers;

- determination of the peak ground acceleration as a conventional design value, derived from the plateau value of a design spectrum;
- determination of the strong motion duration and of the maximum ground displacement by seismic source and wave propagation considerations.

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