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RELIABILITY OF EUROCODE 8 SPECTRA AND THE PROBLEMS OF THEIR APPLICATION TO CENTRAL EUROPEAN EARTHQUAKE REGIONS

Corina SCHOTT[1] and Jochen SCHWARZ[2]

SUMMARY

This paper will examine the recommended spectrum shapes and spectrum describing parameters of the final version of Eurocode 8 [1]. The re-evaluated basic norm spectra are compared with results of statistical investigations of strong motion data for three different subsoil classes: rock, stiff soil and soft soil. A limited distance of less than 20 km and magnitude ranges staggered in half-magnitude units from M_s = 4.2 to 6.2 will be employed, thus meeting the relevant parameters of Central European design events. A new set of spectrum describing parameters will be derived, supporting the use of two different soil factors for the plateau and zero-period range. An additional aspect of this study is the description of qualitative differences to the concept of geological and subsoil dependent spectra prepared for the new draft of the German earthquake code DIN 4149 [2].

INTRODUCTION

In the currently revised version of Eurocode 8 [1], design spectra based on two different types of seismic action are specified (type 1 for regions with higher and type 2 for regions with lower seismicity), and a new subsoil classification scheme. Consequently, design spectra of type 2 are applicable for Central European earthquake regions. Compared to type 1 spectra for soft soil sites in particular, high soil factors *S* are defined that result in high amplifications, but in a narrow range of constant spectral acceleration (see Table 1). It must be stressed that most types of residential buildings will be affected by this tremendous increase of seismic design level.

The proposed spectra are based on studies of different research groups that use a selected set of European strong motion data. The normalization and smoothing techniques applied to the statistically developed mean spectra do not follow a standardized procedure and are also not proved. Thus, harmonized principles for transferring results of statistical approaches to design parameters, whose emphasis is on the determination of suitable spectrum shapes and soil factors, must be investigated. This, then, is what this paper

[1] Research Assistant at Earthquake Damage Analysis Center, Bauhaus-University Weimar, Germany, Email: corina.schott@bauing.uni-weimar.de
[2] Head of Earthquake Damage Analysis Center, Bauhaus-University Weimar, Germany,
Email: jochen.schwarz@bauing.uni-weimar.de

attempts to prove, considering all the while the seismic action type for low seismicity regions in more detail.

DESIGN SPECTRA ACCORDING TO EUROCODE 8

Background of seismicity conditions

Two different types of spectrum shapes (type 1 and type 2) are considered for varying seismicity conditions. In this regard, provisions of Eurocode 8 [1] state: *"If the earthquakes that contribute most to the seismic hazard defined for the site for the purpose of probabilistic hazard assessment has a surface wave magnitude, M_s, not greater than 5,5, it is recommended that the Type 2 spectrum is adopted. "*

No worst case scenario should be taken into account: *"In selecting the appropriate shape of the spectrum, consideration should be given to the magnitude of earthquakes that contribute most to the seismic hazard defined for the purpose of probabilistic a hazard assessment rather than on conservative upper limits (e.g. maximum credible earthquake) defined for that purpose."* In the former, revised version of EC 8, the threshold of surface wave magnitude between type 1 and type 2 spectra was specified as M_s = 6.0.

Subsoil classification

As shown in Table 1, five different subsoil classes (A-E) are defined. The main distinguishing feature is the average shear wave velocity $V_{s,30}$ that exists in the uppermost 30 meters of the subsoil layers. If $V_{s,30}$ is not available, the Standard Penetration Test blow-count N_{SPT} should be used for site classification. The value c_u describes the shear strength of the soil that has not been drained.

Especially ambiguous and critical subsoil conditions that require separate measurements of site examinations are considered by classes S_1 and S_2. These are soils which produce both irregular amplifications of ground motions and soil-structure interaction, and also require special foundations due to their liquefaction potential.

Horizontal elastic response spectra

Using equations (1) to (4) and the parameters of Table 2, elastic design spectra for different seismicity conditions and subsoil classes can be created (Figure 1). Parameter a_g describes the design ground acceleration, S is the soil factor, and η represents the damping correction factor. The range between corner periods T_B and T_C constitutes the branch of constant spectral acceleration, whereas periods T_C and T_D are the limits of the constant spectral velocity branch. In addition, constant spectral displacement starts at control period T_D.

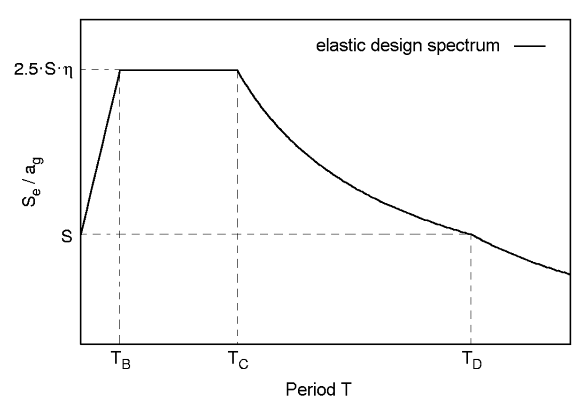


Figure 1. Description of elastic design spectrum as proposed by EC 8 [1]

Table 1. Definition of subsoil classes according to EC 8 [1]

Subsoil	Description of stratigraphic profile	Parameters		
		$V_{s,30}$ [m/s]	N_{SPT} (blows/30cm)	c_u [kPa]
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface	> 800	-	-
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of meters in thickness and characterized by a gradual increase of mechanical properties with depth	360 - 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel, or stiff clay with thicknesses from several tens to many hundreds of meters	180 - 360	15 - 50	70 - 250
D	Deposits of loose-to-medium noncohesive soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil	< 180	< 15	< 70
E	Soil profile consisting of a surface alluvium layer with $V_{s,30}$ values of type C or D, and thicknesses varying between 5 m and 20 m, underlain by stiffer materials with $V_{s,30}$ > 800 m/s			
S_1	Deposits consisting or containing a layer at least 10 m thick of soft clays/silts with high plasticity index (PI > 40) and high water content	< 100	-	10 -20
S_2	Deposits of liquefiable soils, sensitive clays, or any other soil profile not included in types A-E or S_1			

Table 2. Equations for elastic design spectra according to EC8 [1]

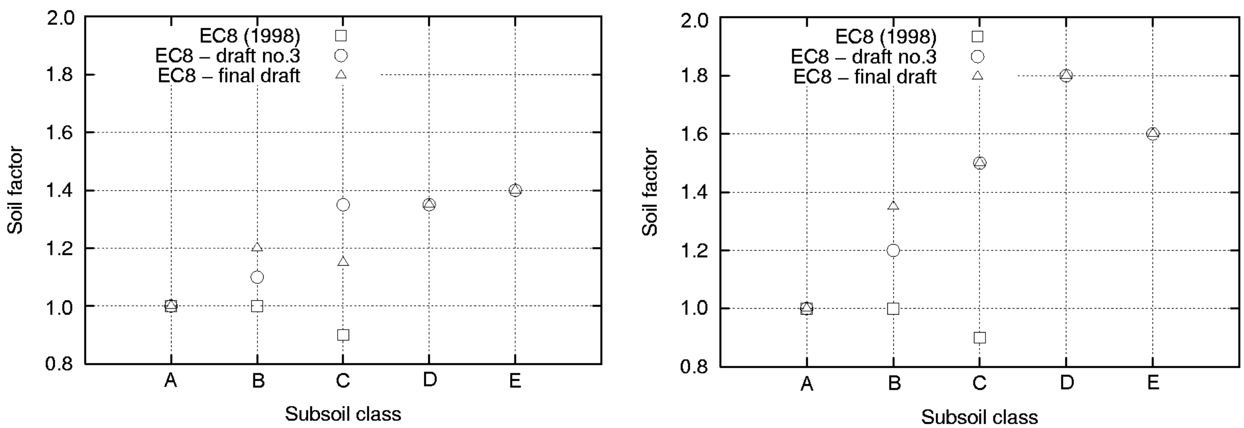
Period range	Equation	Equation
$0s \leq T \leq T_B$	$S_e(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 2.5 - 1)\right]$	(1)
$T_B \leq T \leq T_C$	$S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5$	2)
$T_C \leq T \leq T_D$	$S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \cdot \left[\frac{T_C}{T}\right]$	(3)
$T_D \leq T \leq 4s$	$S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \cdot \left[\frac{T_C \cdot T_D}{T^2}\right]$	(4)

Table 3. Parameters of elastic design spectra for different subsoil classes [1]

Subsoil	$V_{s,30}$ [m/s]	Soil factor S		Period T_B [s]		Period T_C [s]		Period T_D [s]	
		Type 1	Type 2	Type 1	Type 2	Type 1	Type 2	Type 1	Type 2
A	> 800	1.0	1.0	0.15	0.05	0.4	0.25	2.0	1.2
B	360-800	1.2	1.35	0.15	0.05	0.5	0.25	2.0	1.2
C	180-360	1.15	1.5	0.20	0.10	0.6	0.25	2.0	1.2
D	< 180	1.35	1.8	0.20	0.10	0.8	0.30	2.0	1.2
E		1.4	1.6	0.15	0.05	0.5	0.25	2.0	1.2

Development of soil factors in drafts of EC 8

It is common knowledge that soil factor *S* represents the ground motion amplification due to the presence of (soft) subsoil layers in relation to geological bedrock (half-space). Hence, soil factor *S* for subsoil class A (see Table 3) is fixed to 1.0. In the course of time the soil factor for subsoil conditions with $V_{s,30}$ < 800 m/s has considerably changed. For class C, the factor was even lower than for class A in the former version of EC8 [3]. During the investigations of the newly revised EC8 version, the soil factor was modified mainly for subsoil classes B and C.



a) Type 1 **b)** Type 2

Figure 2. Development of soil factors in the different drafts of EC8

EVALUATION OF STRONG MOTION DATA

Investigation of earthquake data used in [4]

In dependence on surface wave magnitude M_s, and epicentral distance R_{epi}, the distribution of empirical data used to determine the control periods of EC8 [4] is shown in Figure 3. Furthermore, the threshold of magnitude M_s is given for the two seismicity conditions.

It becomes clear from Figure 3 that the threshold value demarcating type 1 and type 2 spectra was defined as M_s = 6.0 in [4]. Regardless of this, recordings used for seismicity condition type 1 and type 2 are selected respectively above and below the threshold of magnitude.

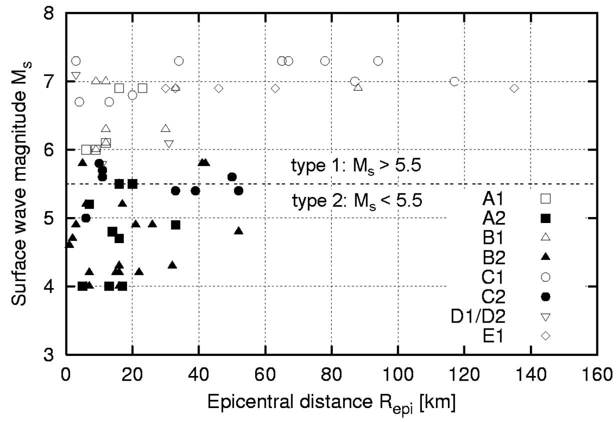


Figure 3. Magnitude-epicentral distance relationship of evaluated strong motion database

An overview of the selected earthquakes, their regions, and the number of strong motion records that are used for the evaluation is given in Table 4. Off all the strong motion records used here, only three were unavailable. Since the availability of only three earthquake records used for statistical investigation of control periods for classes D1 and D2 was constricted, reliability of derived results may not be given.

Plausibility check of strong motion data

The time histories and critically damped ($\xi = 5$ %) response spectra of the strong motion data listed above were examined with the following criteria to determine their plausibility: shear wave velocity (subsoil conditions, frequency content, nonlinear effects of the subsoil, magnitude and distance conditions, capability of amplification.

Problems with strong motion data that repeatedly occur are caused by nonlinear effects within the time histories and by missing information on the pre-event time segments.

Examples illustrating these effects are given in Figures 4 and 5. It can clearly be seen that waveform no. 0055 possesses a much higher value of peak ground acceleration and a higher amplification than all other recordings of class A, type 2. Aside from this, the time history of Figure 5 shows an unusually long-period content for a rock station.

STATISTICAL INVESTIGATIONS OF EMPIRICAL DATA

Assessment of proposed spectrum shape with empirical data

A total of four different statistical approaches for deriving the proposed spectrum shape by empirical data are described below. Irrespective of the method used for the single time histories, response spectra for a damping of 5% were calculated. The above mentioned strong motion data used to derive the spectrum shape in [4] will be denoted as “empirical data” for the rest of the paper.

Method 1: envelope of horizontal components H_{env}

The first approach is taken over by the procedure applied in [4]. “ *For each record the envelope of the 5% damped horizontal acceleration spectra is determined and normalized to the larger value of PGA. The average of each set of spectra is then determined and compared with the proposed spectral shape for the corresponding subsoil class.”*

Table 4. Evaluated strong motion data

Subsoil class Spectrum type	(No. of earthquakes) name [region]1)	Subsoil class Spectrum type	(No. of earthquakes) name [region]
A1 (5)	(3) aftershock Friuly [It] (2) Campano Lucano [It]	A2 (9)	(2) Friuly [It] (7) aftershock Friuly [It]
B1 (8)	(2) Campano Lucano [It] (2) aftershock Friuly [It] (2) Montenegro [Yu] (2) aftersh. Montenegro [Yu]	B2 (24)	(1) Friuly [It] (9) aftershock Friuly [It] (1) Montenegro [Yu] (8) aftersh. Montenegro [Yu] (4) Kalamata [Gr] (1) Plati [Gr]
C1 (11)	(3) Tabas [Ir] (2) Alkion [Gr] (2) Ionian [Gr] (1) Spitak [Ar] *(3) Manjil [Ir]*	C2 (10)	(1) Ionian [Gr] (1) Dursunbey [Tr] (1) Urmiya [Ir] (1) Umbria [It] *(4) Lazio Abruzzo [It]* (1) Killini [Gr] (1) aftershock Spitak [Ar]
D1 / D2 (3)	(1) Gazli [Uz] (1) Basso Tirreno [It] *(1)* 2)	E1 (5)	(5) Campano Lucano [It]

1) It = Italy; Yu = Yugoslavia; Gr = Greece; Tr = Turkey; Ir = Iran; Ar = Armenia; Uz = Uzbekistan

2) *data for this earthquake are not included in ESMD 2000 [5]*

Note: records which were not available are italicized

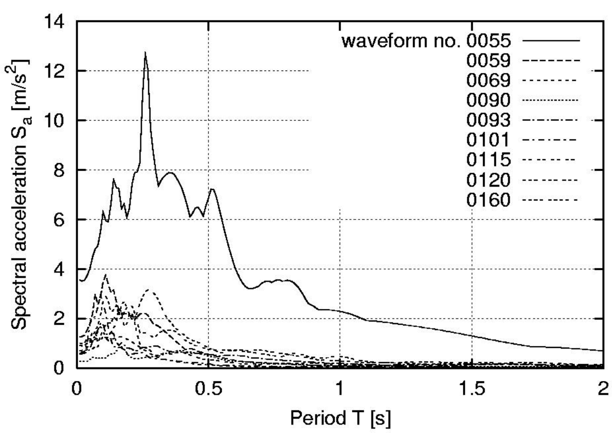


Figure 4. Unscaled response spectra for subsoil class A, spectrum type 2

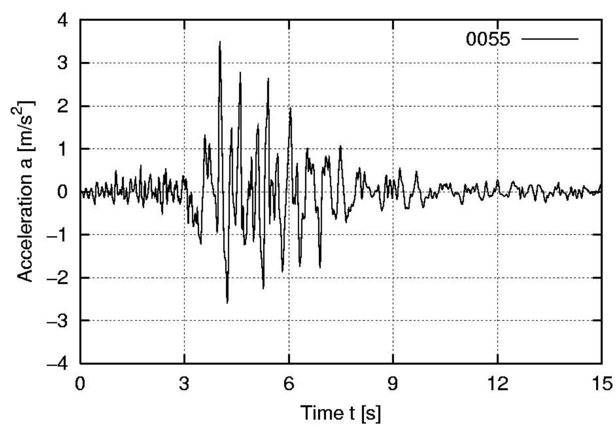


Figure 5. Time history (waveform no. 0055) with long-period contents

Method 2: horizontal components H_1+H_2

For this statistical investigation, the response spectra for both horizontal components H_1 and H_2 are normalized to PGA = 1.0 m/s² and used to calculate both the mean and the median spectra for each subsoil class.

Method 3: horizontal component H_1

Only the horizontal component having the larger value of PGA (H_1) is normalized to PGA = 1.0 m/s² and used to calculate both the mean and the median spectra for each subsoil class.

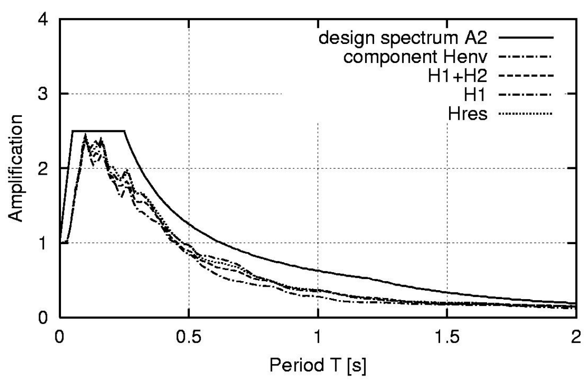
Method 4: horizontal component H_{res}

Here a horizontal resultant response spectrum is calculated according to Equation 5. The SRSS method is applied to superimpose both horizontal components H_1 and H_2. Finally, these response spectra are also normalized to PGA = 1.0 m/s² and used to calculate both the mean and the median spectra for each subsoil class.

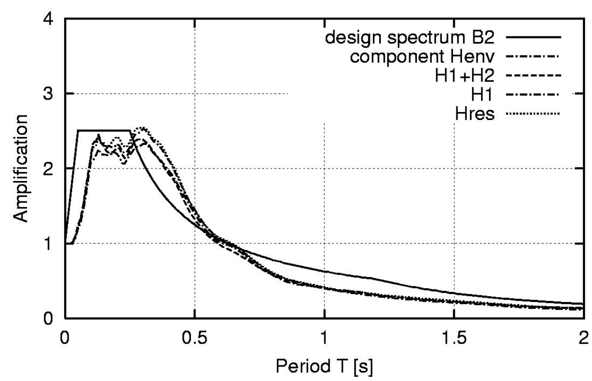
$$S_{a,Hres}(T) = \max_t \sqrt{S^2_{a,H1}(T,t) + S^2_{a,H2}(T,t)} \tag{5}$$

Mean spectra of empirical data

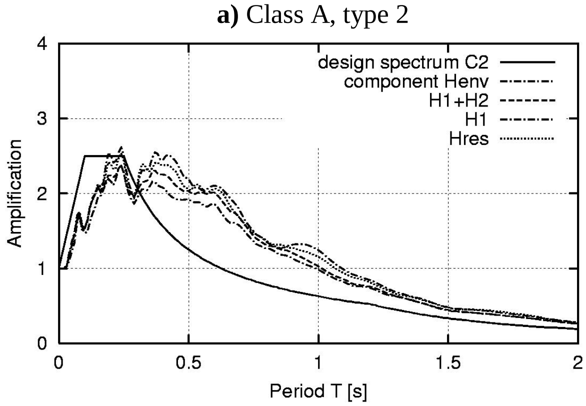
The empirical strong motion data of each subsoil class and spectrum type, as used in [4] to describe the shape including the control periods of the recommended design spectra, were analyzed with respect to the techniques mentioned above. Figure 6 shows the mean response spectra in comparison to the proposed design spectra for seismicity condition type 2. It can be seen that determining control periods does not depend on the type of method used. Only small deviations occur between the four different methods.



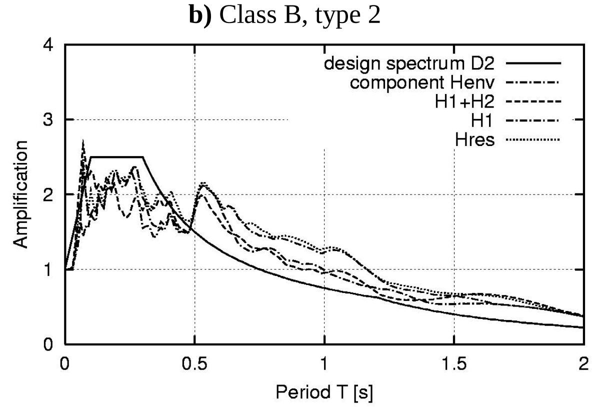
a) Class A, type 2



b) Class B, type 2



c) Class C, type 2



d) Class D, type 2

Figure 6. Mean response spectra determined by different methods

Compared with the other classes, mean spectra of class D2 show variations in terms of a smoothed progression. This is certainly the consequence of only three evaluated earthquake recordings. Nevertheless, a constant value of 2.5 for the amplification of peak ground acceleration seems to be suitable.

Strong motion duration

To calculate the strong motion duration, Equation 6 was applied to the H_1 component of each earthquake recording, where $E(t)$ is the energy-integral, and t_1 is the entire duration of the time history. The beginning of strong motion duration is defined as t_A (5%). Two different investigations are applied to assess the end of strong motion duration t_E (75%) and t_E (90%). The results of the energy-integral are listed in Table 5.

$$E(t) = \int_0^t a^2(t)dt \Big/ \int_0^{t_1} a^2(t)dt \qquad (6)$$

Table 5. Strong motion duration $t_{s,75}$ and $t_{s,90}$

Subsoil class	Strong motion duration t_s ± Standard deviation σ			
	$t_{s,75}$ [s] ± σ		$t_{s,90}$ [s] ± σ	
	Type 1	Type 2	Type 1	Type 2
A	5.95 ± 5.67	1.22 ± 0.76	12.23 ± 13.56	2.78 ± 1.66
B	6.17 ± 4.92	1.83 ± 1.02	11.70 ± 10.04	3.30 ± 1.73
C	10.12 ± 5.84	4.40 ± 2.84	14.98 ± 5.22	7.57 ± 4.12
D	4.24 ± 0.95	4.24 ± 0.95	5.87 ± 0.49	5.87 ± 0.49
E	24.20 ± 14.84		30.05 ± 15.52	

Artificially generated accelerograms, which can be used for design purposes, should comply with the given design spectra of EC8. The final draft of EC8 also indicates that the duration should be consistent with magnitude and important features of the proper seismic event. If no detailed information is available, a minimum duration of 10 seconds should be used. The analysis in Table 5 indicates a rather big difference in strong motion duration for type 1 and type 2 spectra. It is recommended that the strong motion duration in dependence on the seismicity conditions be considered as well.

CONTROL PERIODS OF PROPOSED DESIGN SPECTRA

Validity of existing control periods

Except for subsoil class A, the recommended control periods T_C (right margin of constant spectral acceleration range) for subsoil classes B, C, and D do not cover the empirical response spectra shape (Figure 6). The values of control periods T_B (left margin of constant spectral acceleration range) can be slightly shifted to longer periods.

Formulation of modified control periods

Because of the deficiencies mentioned above, the formulation of modified control periods is necessary. Figure 7 shows the existing periods T_B and T_C (filled marks) compared with the suggested ones (blank marks) for all subsoil classes and spectrum type 2. No data was evaluated for subsoil class E and spectrum type 2 within the scope of [4]. For classes B, C, and D, values of corner period T_C increasingly changed. In contrast, corner period T_B has increased and only changed for classes B and D.

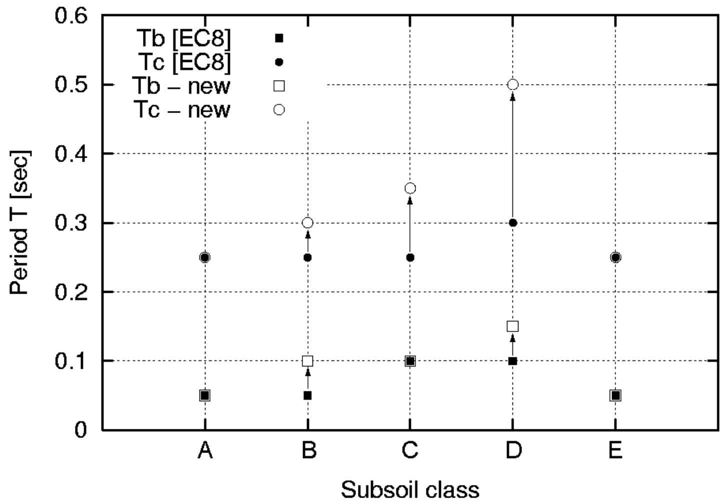


Figure 7. Variations of control periods T_B and T_C for spectrum type 2

Evaluation of periods with statistical investigations of the European Strong Motion Database (ESMD 2000)

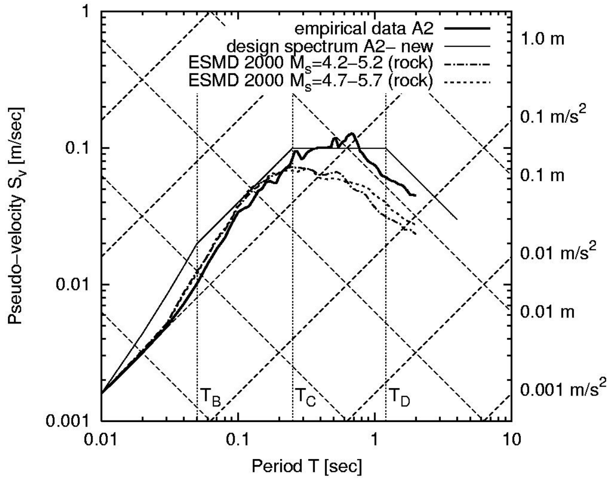
A triply-logarithmic diagram is used to compare the newly proposed spectrum shapes with mean response spectra of empirical data (component H_1+H_2) and statistical investigations of European Strong Motion Database (ESMD 2000) [5].

In [6] and [7], data was selected according to magnitude and distance ranges compatible for German earthquake regions. As a result, data groups for an epicentral distance $R_{epi} \leq 20$ km were assembled from ESMD 2000 [5] in conjunction with the following:

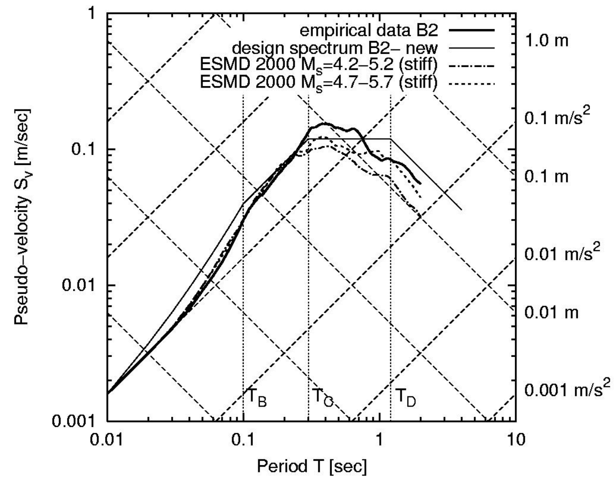
a) $3.7 \leq M_s \leq 4.7$
b) $4.2 \leq Ms \leq 5.2$
c) $4.7 \leq Ms \leq 5.7$
d) $6.2 \leq Ms \leq 6.2$

The subsoil conditions are limited to rock, stiff soil, and soft soil. Only strong motion recordings of free field stations were included in the extensive statistical investigations. The mean response spectra of data groups (b) and (c) are displayed for three different subsoil classes in this paper, since the input parameters are applicable for comparison with EC8 type 2 spectra.

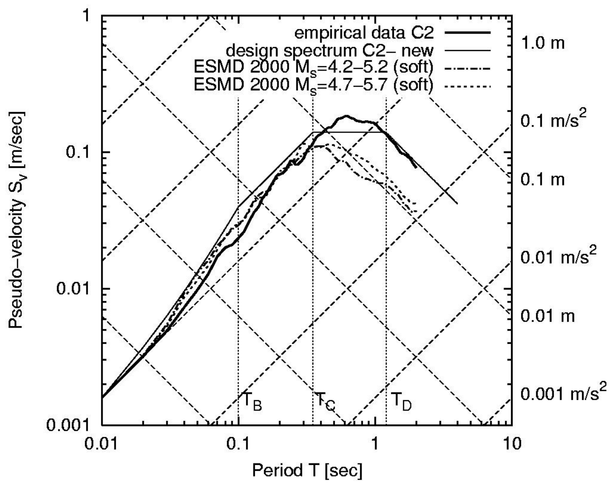
The evaluation of various ESMD 2000 data sets shows smoothed mean spectra of higher quality than investigations of empirical data from [4] do. The position of control periods can be assessed with certainty. Figure 8 contains the newly defined shape of design spectra compared with mean response spectra of empirical data and analyses of ESMD 2000 in dependence on the subsoil class.



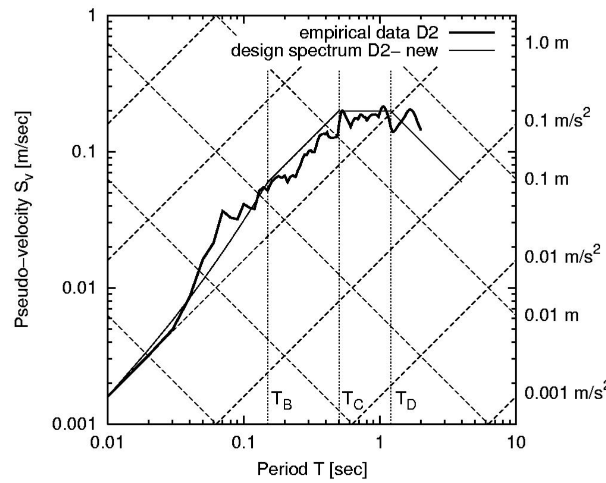
a) Class A



b) Class B



c) Class C



b) Class D

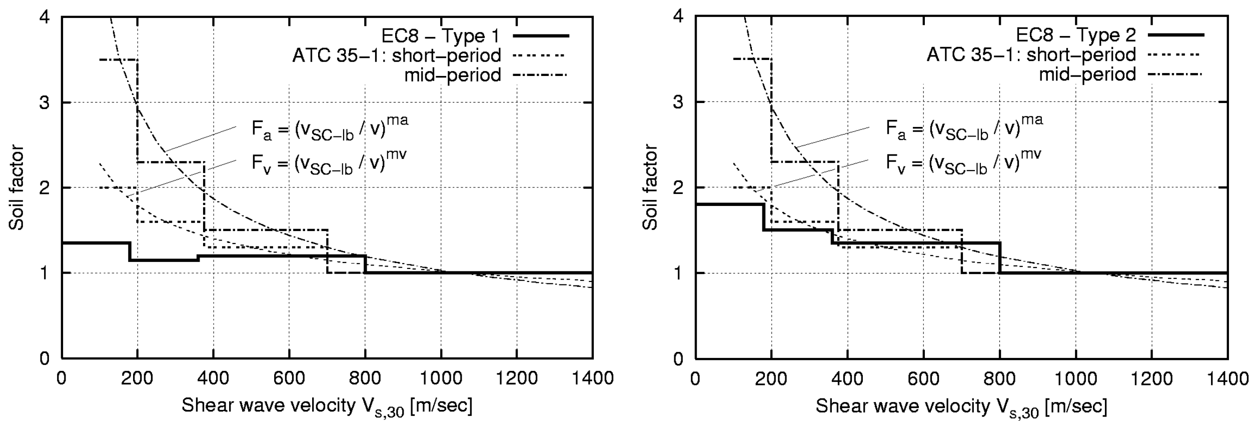
Figure 8. Mean response spectra, type 2 (component H_{res})

SPECTRAL SOIL AMPLIFICATION FACTORS

As stated in [4], empirical data is only used to determine the control periods. " *The exercise presented here is useful to explore the validity of the control periods established for each subsoil class, but since only the shape is explored and since the factor S scales the ordinates at all periods equally, this investigation does not serve to confirm the proposed values for S.*" Approaches with new data sets are conducted independently to develop soil amplification factors. Nevertheless, the strong motion data used are not comprehensible. Therefore, investigations of different methods for validity of existing and developing of new soil factors are employed.

Application of different methods for developing soil factors

Approach 1: Classification of proposed soil factors referring to the procedure of ATC 35-1[8]
To classify the suggested soil factors in EC8, a comparison with the approach for determining soil factors proposed in ATC 35-1 is applied (Figure 2).



a) Type 1 **b)** Type 2

Figure 9. Comparison of soil factors with provisions given in ATC 35-1

In order to investigate the local geological conditions and estimates of amplification factors F_a and F_v in ATC 35-1, only strong-motion recordings of Loma Prieta earthquake are used, whereas a distinction between short-period ranges (0.1-0.5 s, constant spectral acceleration) and mid-period ranges (0.4-2.0 s, constant spectral velocity) is made. To derive F_a and F_v, either a discrete or a continuous function can be used. Unlike the procedure used in EC8, no difference in the seismicity conditions is implied in ATC 35-1 for the creation of response spectra. In fact, the dependence of the soil factor on peak ground acceleration is shown for the continuous function method. The higher the peak ground acceleration, the lower the soil amplification factor. Nevertheless, this fact is reflected in EC8 with different soil factors for two different seismicity conditions.

Figure 9 shows a decrease of the soil amplification factor (for 0.1 g) with increasing shear wave velocity (ATC 35-1) . For short-period motion, this decrease is stronger than for mid-period motion. As it can be seen in Figure 9a (EC8 - Type 1), a break between $V_{s,30}$ = 180-360 m/s is rather unusual.

Approach 2: Intensity based soil factors with data of ESMD 2000

The final draft of EC8 includes soil factors recommended by [9]. They also used a data set of strong motion recordings provided by ESMD 2000. A detailed documentation of the applied data, which is staggered in five different magnitude ranges (4.0<M<4.5, 4.5<M<5.0, 5.0<M<5.5, 5.5<M<6.0, 6.0<M), is not given. Thus their application for own investigations cannot be realized. By using the average normalized spectral curves for each subsoil class, the Housner spectrum intensity according to Equation 7 was calculated and finally related to geological condition rock (cf. Equation 8).

$$I_{A,B,C} = \int_{0.05}^{2.5} \overline{R \cdot S_a(T)}\,dt \tag{7}$$

$$S_B = \frac{I_B}{I_A} \qquad S_c = \frac{I_c}{I_A} \tag{8}$$

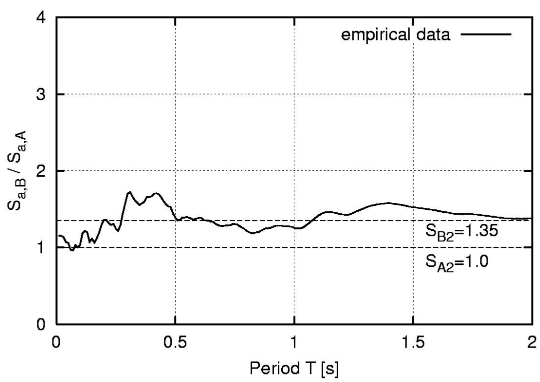
The ESMD 2000 data base was searched for recordings with certain magnitude ranges (Table 6) and limited epicentral distance $R_{Epi} \leq 20$ km in order to meet the relevant conditions of Central European earthquake regions. The results of applying the Housner-Intensity method to these data are shown (Table 6) in comparison with proposed soil factors. For stiff soil $S_{(ESMD)}$ = 0.98 is considerably lower than $S_{(EC8)}$ = 1.35, whereas for soft soil $S_{(ESMD)}$ = 2.01 is much higher than $S_{(EC8)}$ = 1.5. Since the achieved results are not continuously and specified soil factors, S could not be approved, making further investigations necessary.

Table 6. Results of predicted soil factors on the basis of Housner spectrum intensity

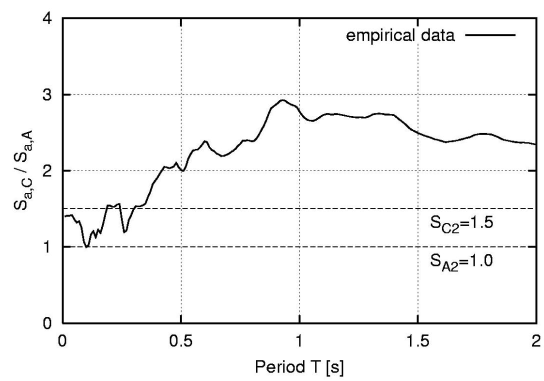
Subsoil	Magnitude	$I_{(T=2.5s)}$ (ESMD)	S (ESMD)	S [9]	$I_{(T=2.5s)}$ (ESMD)	S (ESMD)	S (EC8) Type 2
rock (A)	$4.5 \le M_s \le 5.0$	11.73			10.62	1.0	1.0
	$5.0 \le M_s \le 5.5$	13.45					
stiff (B)	$4.5 \le M_s \le 5.0$	8.41	0.72	1.15	10.37	0.98	1.35
	$5.0 \le M_s \le 5.5$	13.67	1.02	1.52			
soft (C)	$4.5 \le M_s \le 5.0$	16.04	1.37	1.16	21.31	2.01	1.5
	$5.0 \le M_s \le 5.5$	41.25	3.07	1.74			

Approach 3:Relations between mean spectra of empirical data

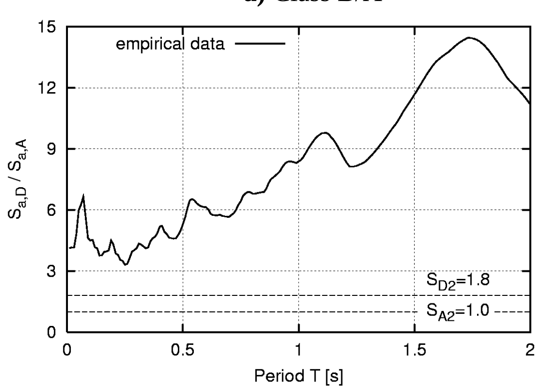
The third approach was carried out on the basis of empirical data [4]. For each subsoil class of type 2 spectra, the mean acceleration response spectra of raw data were calculated for component H_1+H_2. The relation of the average values of spectral acceleration in dependence on the period between soil and rock conditions, and compared with appropriate soil factors S of EC8, is shown in Figure 10.



a) Class B/A



b) Class C/A



c) Class D/A

Figure 10. Mean response spectra of empirical data in relation to rock, type 2 (component H_1+H_2)

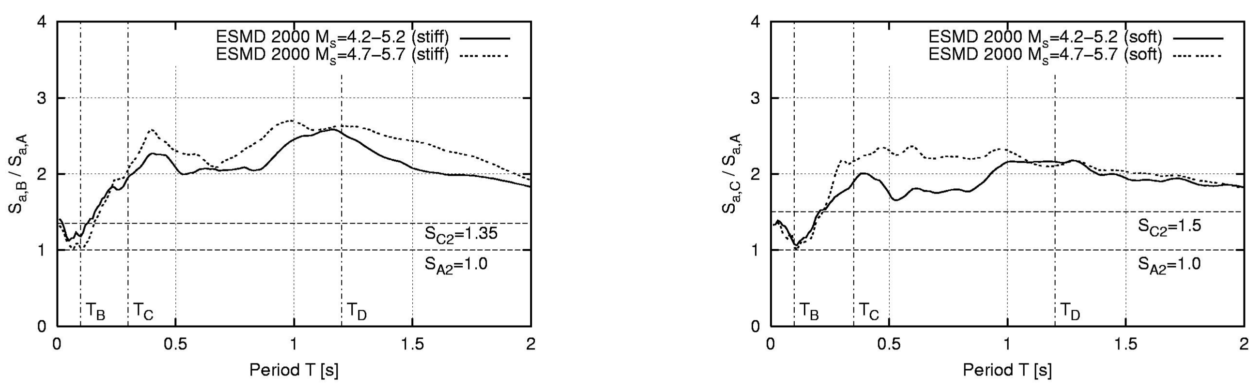
Approach 4: Evaluation of varying soil factors for different spectral ranges with statistical investigations of European Strong Motion Data (ESMD 2000)

For this type of soil factor, evaluation data of ESMD [5] is consulted again. As the results of Approach 3 have already shown, a unique scaling of magnitude and distance conditions (of raw data) is inevitable. By means of attenuation relationships as proposed by Ambraseys et al. [10], a scaling factor is generated (Table 7). The mean value of surface wave magnitude M_s and epicentral distance R_{epi} was detected for ranges M_s = 4.2-5.2, M_s = 4.7-5.7, and $R_{epi} \leq$ 20km. Based on these values and the corresponding subsoil classification, the PGA -values of respective attenuation relationship response spectra (ASB 1996) were calculated.

Table 7. Scaling factors as generated using the attenuation relationship of Ambraseys et al. [10]

Subsoil	Magnitude	Mean value ESMD 2000		ASB 1996
		M_s	R_{Epi} [km]	S_a (T=0.04s) [m/s²]
rock (A)	$4.2 \leq M_s \leq 5.2$	4.7	11.9	0.5630
	$4.7 \leq M_s \leq 5.7$	5.2	12.5	0.7142
stiff (B)	$4.2 \leq M_s \leq 5.2$	4.7	11.2	0.7932
	$4.7 \leq M_s \leq 5.7$	5.1	11.5	0.9417
soft (C)	$4.2 \leq M_s \leq 5.2$	4.7	11.7	0.7491
	$4.7 \leq M_s \leq 5.7$	5.1	12.1	0.9570

The mean spectra of ESMD 2000 [6] and [7] were standardized by the PGA -values given in Table 7. The soil spectra were related to rock spectra (Figure 11) thereafter. While the curves show a much more balanced progression, they display a nearly constant amplification level for periods larger than T_C. From period T_B to T_C, a nearly linear increase of the soil amplification can be observed. As the author`s recommendation is to adopt two different soil factors S_1 for period range $0.01 \leq T \leq T_B$ and S_2 for period range $T_B \leq T \leq T_C$, the results of Figure 11 were analyzed for distinct period ranges (Table 8). Since mean values of amplification factors do not tend to increase continuously from stiff to soft soil, large differences between S_1 and S_2 can be recognized.



a) Class B/A **b)** Class C/A

Figure 11. Mean response spectra of ESMD 2000 data related according to rock (component H_1+H_2)

Table 8. Mean values of amplification factor for different period ranges

Subsoil	Magnitude	$0.01 \leq T \leq T_B$	$T_B \leq T \leq T_C$	EC8 [1]
stiff (B)	$4.2 \leq M_s \leq 5.2$	1.29	1.65	1.35
	$4.7 \leq M_s \leq 5.7$	1.13	1.61	
soft (C)	$4.2 \leq M_s \leq 5.2$	1.27	1.51	1.5
	$4.7 \leq M_s \leq 5.7$	1.24	1.62	

Approach 5: Concept of geological and subsoil dependent spectra of German code
The present draft of the German earthquake code DIN 4149 [2] not only regards the influence of a globally described subsoil, but also the geological profile at a certain depth. A twofold classification is carried out distinguishing between the type of soil materials of the uppermost 25 m of soil layers and their total thicknesses above geological bedrock. Soil material types are represented by three different soil condition classes: 1, 2, and 3. Shear wave velocity of the near-surface layers $V_{s,25}$ can principally be regarded as the main distinguishing parameter between soil condition classes 1, 2, and 3 (SC 1: $V_{s,25}$ > 800m/s; SC 2: 350m/s ≤ $V_{s,25}$ ≤ 800m/s; SC 3: $V_{s,25}$ < 350m/s).

Geological subsoil classes (A, B, and C) consider the geological subsurface conditions, and hence stand for the thickness of overlying sediments. Geological subsoil class A can be characterized by missing or overlying sediments with a maximum thicknesses of 25 m, whereas class C is described by deep, mostly Quaternary alluvial layers reaching depths between 100 and 1000 m. Geological subsoil class B represents the transition zones between classes A and C, as well as shallow basin structures with thicknesses of sedimentary layers between 25 and 100 m. The geological conditions within Germany's earthquake regions admit six possible combinations between the different geological subsoil classes and soil condition classes.

CONCLUSIONS

A selection of strong motion data regarding the recently introduced seismicity conditions was used in [4] to determine the shape for design spectra in the final draft of EC8 [1]. The evaluated earthquake time histories showed some deficiencies. Inconsistencies appeared when comparing the proposed spectrum shapes with those resulting from statistical investigations of the empirical data as well as from the analysis of ESMD 2000 data [6] and [7]. Four different methods were introduced to calculate the mean response spectra, among which an innovative type is included using the resulting horizontal component. However, it could be shown that control periods T_B, T_C, and T_D do not depend on the applied method. Recommendations were given to shift the periods confining the range of constant spectral acceleration T_B and T_C to longer periods.

In contrast, the determination of appropriate soil amplification factors *S* implies general problems and requires further consideration. Therefore, new data sets of strong motion recordings were used while different approaches were applied to derive the soil factor *S*. In almost the same manner as the Housner spectrum intensity [9] was implemented, the provisions given in ATC 35-1 [8] and the relations of scaled and unscaled mean spectra between geological soil and rock conditions using several data sets did not induce consistent results. It is the author`s opinion that the concept of geological and subsoil dependent spectra proposed in the German seismic code DIN 4149 [2] is probably the best to use. In order to estimate reliable soil factors, investigations on borehole profiles are strongly recommended. Finally it became evident during these examinations that consistent data sets are imperative for statistical investigations.

Table 9. Comparison of soil factors as provided by DIN 4149 and EC8

DIN 4149 [2]		EC8 [1]	
Subsoil conditions *)	Soil factor S	Subsoil conditions	Soil factor S, (type 2)
A1	1.0	A	1.0
A2	1.25	B	1.35
A3	1.5	D resp. E	1.8 resp. 1.6
B2	1.0	B	1.35
B3	1.25	D	1.8
C3	0.75	C resp. D	1.5 resp. 1.8

*) change of denotation in the final version (2004) is to be expected to achieve a better correlation with EC8

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