Simplified Acceleration Response Spectra for a Soft Soil Layer Underlain by a Viscoelastic Half-Space

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ABSTRACT: Earthq3uake response spectra as given in EC 8 are defined for soils with shear wave velocities greater than 100-150 m/s. For soft soil layers, e.g. of clay underlain by bedrock, resonance effects of the layer significantly influence the shape of the spectrum. Hence, specific investigations are stipulated in the code for soft soil layers. Based on an intensive parameter study, simplified formula for equivalent horizontal acceleration response spectra for a soft soil layer on a viscoelastic half-space are derived. They allow defining an acceleration response spectrum for soft soils without cumbersome numerical computations for a wide range of soil layer heights and material parameters. The results of this simplified method show a good agreement with more precise one-dimensional shear wave propagation analyses. The given spectra are suited for the earthquake design of buildings with a foundation on soft soil.

KEY WORDS: earthquake response spectra; micro zoning; site amplification; site effects; soft soil layer.

1 INTRODUCTION

The impact of earthquakes on buildings is described in codes by acceleration response spectra. On soft soils, however, site effects strongly contribute to the ground motion at the surface. Response spectra given in codes do not include such site effects so that for soft soil layers specific studies are required.

In Eurocode 8 the influence of soil conditions on the response spectrum is described by five regular ground types, A to E, and two special ground types, S_1 and S_2, requiring particular investigations [1]. Type S_1 for deposits of soft clays/silts with an average shear wave velocity $v_{s,30} < 100$ m/s corresponds to the case of soft soil layers as considered here. The national annex of Eurocode 8 for Germany [2], however, defines separate ground types which differ from the ground types given in [1]. In [2] specific investigations are required for soft soils with shear wave velocities $v_s < 150$ m/s.

A soft soil layer influences the frequency content as well as the amplitudes of free field acceleration time histories. Horizontal free field acceleration time histories and the corresponding response spectra on the top of a soft soil layer can be determined with the theory of a shear wave propagating in vertical direction (SH waves). The application of the theory of SH waves to layered soils is well established. It takes into account the basic influence of a soft layer, whereas it neglects two- and three-dimensional effects as wave reflections in valleys and the influence of heavy buildings known as site-city interaction.

For practical purposes, standard software based on the one-dimensional theory of horizontally polarized shear waves propagating in vertical direction including (linearized) nonlinear soil parameters can be utilized [3]. The application of this method, however, requires specialized skills and knowledge not widely available at engineering consultant companies. Therefore a method to derive simplified response spectra for the model of a soft soil layer underlain by a half-space has been developed for soil conditions in Germany acc. to [2]. The simplified spectra may be applied directly to the earthquake design of buildings on a soft soil.

2 METHOD OF ANALYSIS

2.1 SH wave theory

The model of a layer over a viscoelastic half-space as shown in Fig. 1 is studied. The acceleration in the free field at the top of the layer related to the acceleration at the top of the half-space in frequency domain is denoted as transfer function. It can be written as

$$F(\Omega) = \frac{u_F(\Omega)}{u_G(\Omega)} = \frac{\ddot{u}_F(\Omega)}{\ddot{u}_G(\Omega)} \tag{1}$$

where $\Omega = 2 \cdot \pi \cdot f$ is the circular frequency of vibration. Transfer functions for SH waves in a layered soil can be determined by the finite element method or by the transfer matrix method [4, 5, 6]. For a single layer over a half-space the transfer function is given by

$$F(\Omega) = \frac{1}{\cos(\Omega \cdot h / \tilde{v}_{s,S}) + i \cdot \tilde{\beta} \cdot \sin(\Omega \cdot h / \tilde{v}_{s,S})} \,. \tag{2}$$

with the complex shear wave velocities

$$\tilde{v}_{s,S} = \sqrt{\frac{G_S \cdot (1 + 2 \cdot i \cdot \xi_S)}{\rho_S}} \,, \quad \tilde{v}_{s,G} = \sqrt{\frac{G_G \cdot (1 + 2 \cdot i \cdot \xi_G)}{\rho_G}} \tag{3}$$

and the complex impedance ratio

$$\tilde{\beta} = \frac{\rho_S \cdot \tilde{v}_{s,S}}{\rho_G \cdot \tilde{v}_{s,G}} \,. \tag{4}$$

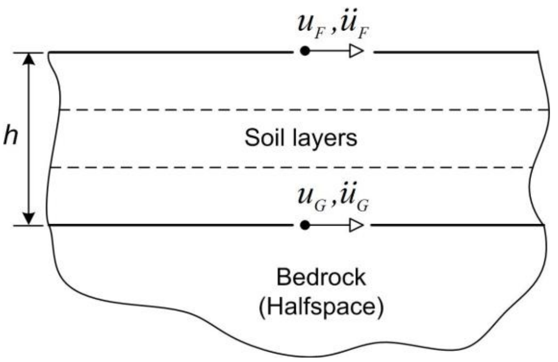

Figure 1. Soil model.

Here G_S, G_G are the shear moduli, ρ_S, ρ_G the densities and ξ_S, ξ_G the hysteretic damping ratios of the layer and the half-space respectively. For a system without damping, i.e. with $\xi_S = \xi_G = 0$, the shear wave velocities acc. to (3) and the impedance ratio acc. to (4) become real. They are denoted as $v_{s,S}$, $v_{s,G}$ and β respectively. For a soft layer the impedance is $0 \le \beta \le 1$ where $\beta = 0$ characterizes the case of a rigid half-space. The transfer function is $|F(\Omega)| \ge 1$ as $\sqrt{\cos^2(\Omega \cdot h / v_{s,S}) + \beta^2 \cdot \sin^2(\Omega \cdot h / v_{s,S})} \le 1$ with $\beta \le 1$.

Two typical transfer functions for $\xi_G = 1\%$, $\xi_S = 5\%$ and $\xi_S = 10\%$, respectively, are given in Fig. 2. The peaks of the functions appear at the eigenfrequencies

$$f_{S,j} = \frac{v_{s,S}}{4 \cdot h} \cdot (2 \cdot j - 1), \quad j=1, 2, 3 \ldots \tag{5}$$

of the soft layer over a rigid half-space. The corresponding periods are $T_{S,j} = 1/f_{S,j}$. The values of the maxima of the transfer functions can be given in a good approximation by

$$|F(\Omega)|_{\max} = \frac{1}{\sinh\left(\frac{\pi}{2} \cdot (2 \cdot j - 1) \cdot \xi_S\right) + \beta \cdot \cosh\left(\frac{\pi}{2} \cdot (2 \cdot j - 1) \cdot \xi_S\right)} \tag{6}$$

The impedance ratio β indicates the influence of the radiation damping of the half-space, whereas ξ_S represents the internal damping of the soil of the layer. Eq. (6) shows that the hysteretic damping ξ_S of the layer as well as the impedance ratio β reduce the maxima of the transfer function.

2.2 *Computation of the free field response spectrum*

The computation of the free field motion at the layer surface is based on an earthquake motion defined at the bedrock, i.e. at the top of the half-space. This input motion is represented by an horizontal acceleration response spectrum. In order to compute the corresponding response spectrum at the top of the layer, an analysis of the SH-wave propagation throughout the layer is carried out. First an artificial acceleration time history compatible with the response spectrum defined at the top of the half-space is generated. Transforming the time history into the frequency domain and applying eq. (2) the free field acceleration time history at the top of the layer is obtained. Employing this, the free field acceleration response spectrum at the top of the layer is computed. All response spectra are determined for 5% damping.

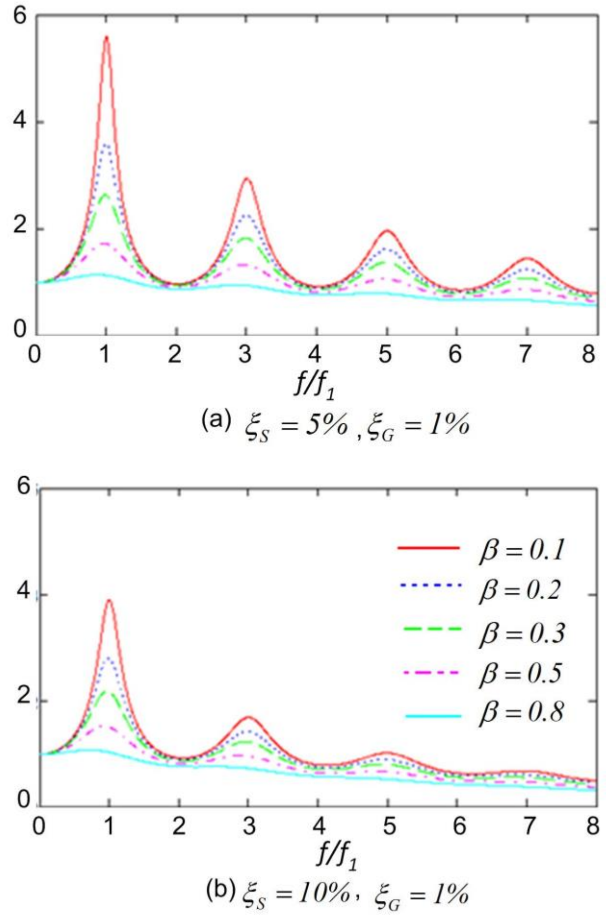

Figure 2. Transfer functions.

2.3 *Response spectrum of the bedrock*

For the bedrock a ground of type C-S acc. to [2] is assumed. It corresponds to granular soils with medium density and shear wave velocities between 150 m/s and 350 m/s over deep deposits of sediments as are typical for the foothills of the Alps in Germany.

The horizontal elastic acceleration spectrum acc. to [2] is defined as:

$$
\begin{aligned}
T_A \le T \le T_B: &\quad S_e(T) = a_{g,0} \cdot \left[0{,}4 + \frac{T}{T_B} \cdot (\eta - 0{,}4)\right] \\
T_B \le T \le T_C: &\quad S_e(T) = a_{g,0} \cdot \eta \\
T_C \le T \le T_D: &\quad S_e(T) = a_{g,0} \cdot \eta \cdot \left(\frac{T_C}{T}\right) \\
T_D \le T: &\quad S_e(T) = a_{g,0} \cdot \eta \cdot \left(\frac{T_C}{T}\right) \cdot \left(\frac{T_D}{T}\right)
\end{aligned} \tag{7}
$$

with

$$a_{g,0} = a_{gR} \cdot \gamma_I \cdot S \cdot 2,5 \tag{7a}$$

The reference peak acceleration of the ground is set to be $a_{gR} = 1{,}0\ m/s^2$, the importance factor $\gamma_I = 1{,}0$ and the damping correction factor $\eta = 1{,}0$. For ground type C-S the control periods are $T_A = 0$, $T_B = 0{,}1\ s$, $T_C = 0{,}5\ s$, $T_D = 2{,}0\ s$ and the soil factor is $S = 0{,}75$. The response spectrum with $a_{g,0} = 0{,}75 \cdot 2{,}5 = 1{,}875\ m/s^2$ is shown in Fig. 3.

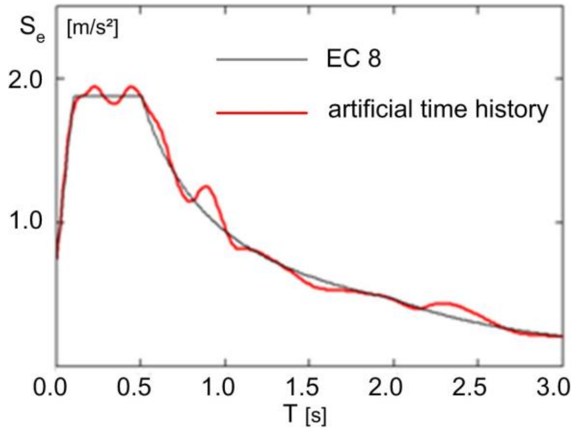

Figure 3. Acceleration response spectrum on bedrock.

Fig. 3 also shows the response spectrum of an artificial spectrum-compatible acceleration time history. It agrees well with the target spectrum. The investigations in this study have been conducted using five artificial time histories generated with the program SYNTH [4].

2.4 Soil models

In order to investigate the influence of a soft soil layer on the free field response spectrum a parameter study has been performed [7]. The height h of the layer has been varied between 5 m and 50 m. For the shear wave velocity $v_{s,G}$ in bedrock the following values have been adopted: 154, 250, 350, 450, 520 and 1000 [m/s]. The damping ξ_S in the soil layer is assumed to be 5%, 10% and 15% and the damping in the bedrock $\xi_G = 1\%$. The shear wave velocity in the soil layer is $v_{s,S} = 90\ m/s$ and the densities in the layer and in the bedrock are $\rho_S = 1900\ kg/m^3$ and $\rho_G = 2200\ kg/m^3$ respectively.

2.5 Free field response spectra

Some response spectra at the top of the layer for $v_{s,S} = 90\ m/s$ and $v_{s,G} = 350\ m/s$ are shown in Fig. 4. The peaks of the curves occur at the periods corresponding to the resonance frequencies of the layer on a rigid base acc. to eq. (5). At these periods, the response accelerations are significantly amplified compared to the spectrum at the bedrock also given in Fig. 4.

All computations have been done with SHAKE 2000 [3] and checked with a software developed for the one-layer system.

3 EQUIVALENT SYSTEMS

Two soil models are considered to be equivalent when they possess the same transfer function. One of the models is called the reference model the other one is the actual model.

Two systems are approximately equivalent when they have the same eigenfrequencies acc. to eq. (5) and the same magnitudes of peaks [8]. Denoting the reference model with the index "ref", the eigenfrequency criterion gives $v_{s,S,ref} / h_{ref} = v_{s,S} / h$ or

$$h_{ref} = h \cdot \frac{v_{s,S,ref}}{v_{s,S}} \tag{8}$$

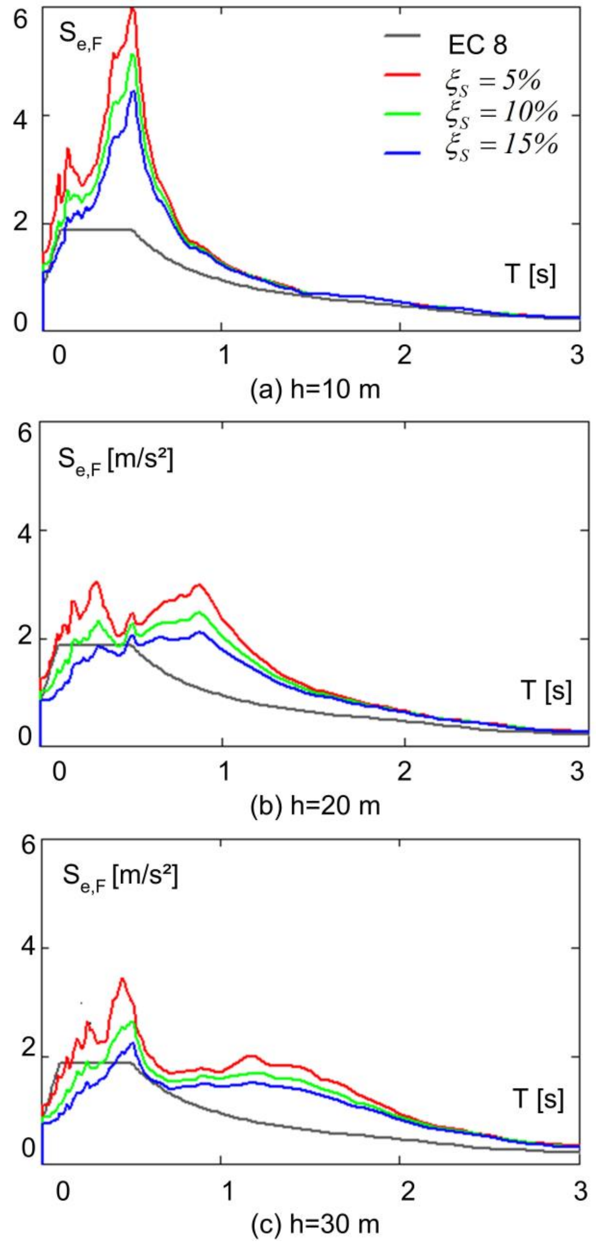

Figure 4. Free field acceleration response spectra.

The “peak” criterion as established in eq. (6) for the j-th peak is:

$$\sinh\left(\frac{\pi}{2}\cdot(2\cdot j-1)\cdot\xi_{S,ref}\right)+\beta_{ref}\cdot\cosh\left(\frac{\pi}{2}\cdot(2\cdot j-1)\cdot\xi_{S,ref}\right)$$
$$=\sinh\left(\frac{\pi}{2}\cdot(2\cdot j-1)\cdot\xi_{S}\right)\;+\;\beta\;\cdot\cosh\left(\frac{\pi}{2}\cdot(2\cdot j-1)\cdot\xi_{S}\right)$$

After an approximate linearization one obtains

$$\xi_{S,ref}\approx\frac{2}{\pi\cdot(2\cdot j-1)}\cdot\left(\beta-\beta_{ref}\right)+\xi_S\cdot \qquad (9)$$

Eq. 9 shows that an increase of the shear wave velocity in the half-space, i.e. a decrease of β acc. to eq. (4), corresponds to a reduction of the internal damping $\xi_{S,ref}$ in the layer of the reference model. Hence, in the reference model the difference between the radiation damping of the actual and the reference model is approximately expressed by an increase or decrease of the internal damping ξ_S in the layer. An example with $\xi_{S,ref}=10\%$ and $\beta_{ref}=0.25$ for $j=1$ is shown in Fig. 5.

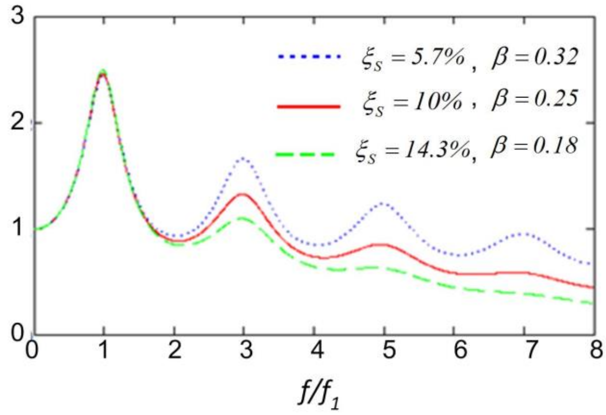

Figure 5. Transfer functions for SH waves.

Free field acceleration response spectra of equivalent systems with the same transfer function are identical. For approximately equivalent systems the approximation with $\xi_{S,ref}$ is valid at one of the eigenfrequencies acc. to eq. 9, e.g. for $j=1$. As an example the response spectrum of a soil model consisting of a layer with $v_{s,S}=50\,m/s$, $h=10\,m$, $\xi_S=10\%$ and a bedrock with $v_{s,G}=500\,m/s$ and $\beta=(1{,}9\cdot 50)/(2{,}2\cdot 500)=0.086$ (eq. (4)) is investigated. The periods of the system with a rigid base acc. to eq. (5) are $T_{S,1}=0.80\;s$, $T_{S,2}=0.27\;s$ and $T_{S,3}=0.16\;s$. With $v_{s,S,ref}=90\;m/s$ the equivalent layer height is obtained as $h_{ref}=18\,m$ (eq. (8)). A reference model with a shear wave velocity in the half-space of $v_{s,G,ref}=1000\;m/s$ gives $\beta_{ref}=(1{,}9\cdot 90)/(2{,}2\cdot 1000)=0.078$. The damping in the layer of the reference model is $\xi_{S,ref}=10{,}5\%$ for $j=1$ and $\xi_{S,ref}=10{,}2\%$ for $j=2$. The free field response spectra of the actual system and the reference model for $j=1$ are shown in Fig. 6. Both spectra are in good agreement. Other systems may have a slight deviation depending on the eigenfrequencies ($j=1$ or $j=2$) for which peaks have been adapted.

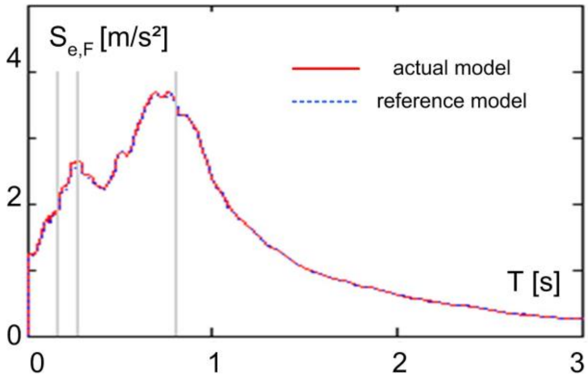

Figure 6. Response spectra: actual vs. reference model.

4 EQUIVALENT RESPONSE SPECTRA

4.1 *Basic formula for acceleration response spectra*

Based on the parameter study described in section 2.4, simplified formulas for equivalent response spectra of a layer over a half-space have been developed [8]. Taking the resonance behavior of the layer into account, two sets of parameters, one for the first period and another for the second period are given. For each period T of the response spectrum the maximum of both spectra is decisive:

$$S_{S,e}=\max(S_{S,e,1},S_{S,e,2}) \qquad (10)$$

The formulas for $S_{S,e,i}(T)$ are adapted on the description of the response spectrum in EC 8. They are defined as:

$$T_{A,i}\le T\le T_{B,i}:\quad S_{S,e,i}(T)=S_e(0)+\frac{T}{T_{B,i}}\left(\alpha_i\cdot S_e(T_i)-S_e(0)\right)$$
$$T_{B,i}\le T\le T_{C,i}:\quad S_{S,e,i}(T)=\alpha_i\cdot S_e(T_i)$$
$$T_{C,i}\le T\le T_{D,i}:\quad S_{S,e,i}(T)=\alpha_i\cdot S_e(T_i)\cdot\left(\frac{T_{C,i}}{T}\right)^{n_i}$$
$$T_{D,i}\le T:\quad S_{S,e,i}(T)=\alpha_i\cdot S_e(T_i)\cdot\left(\frac{T_{C,i}}{T}\right)^{n_i}\cdot\left(\frac{T_{D,i}}{T}\right) \qquad (11)$$

with $i=1,2$.

The parameter sets for *i*=1 and *i*=2 correspond to the response spectra for the first and second eigenfrequency of the layer, respectively. They will be given in the following. The periods $T_{A,i}$, $T_{B,i}$, $T_{C,i}$, $T_{D,i}$ are the control periods of the spectrum. The parameter α_i describes the amplification of the response spectra acceleration of the bedrock by the layer at the *i*-th resonance period.

All parameters have been adapted to the response spectra of the parameter study described in section 2.4. Altogether 342 models with different layer heights, damping and bedrock shear wave velocities have been investigated.

4.2 Control periods

Basically the control periods correspond to the periods at the resonance of the layer on a rigid half-space [6]. However, the investigations revealed a pronounced peak corresponding to a period of vibration T=0.5 s occurring for all the heights due to the initial spectrum at the bedrock. Therefore some adaptions have been made [7].

The control periods are given with $T_D = 2\ s$ by

$$T_{A,i} = 0;\quad T_{B,i} = T_{L,i+1};\ T_{C,i} = T_{L,i};\ T_{D,i} = \max\left(T_{C,i}, T_D\right) \tag{12}$$

with

$$T_{L,1} = \max\left(0{,}5\ s;\ \frac{4 \cdot h}{v_{s,S}}\right)$$

$$T_{L,2} = \begin{cases} \max\left(0{,}5\ s;\ \dfrac{4 \cdot h}{3 \cdot v_{s,S}}\right) & if \quad \dfrac{4 \cdot h}{v_{s,S}} > 0{,}5\ s \\ \dfrac{4 \cdot h}{v_{s,S}} & otherwise \end{cases}$$

$$T_{L,3} = \frac{4 \cdot h}{5 \cdot v_{s,S}} \tag{13}$$

4.3 Amplification factors α_i

The ratio between the response spectrum accelerations at the top of the layer and the ones from eq. (7) is defined as being the amplification parameter α. Two parameters, α_1 and α_2, are required in order to define the spectra for the first two resonance peaks of the layer. For each investigated shear wave velocity of the half-space a different set of α_1 and α_2 parameters is to be fixed.

For a given shear wave velocity in the layer of $v_{s,S} = 90\, m/s$ and in the half-space $v_{s,G}$ and a presumed damping ξ_S in the layer the amplification factors depend only slightly on the layer height [7]. Therefore an average value can be taken for all layer heights. For $v_{s,S} = 90\, m/s$ the variation of amplification factors α_1 and α_2 with the shear wave velocity in the half-space and the damping in the layer is given in Tables 1 and 2 and shown in Fig. 7. Intermediate values may be got by interpolation.

4.4 Decay factors n_i

The parameters n_i control the sharpness of the decay of the curves in the response spectrum. They have been determined by numerical experiments as given in Tables 3 and 4 and shown in Fig. 8 (values in brackets for 450 m/s by interpolation). Intermediate values may be interpolated.

Table 1. Amplification factor α_1.

$v_{s,G}$ [m/s]	154	250	350	450	520	1000
$\xi_S = 5\%$	1.62	2.24	2.75	(3.15)	3.37	4.35
$\xi_S = 10\%$	1.46	1.96	2.35	2.63	2.81	3.49
$\xi_S = 15\%$	1.29	1.68	1.94	2.12	2.24	2.62

Table 2. Amplification factor α_2.

$v_{s,G}$ [m/s]	154	250	350	450	520	1000
$\xi_S = 5\%$	1.20	1.50	1.73	(1.86)	1.93	2.22
$\xi_S = 10\%$	0.98	1.20	1.36	(1.45)	1.49	1.69
$\xi_S = 15\%$	0.75	0.89	0.98	1.02	1.05	1.15

Table 3. Decay factor n_1.

$v_{s,G}$ [m/s]	154	250	350	450	520	1000
$\xi_S = 5\%$	1.30	1.50	1.50	(1.83)	1.90	2.10
$\xi_S = 10\%$	1.18	1.35	1.35	(1.60)	1.65	1.85
$\xi_S = 15\%$	1.05	1.20	1.20	(1.37)	1.40	1.60

Table 4. Decay factor n_2.

$v_{s,G}$ [m/s]	154	250	350	450	520	1000
$\xi_S = 5\%$	1.20	1.40	1.50	(1.57)	1.60	1.50
$\xi_S = 10\%$	1.00	1.10	1.20	(1.27)	1.30	1.25
$\xi_S = 15\%$	0.80	0.80	0.90	(0.97)	1.00	1.00

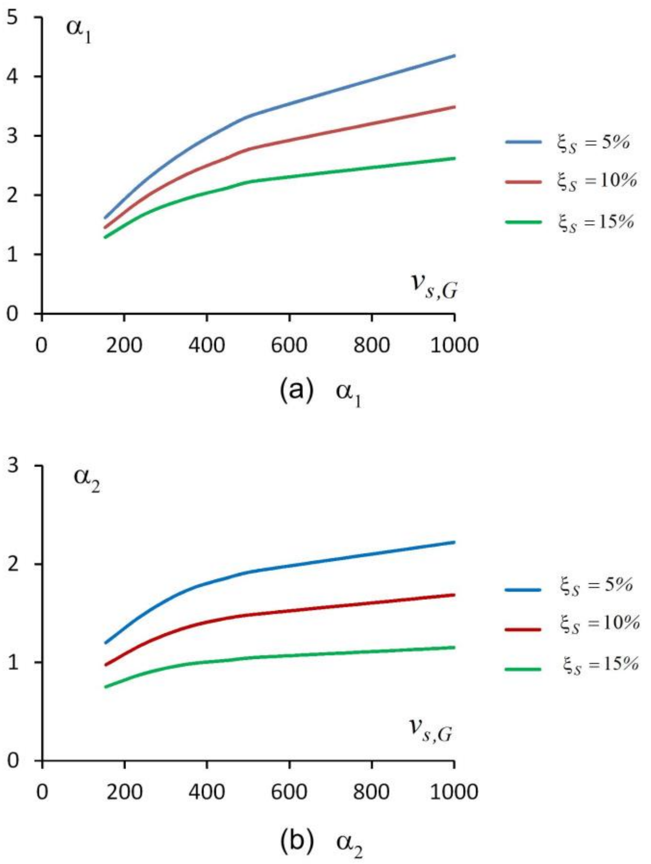

Figure 7. Amplification factors.

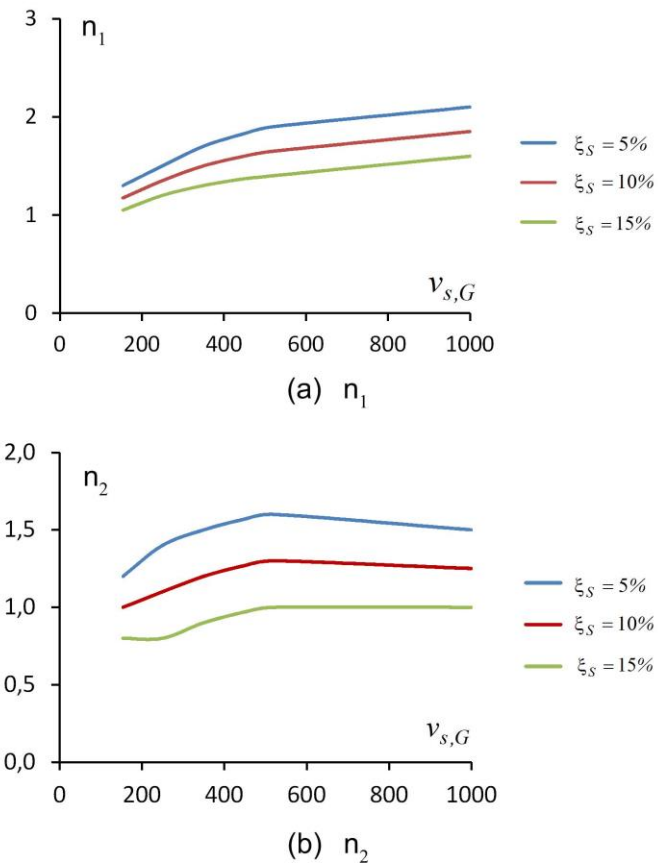

Figure 8. Decay factors.

4.5 *Verification of the simplified response spectra*

The simplified response spectra acc. to eqns. (11, 11a, 12, 13) have been verified for all investigated shear wave velocities ($v_{s,S} = 90$ *m/s*; $v_{s,G} =$ 153, 250, 350, 450, 520, 1000 *m/s*), layer heights between 5 and 50 m and for the damping ratios $\xi_S = 5\%$, 10% and 15% in the layer. The shear wave velocity in the layer, the damping in the half-space and soil densities were kept constant as $v_{s,S} = 90$ ms, $\xi_G = 1\%$, $\rho_S = 1900\ kg/m^3$ and $\rho_G = 2200\ kg/m^3$, respectively [7]. The simplified response spectra agree very well with the exact response spectra of the system. Some examples for $v_{s,S} = 90\ m/s$, $v_{s,G} = 350\ m/s$ and $\xi_S = 5\%$ are given in Fig. 9.

5 CONSTRUCTION OF SIMPLIFIED RESPONSE SPECTRA

5.1 *Generals*

For a soil layer on a half-space the response spectrum can be constructed in two steps. First an equivalent reference model is determined. It should possess the same eigenfrequencies (for a layer on a rigid base) and the same impedance ratio. In the next step an equivalent simplified response spectrum of the reference model is obtained acc. to section 4. The construction of an equivalent acceleration response spectrum will be demonstrated by an example.

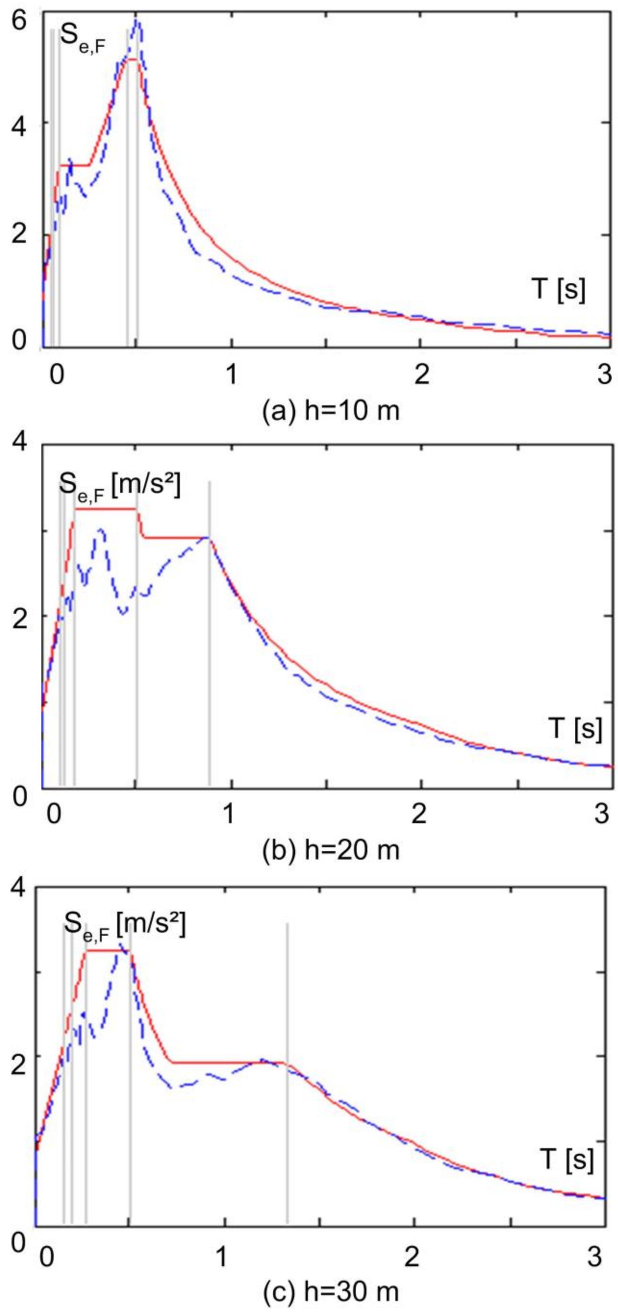

Figure 9. Free field acceleration response spectra, $v_{s,S} = 90\ m/s$, $\xi_S = 5\%$, $v_{s,G} = 350\ m/s$.

5.2 *Data of the ground model*

The data will be as follows:

soil layer:

$v_{s,S} = 70\ m/s$, $\rho_S = 1900\ kg/m^3$, $\xi_S = 7\%$, $h = 27$ m

half-space:

$v_{s,G} = 220\ m/s$, $\rho_G = 2200\ kg/m^3$, $\xi_G = 1\%$

earthquake parameters:

$a_{gR} = 1{,}0\ m/s^2$, $\gamma_I = 1{,}0$, $\eta = 1{,}0$, ground type C-S [2].

The impedance ratio is $\beta = \rho_S \cdot v_{s,S} / (\rho_G \cdot v_{s,G})$ or $\beta = (1{,}9 \cdot 70)/(2{,}2 \cdot 220) = 0.275$, the periods of the layer on a fixed base are obtained acc. to eq. (5) as $T_{S,1} = 1.54\,s$, $T_{S,2} = 0.51\,s$, $T_{S,3} = 0.31\,s$, $T_{S,4} = 0.22\,s$.

5.3 Reference model

The computations for the equivalent reference system have been done with $v_{s,S,ref} = 90\ m/s$, $\rho_{S,ref} = 1900\ kg/m^3$, $\rho_{G,ref} = 2200\ kg/m^3$, $\xi_{G,ref} = 1\%$. These values are fixed, whereas the height, damping of the layer and the shear wave velocity in the half-space of the reference system are determined as described below.

The height of the reference system is obtained with eq. (8) as:

$$h_{ref} = h \cdot \frac{v_{s,S,ref}}{v_{s,S}} = 27 \cdot 90/70 = 34{,}71\ \ m.$$

With $\beta_{ref} = \beta$ or $\rho_{S,ref} \cdot v_{s,S,ref} / (\rho_{G,ref} \cdot v_{s,G,ref}) = \beta$ the shear wave velocity in the half-space of the reference system is obtained to be

$$v_{G,ref} = v_{s,S,ref} \cdot \rho_{S,ref} / (\rho_{G,ref} \cdot \beta) \tag{14}$$

or $v_{G,ref} = 90 \cdot 1{,}9/(2{,}2 \cdot 0{,}275) = 283{,}9\ m/s$. The damping in the layer of the reference system acc. to eq. (9) is $\xi_{S,ref} = \xi_S = 7\%$ since $\beta_{ref} = \beta$.

5.4 Response spectrum

The equivalent simplified response spectrum is characterized by the control periods and corresponding amplification and decay factors. According to eqn.'s (12) and (13) with $h = h_{ref}$ and $v_{s,S} = v_{s,S,ref}$ the following control periods are obtained:

$$T_{A,1} = 0,\ T_{B,1} = 0{,}51,\ T_{C,1} = 1{,}54,\ T_{D,1} = 2{,}0;$$

$$T_{A,2} = 0,\ T_{B,2} = 0{,}31,\ T_{C,2} = 0{,}51,\ T_{D,2} = 2{,}0.$$

The response spectrum at the surface of the half-space is given by eq. (7). With the earthquake parameters given above the following response accelerations are obtained:

$$S_e(T_{S,1}) = 0{,}608\ \ m/s^2,\quad S_e(T_{S,2}) = 1{,}823\ \ m/s^2$$

The amplification and decay factors for the reference model are got from Tables 1 to 4 by interpolation for $v_{G,ref} = 283{,}9$ m/s and $\xi_{S,ref} = 7\%$ as $\alpha_1 = 2{,}28$, $\alpha_2 = 1{,}44$, $n_1 = 1{,}44$, $n_2 = 1{,}31$, respectively. The corresponding response spectra $S_{S,e,1}(T)$, $S_{S,e,2}(T)$ acc. to eqn.'s (11), (11a) are shown in Fig. (10). The final spectrum $S_{S,e}$ at the top of the soil layer acc. to eq. (10) as envelope of the spectra $S_{S,e,1}, S_{S,e,2}$ is shown in Fig. (11) together with the response spectrum S_e at the top of the half-space. It illustrates the shift of the periods and the amplification of the response accelerations caused by the soft soil layer.

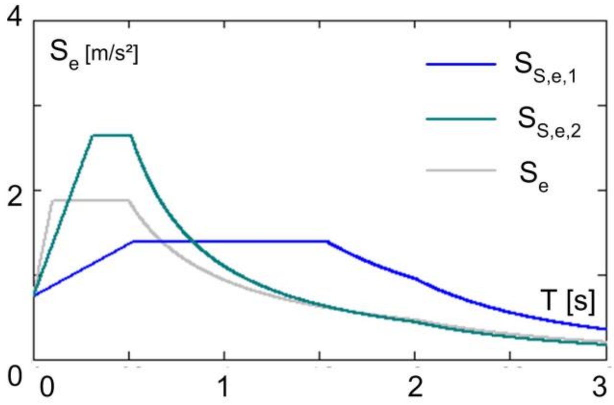

Figure 10. Acceleration response spectra.

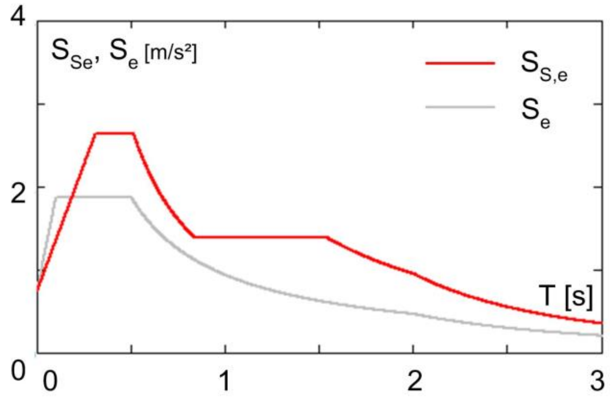

Figure 11. Acceleration response spectra at the top of the soft soil layer and of the half-space.

6 CONCLUSIONS

An easy-to-handle method for constructing horizontal acceleration response spectra for a viscoelastic layer on a half-space has been developed. The spectra can be applied to the design of buildings on soft ground.

The parameters are given for a ground of type C-S acc. to EC 8 and the German NAD [1, 2] with respect to the half-space. The method has been validated for a comprehensive set of parameters of the soil layer and the half-space (section 4.5). Considerable extension of the material presented in the paper to other ground conditions and soil profiles is possible.

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