

EARTHQUAKE RESPONSE SPECTRA OF A SOFT SOIL LAYER OVER A HALF-SPACE

– *Final report* –

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Literature

Abstract

Earthquake 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 specific investigations are stipulated in the German NAD of the code (3).

A set of acceleration response spectra for a viscoelastic layer on a viscoelastic half-space is given. The shear wave velocities in the layer are 90 m/s, the material damping values considered are 5, 10 and 15%. The shear wave velocity of the bedrock is varied between 154 and 1000 m/s. The response spectrum of the bedrock is assumed acc. to EC8 (and the German NAD [3]) for the ground type C-S.

Based on this parameter study, a simplified method for constructing horizontal acceleration response spectra for a viscoelastic layer on a half-space has been developed. The spectra are ready to be applied on the design of buildings on soft ground.

1 OVERVIEW

Horizontal acceleration response spectra for Lake Constance clay were computed using SHAKE2000 software [1]. The analyzed layer heights are between 5 and 50 m. Five artificial time history accelerations generated using SYNTH program [2] are used in computing the response spectra within SHAKE2000. The response spectrum given in EC 8 [3] was used in order to obtain these five time histories which are presented in chapter 4. The final result given by SHAKE2000 is computed as being the average between the results of each input of these artificial time histories.

A simplified method for the determination of response spectra of the one-layer model is proposed.

2 SOIL MODELS

The analyses have been performed for a clay layer with a shear wave velocity of 90 m/s underlain by bedrock (Fig. 1). For the bedrock different models with the shear wave velocities given in Table 1 have been investigated.

Table 1: Soil parameters

Soil	Density [KN/m ³]	Shear modulus [MN/m ²]	Shear wave velocity [m/s]	Damping [%]
Clay	$\rho_S = 19$	15	$v_{s,S} = 90$	$\xi_S = 5$ 10 15
Gravel(Bedrock)	$\rho_G = 22$	270	$v_{s,G} = 154$ 250 350 450 520 1000	$\xi_S = 1$

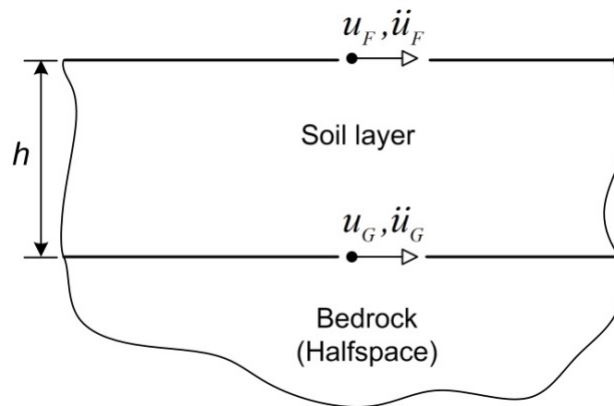


Figure 1: Soil layer over a viscoelastic halfspace

The steps for the analyzed heights h are 2.5m for the interval [5 m...10 m] and 5 m for the interval [50 m...100 m]. The eigenfrequencies and periods of an elastic layer with a shear wave velocity of 90 m/s on a rigid base (see section 6.2) are given in table 2.

Table 2: Eigenfrequencies and periods of an elastic layer with rigid base ($v_s=90$ m/s)

h [m]	f_j			$T_j=1/f_j$		
	j			j		
	1	2	3	1	2	3
2.5	9.00	27.00	45.00	0.11	0.04	0.02
5	4.50	13.50	22.50	0.22	0.07	0.04

12.5	1.80	5.40	9.00	0.56	0.19	0.11
15	1.50	4.50	7.50	0.67	0.22	0.13
17.5	1.29	3.86	6.43	0.78	0.26	0.16
20	1.13	3.38	5.63	0.89	0.30	0.18
22.5	1.00	3.00	5.00	1.00	0.33	0.20
25	0.90	2.70	4.50	1.11	0.37	0.22
27.5	0.82	2.45	4.09	1.22	0.41	0.24
30	0.75	2.25	3.75	1.33	0.44	0.27
32.5	0.69	2.08	3.46	1.44	0.48	0.29
35	0.64	1.93	3.21	1.56	0.52	0.31
37.5	0.60	1.80	3.00	1.67	0.56	0.33
40	0.56	1.69	2.81	1.78	0.59	0.36
42.5	0.53	1.59	2.65	1.89	0.63	0.38
45	0.50	1.50	2.50	2.00	0.67	0.40
47.5	0.47	1.42	2.37	2.11	0.70	0.42
50	0.45	1.35	2.25	2.22	0.74	0.44
55	0.41	1.23	2.05	2.44	0.81	0.49
60	0.38	1.13	1.88	2.67	0.89	0.53
65	0.35	1.04	1.73	2.89	0.96	0.58
70	0.32	0.96	1.61	3.11	1.04	0.62
75	0.30	0.90	1.50	3.33	1.11	0.67
80	0.28	0.84	1.41	3.56	1.19	0.71
85	0.26	0.79	1.32	3.78	1.26	0.76
90	0.25	0.75	1.25	4.00	1.33	0.80
95	0.24	0.71	1.18	4.22	1.41	0.84
100	0.23	0.68	1.13	4.44	1.48	0.89

For heights greater than about 70 m the first period of vibration is greater than 3 seconds. The simplified spectra are computed considering the first two periods of vibrations. Considering this fact the study was restricted up to 50 m.

3 EARTHQUAKE TIME HISTORIES

Artificial earthquake time histories referring to the top of the bedrock have been generated based on an elastic horizontal acceleration response spectrum acc. to EC8, German National Annex. The horizontal elastic acceleration spectrum acc. to EC8 [3] is defined as:

$$\begin{aligned}
 T_A \leq T \leq T_B : \quad S_e(T) &= a_{g,0} \cdot \left[0,4 + \frac{T}{T_B} \cdot (\eta - 0,4) \right] \\
 T_B \leq T \leq T_C : \quad S_e(T) &= a_{g,0} \cdot \eta \\
 T_C \leq T \leq T_D : \quad S_e(T) &= a_{g,0} \cdot \eta \cdot \left(\frac{T_C}{T} \right)
 \end{aligned} \tag{1}$$

$$T_D \leq T: \quad S_e(T) = a_{g,0} \cdot \eta \cdot \left(\frac{T_C}{T}\right) \cdot \left(\frac{T_D}{T}\right)$$

with

$$a_{g,0} = a_{gR} \cdot \gamma_I \cdot S \cdot 2,5 \tag{1a}$$

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

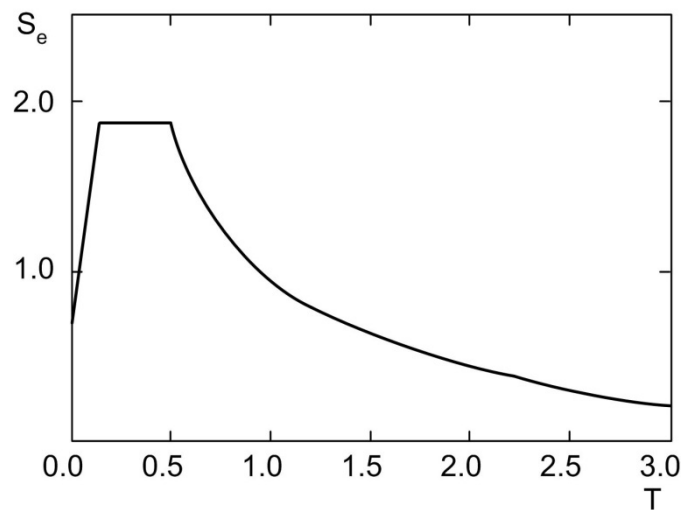


Figure 2: Acceleration response spectrum for ground type C-S acc. to [3]

As the response spectrum is linearly dependent on these parameters, it can be adjusted easily later by multiplying the response spectrum with the actual parameters. However, it should be observed that for $T=0$ the spectral value is $a_{gR} \cdot \gamma_I \cdot S$.

The artificial acceleration time histories for the target spectrum in Fig. 2 are computed as the sum of several hundred sine waves with randomly distributed phase angles and are iteratively adjusted to the target spectrum. Figure 3 shows a typical acceleration time history created in SYNTH [2].

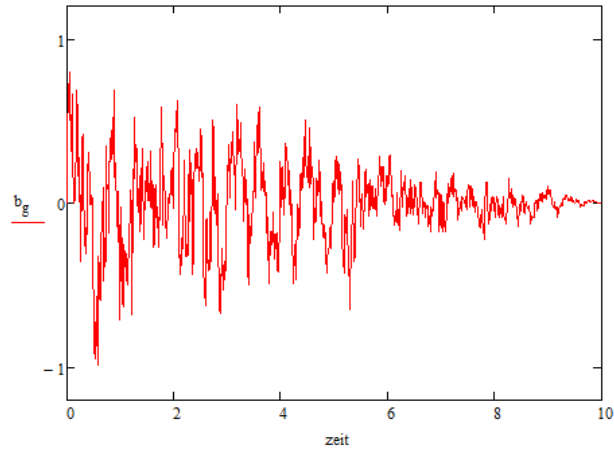
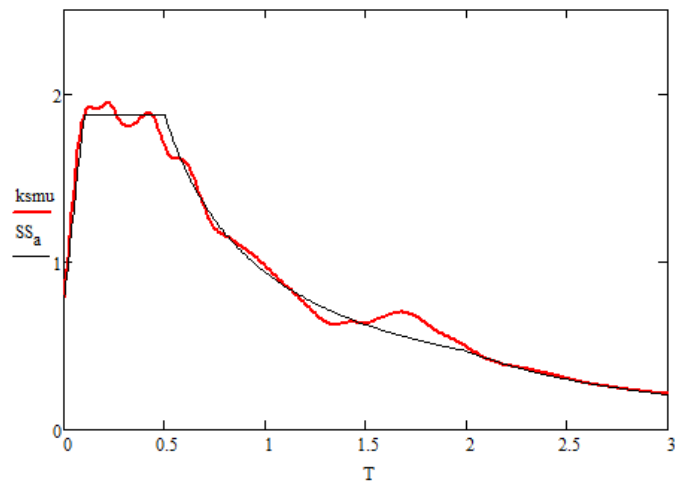
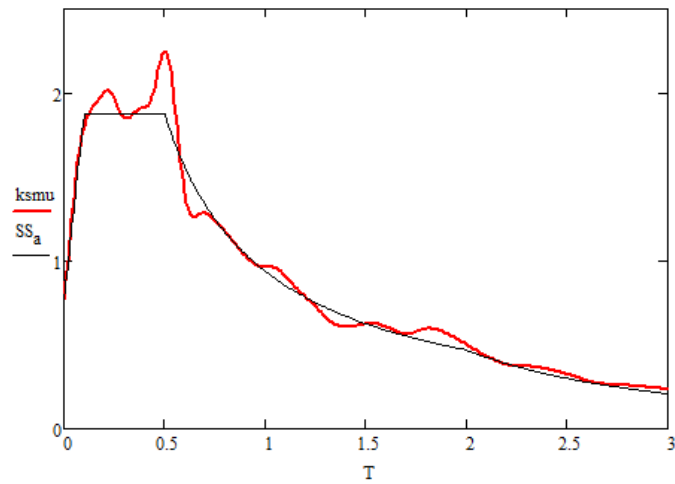


Figure 3: Artificial acceleration time history

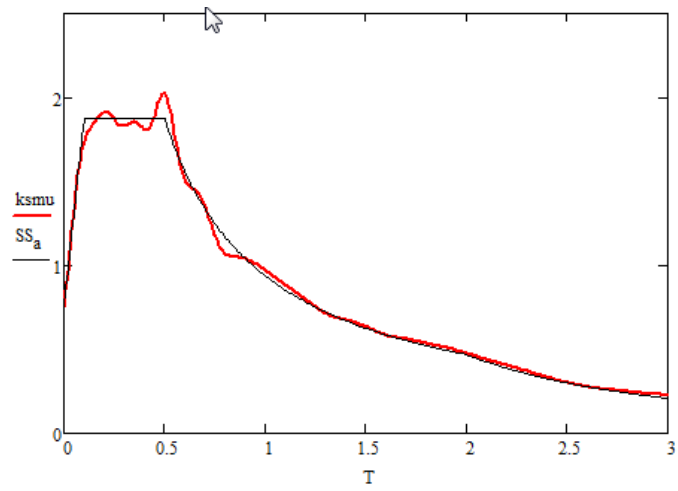
Five artificial time acceleration time histories have been generated to be used in the following analyses. Their 5% acceleration response spectra shown in the figures 4(a) – 4(e) compare well with the source spectrum in Fig. 2.



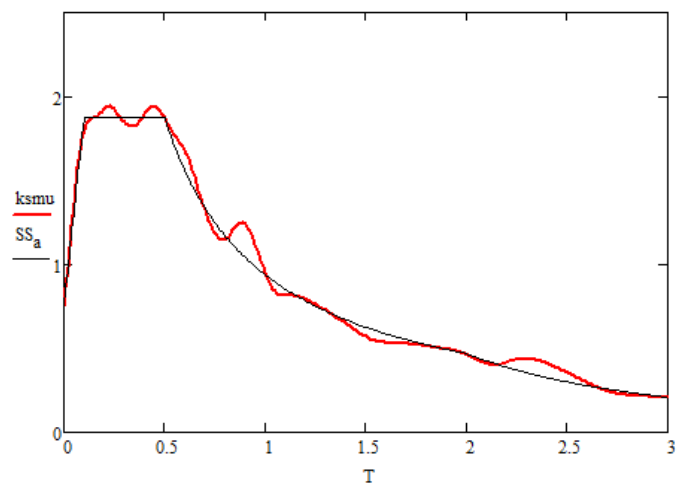
(a) IY5



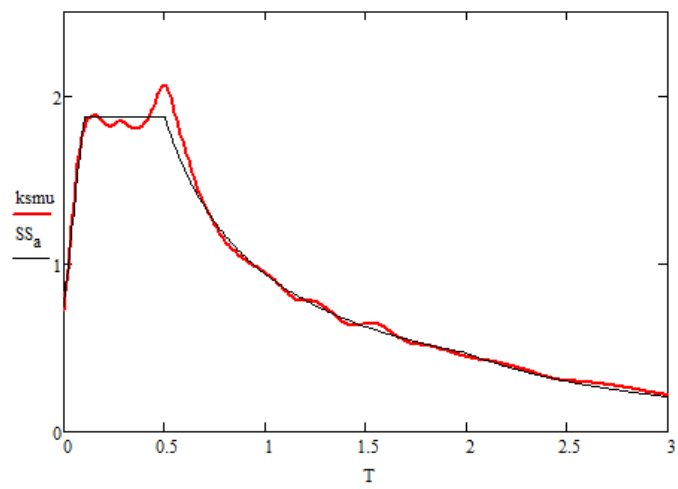
(b) IY20



(c) IY40



(d) IY100



(e) IY1000

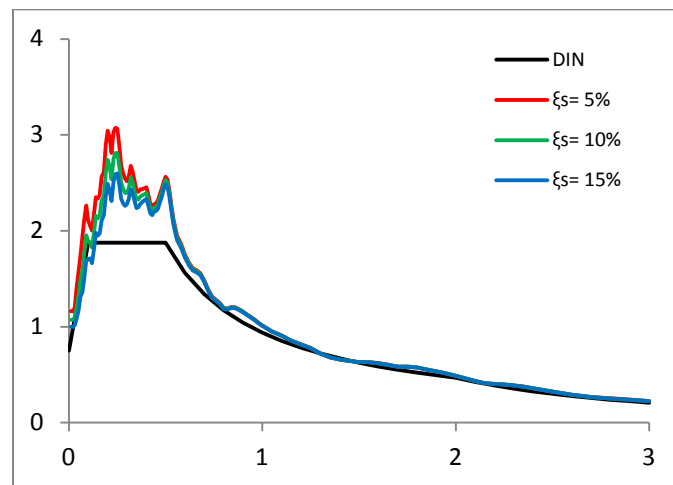
Figure 4 a-e: Response spectra of the artificial acceleration time histories vs. target spectrum

4 ACCELERATION RESPONSE SPECTRA OF A LAYER

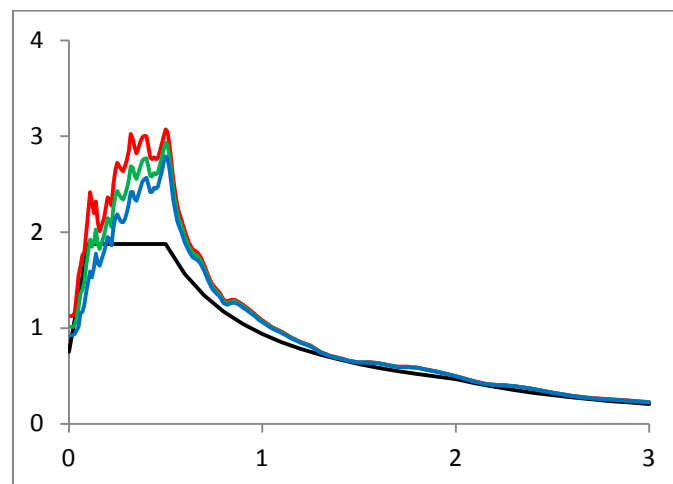
This chapter contains the graphical representation of the acceleration response spectra on the top of the elastic layer, obtained with SHAKE2000 for the heights and damping values given in table 1. The analyses are performed using 6 different shear wave velocities for the half space while the shear wave velocity in the layer is kept constant. The hysteretic material damping in the layer is assumed to be 5%, 10%, 15%. This allows adopting the damping to the strain level in the layer.

It should be noted that the spectrum at the top of the bedrock in Fig. 2 is for shear wave velocities between 150 m/s and 350 m/s. Hence the computations for 450, 520 and 1000 m/s are to be used for equivalent models only (see chapter 5).

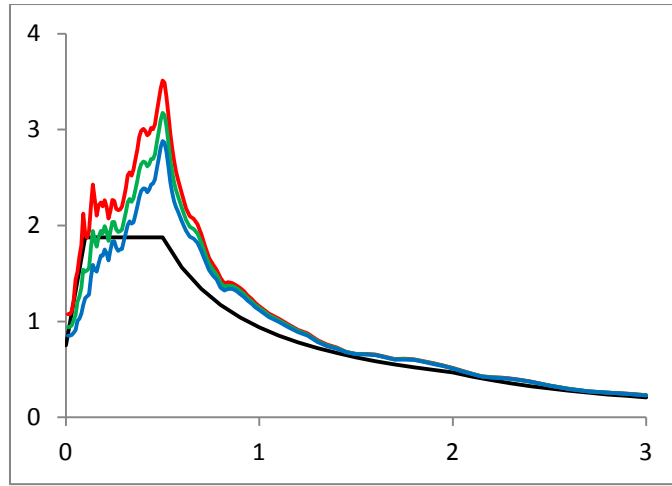
4.1 Bedrock shear wave velocity equal to 154 m/s



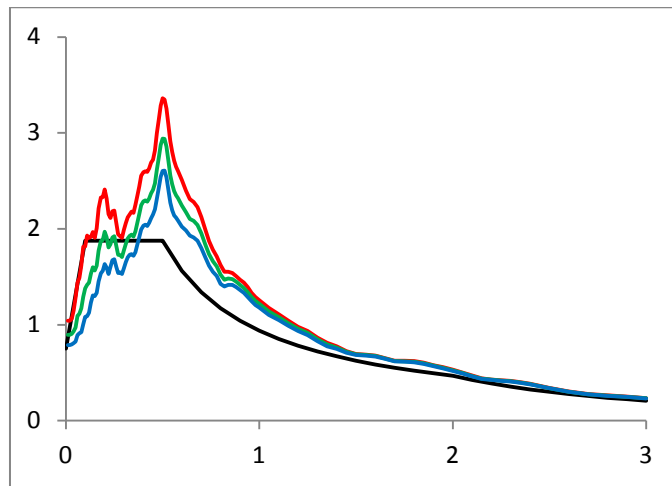
5m ($v_{s,G} = 154$ m/s)



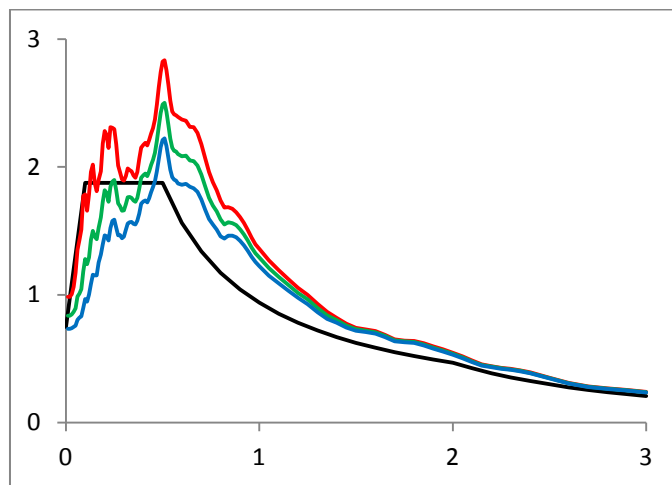
7.5m ($v_{s,G} = 154$ m/s)



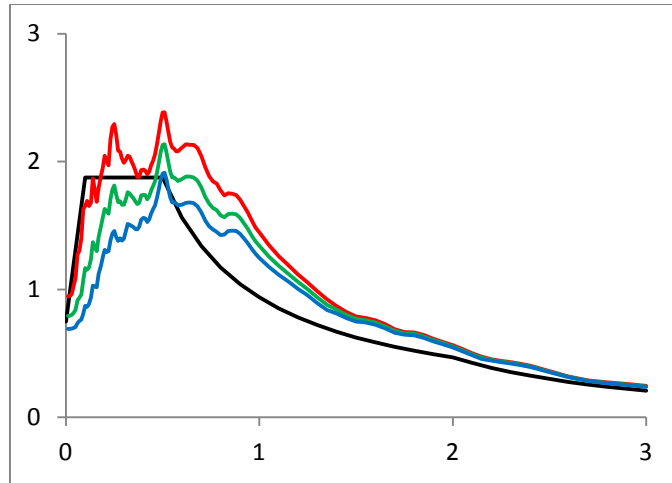
10m ($v_{s,G} = 154$ m/s)



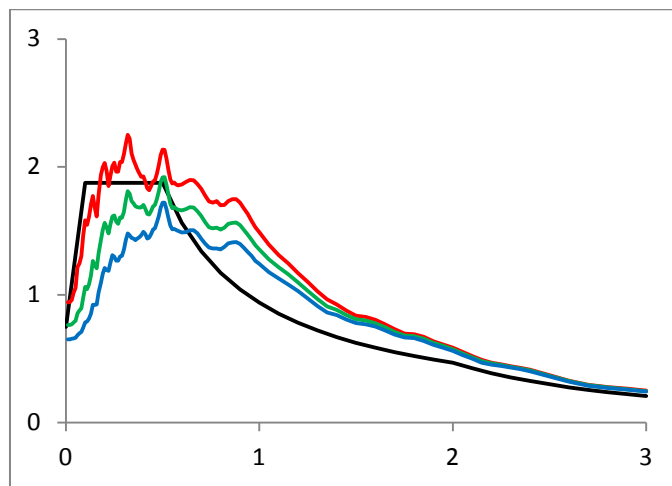
12.5m ($v_{s,G} = 154$ m/s)



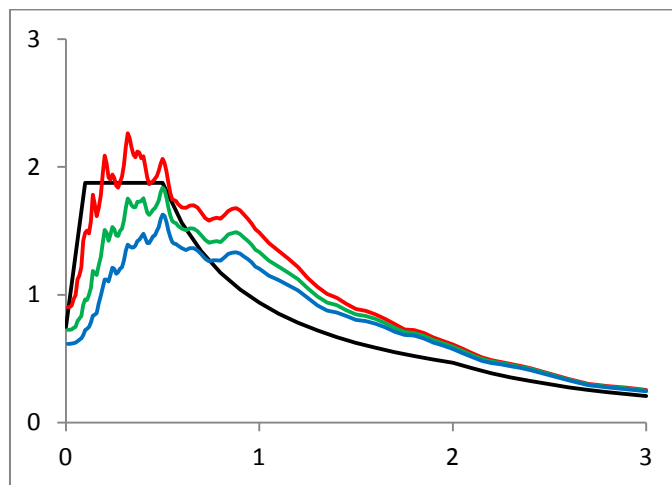
15m ($v_{s,G} = 154$ m/s)



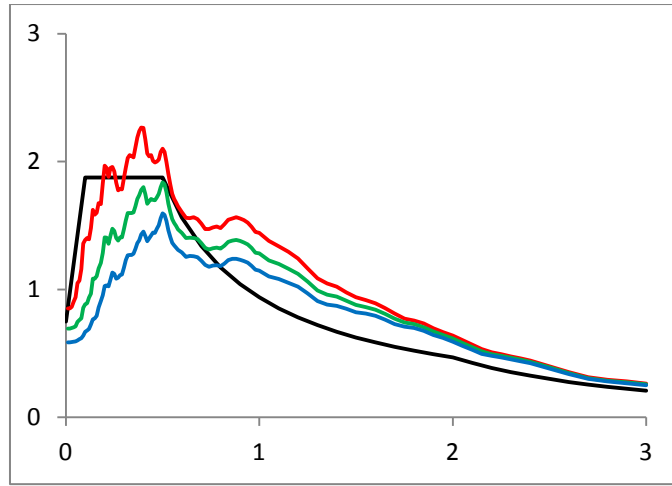
17.5m ($v_{s,G} = 154$ m/s)



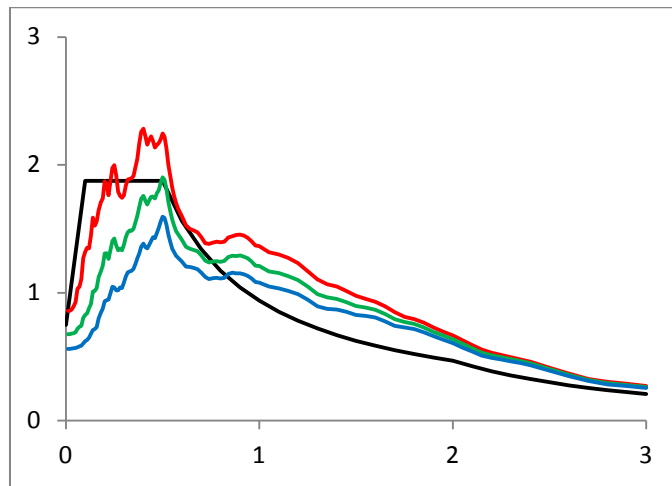
20m ($v_{s,G} = 154$ m/s)



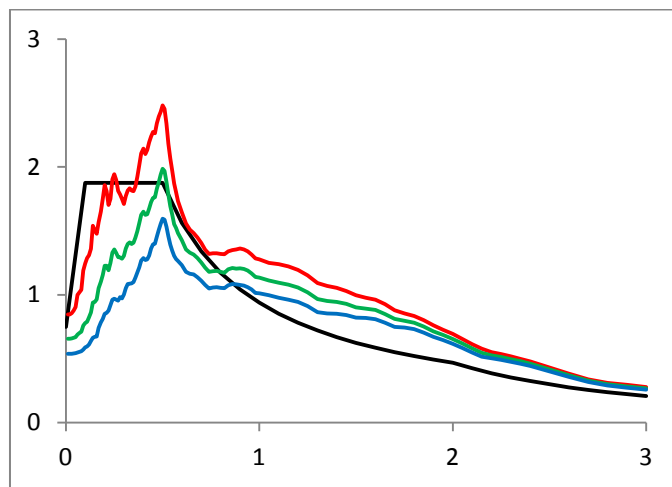
22.5m ($v_{s,G} = 154$ m/s)



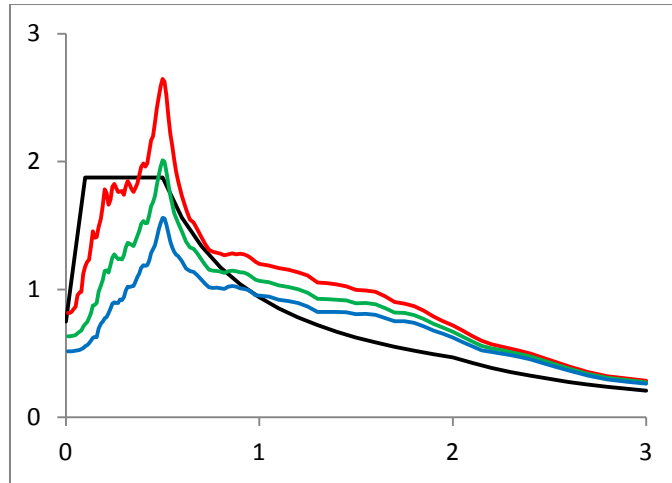
25m ($v_{s,G} = 154$ m/s)



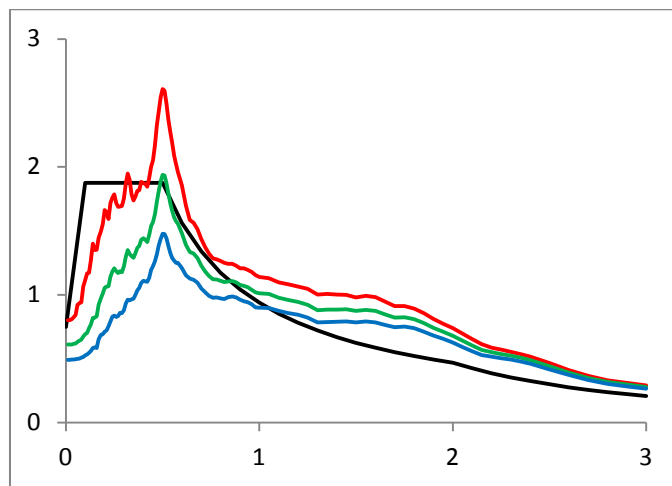
27.5m ($v_{s,G} = 154$ m/s)



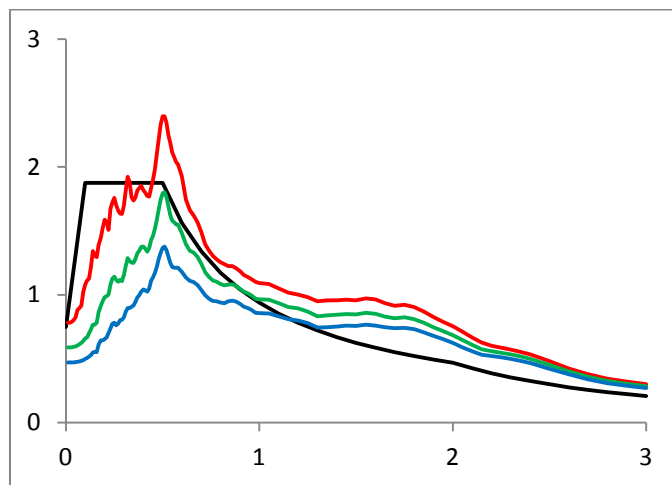
30m ($v_{s,G} = 154$ m/s)



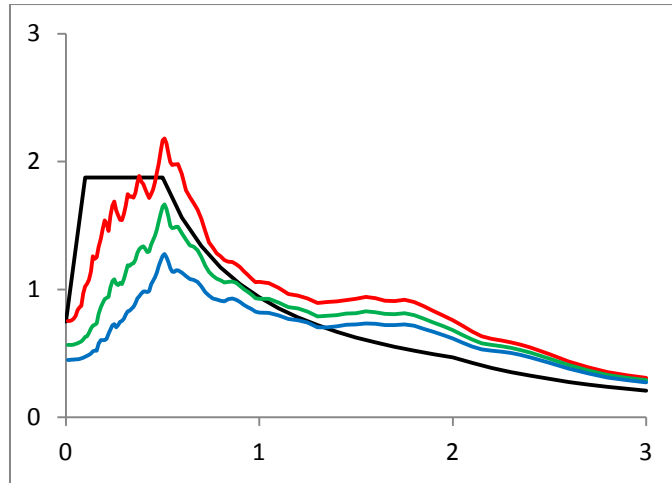
32.5m ($v_{s,G} = 154$ m/s)



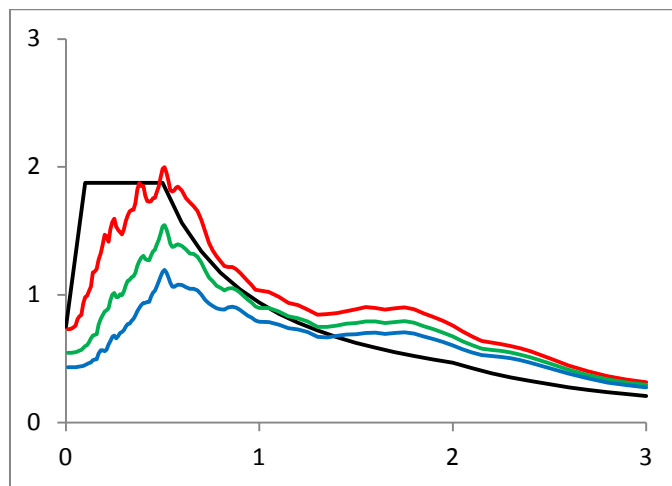
35m ($v_{s,G} = 154$ m/s)



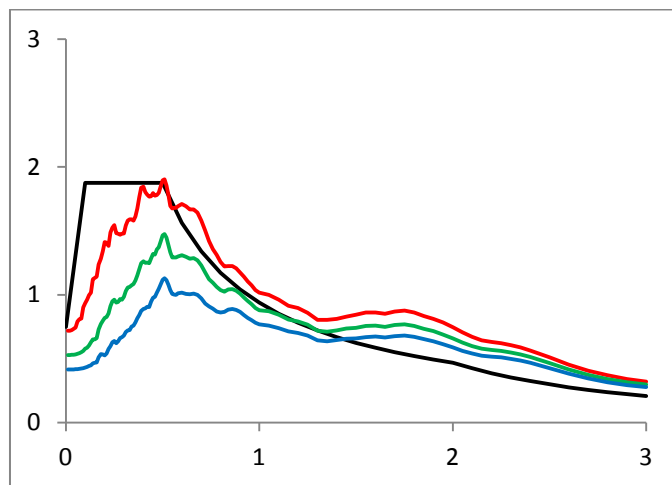
37.5m ($v_{s,G} = 154$ m/s)



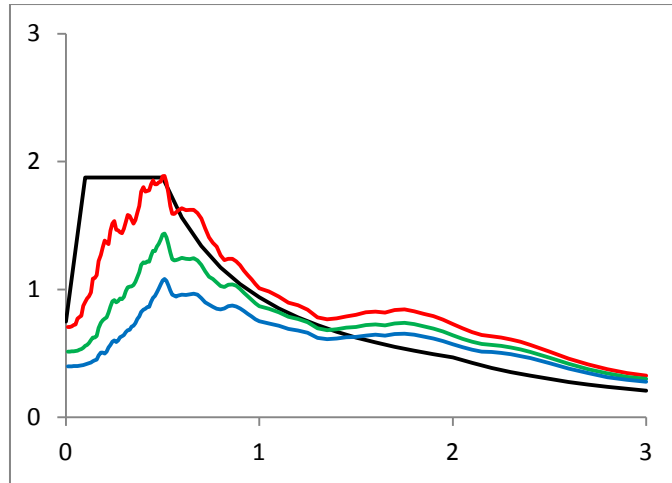
40m ($v_{s,G} = 154$ m/s)



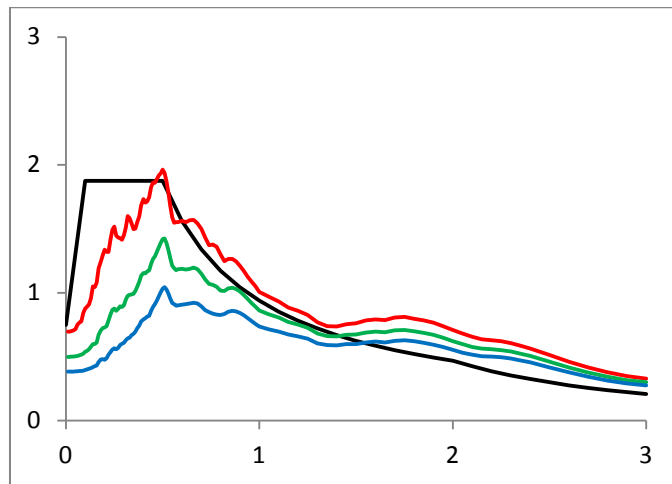
42.5m ($v_{s,G} = 154$ m/s)



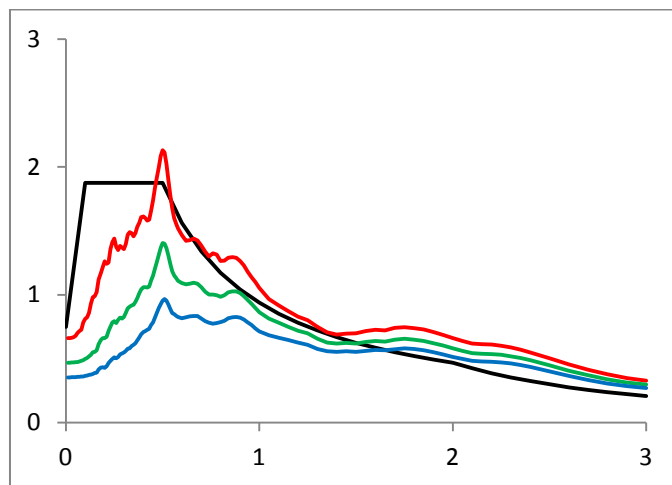
45m ($v_{s,G} = 154$ m/s)



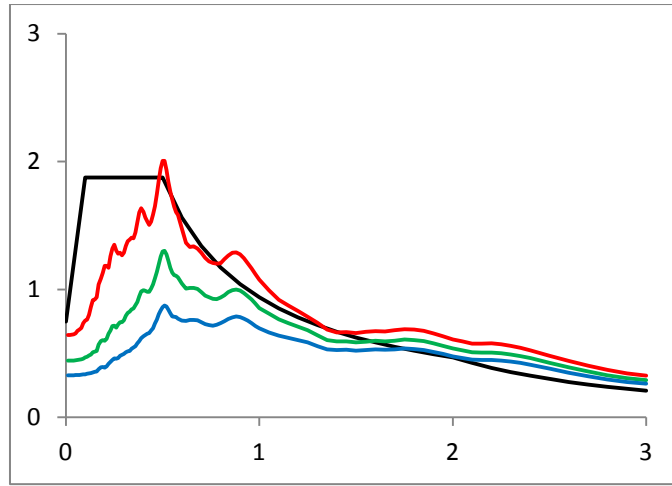
47.5m ($v_{s,G} = 154$ m/s)



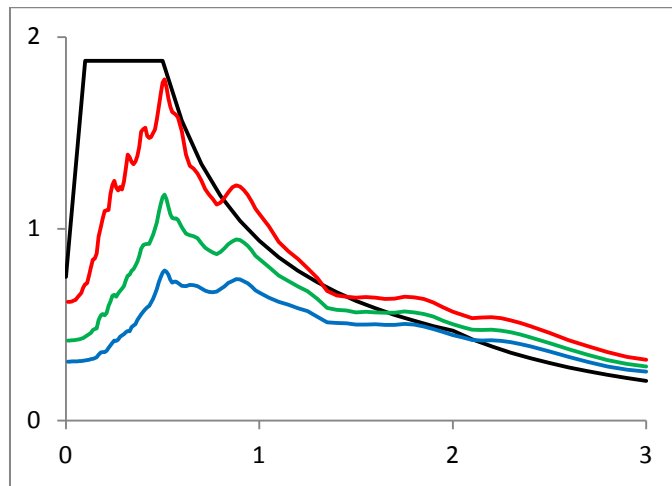
50m ($v_{s,G} = 154$ m/s)



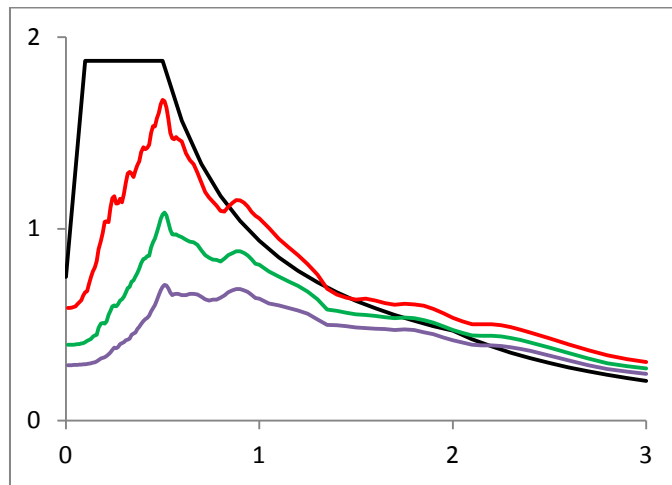
55m ($v_{s,G} = 154$ m/s)



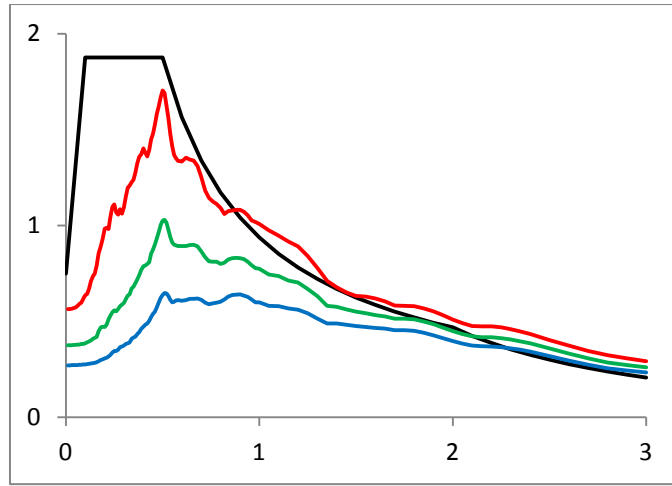
60m ($v_{s,G} = 154$ m/s)



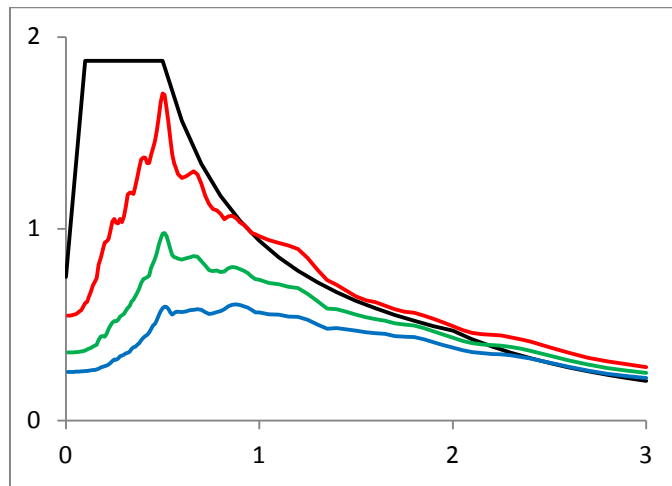
65m ($v_{s,G} = 154$ m/s)



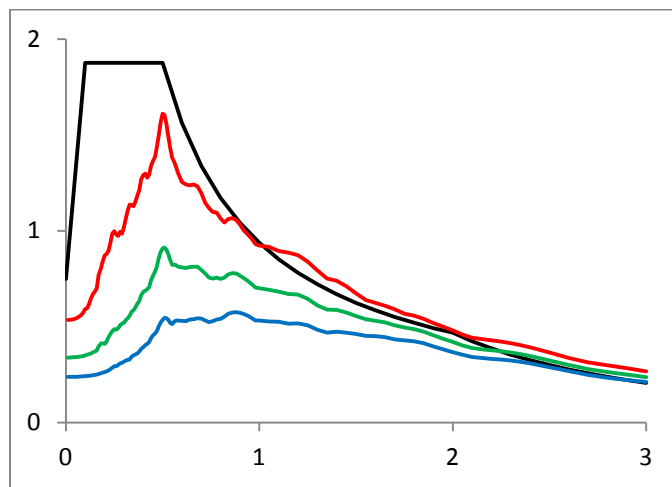
70m ($v_{s,G} = 154$ m/s)



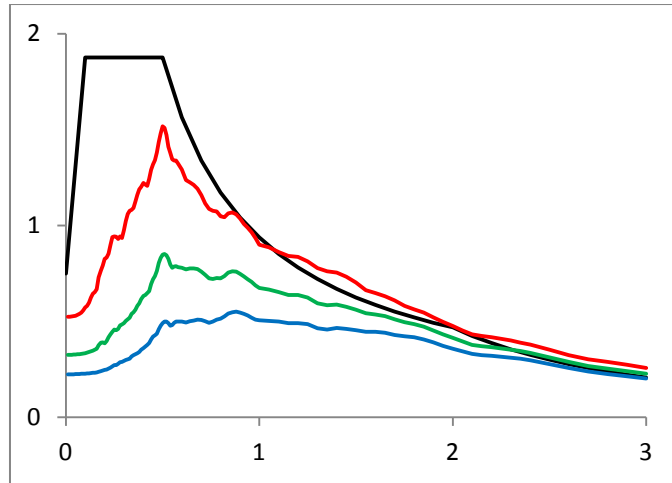
75m ($v_{s,G} = 154$ m/s)



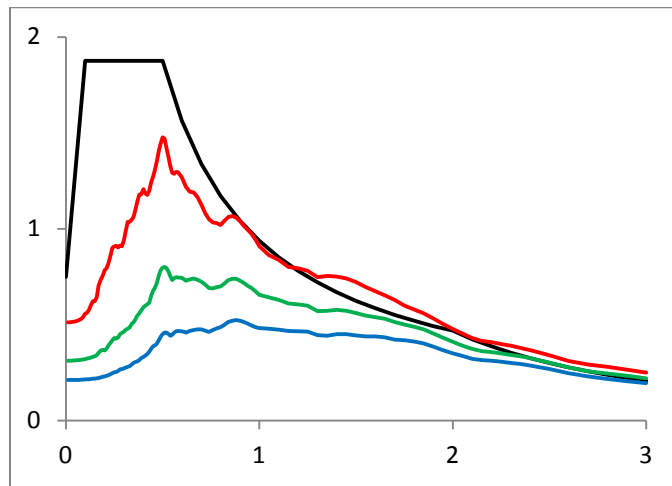
80m ($v_{s,G} = 154$ m/s)



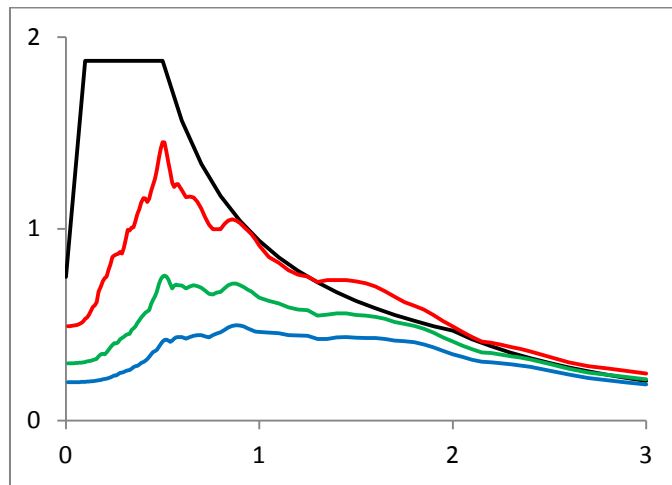
85m ($v_{s,G} = 154$ m/s)



90m ($v_{s,G} = 154$ m/s)

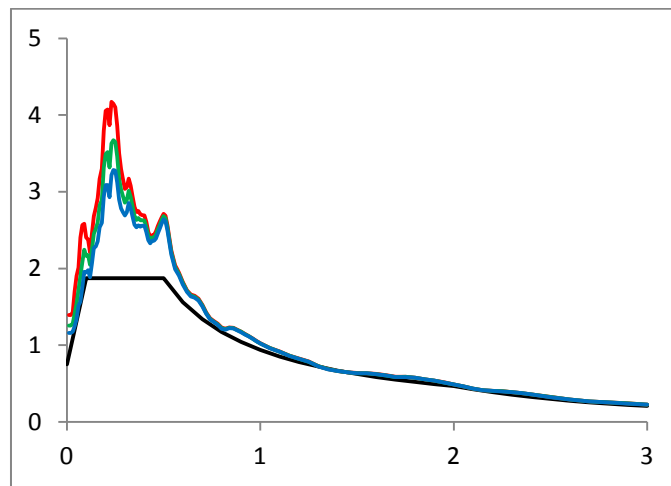


95m ($v_{s,G} = 154$ m/s)

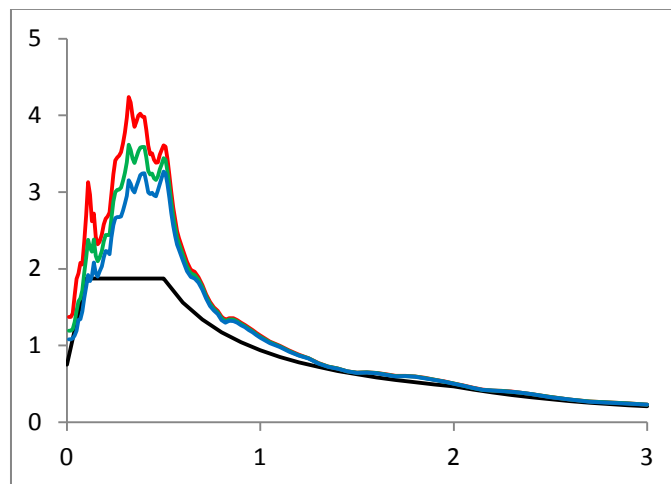


100m ($v_{s,G} = 154$ m/s)

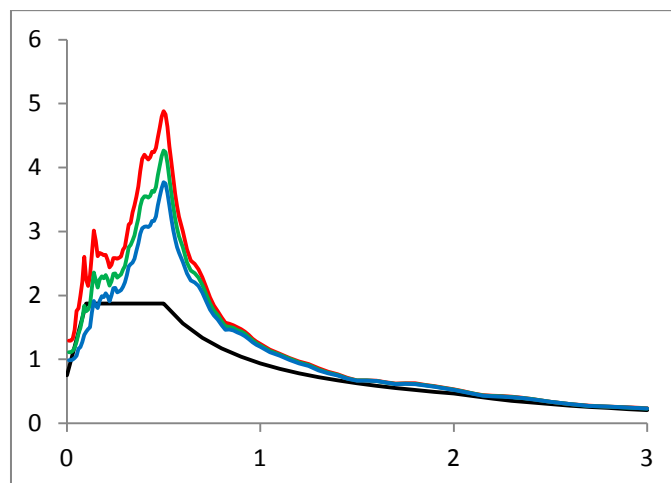
4.2 Bedrock shear wave velocity equal to 250 m/s



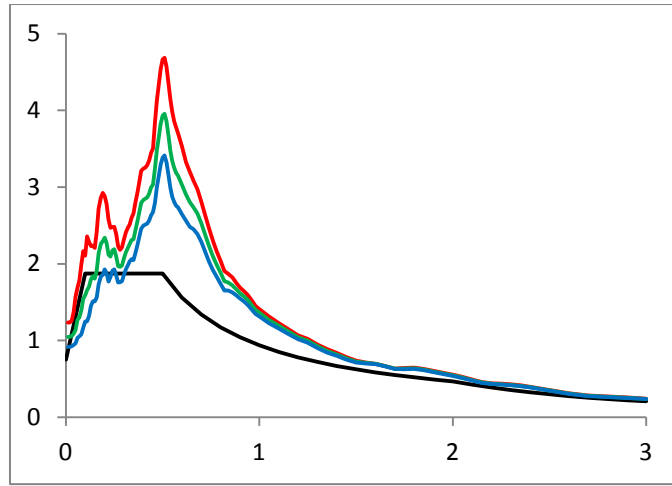
5m ($v_{s,G} = 250$ m/s)



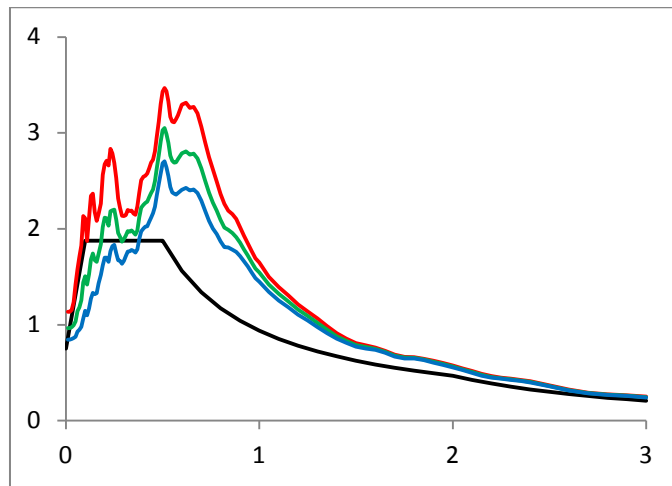
7.5m ($v_{s,G} = 250$ m/s)



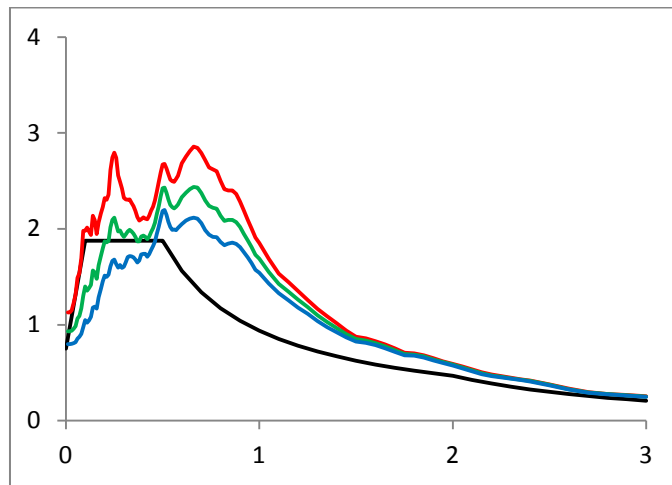
10m ($v_{s,G} = 250$ m/s)



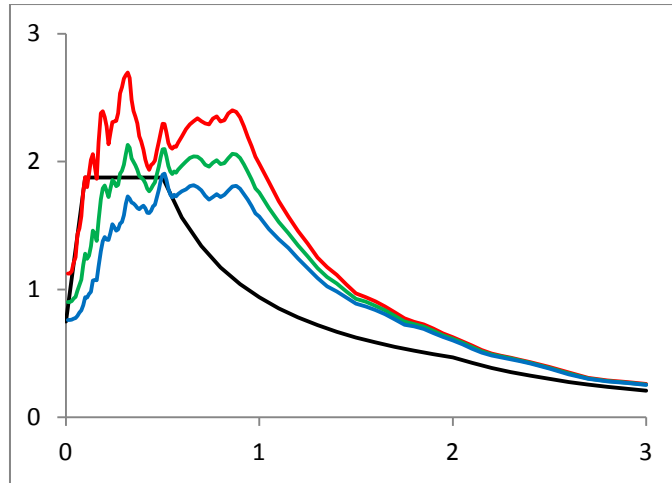
12.5m ($v_{s,G} = 250$ m/s)



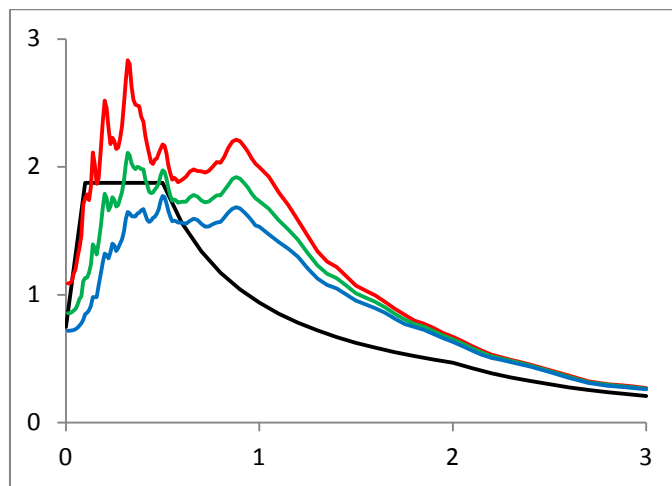
15m ($v_{s,G} = 250$ m/s)



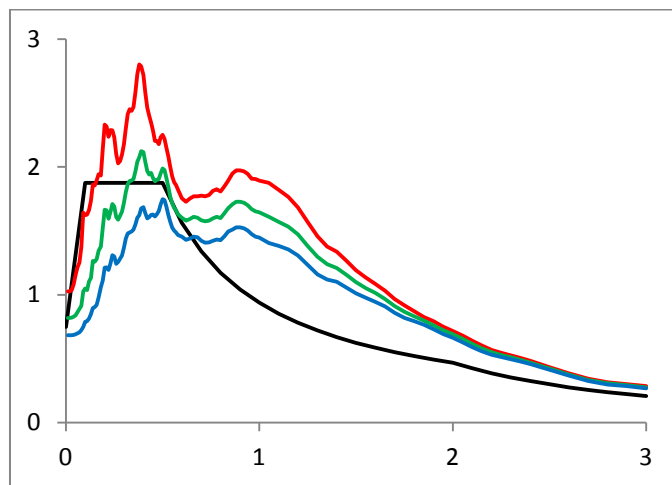
17.5m ($v_{s,G} = 250$ m/s)



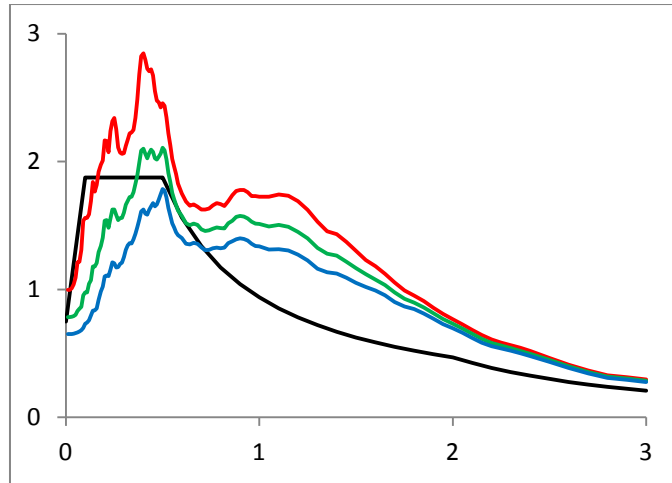
20m ($v_{s,G} = 250$ m/s)



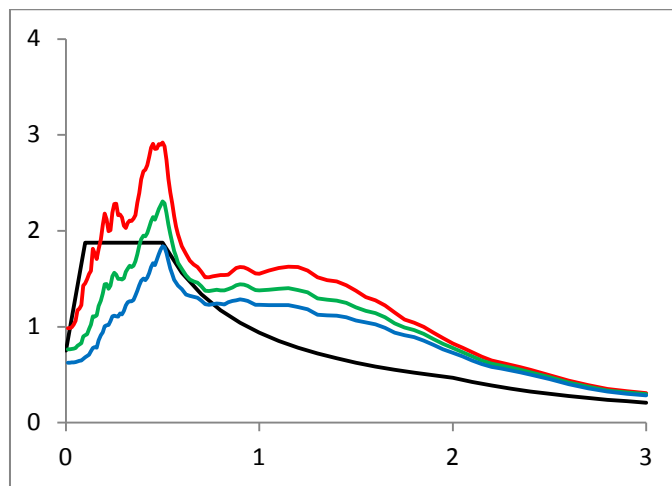
22.5m ($v_{s,G} = 250$ m/s)



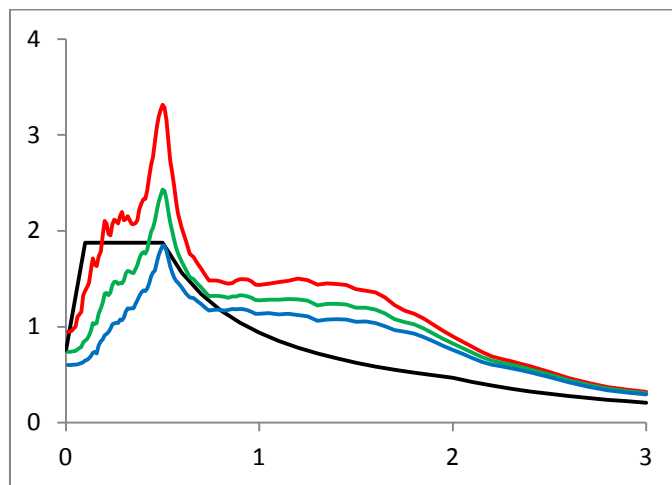
25m ($v_{s,G} = 250$ m/s)



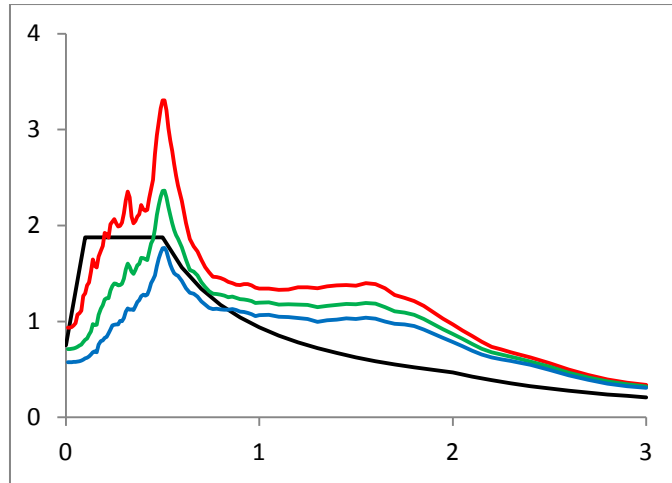
27.5m ($v_{s,G} = 250$ m/s)



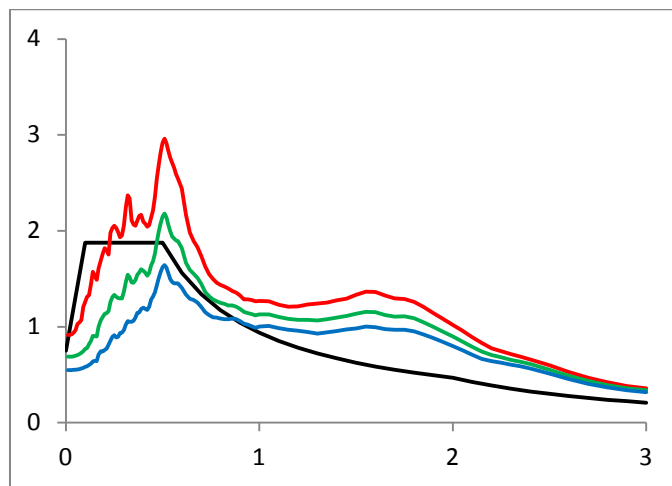
30m ($v_{s,G} = 250$ m/s)



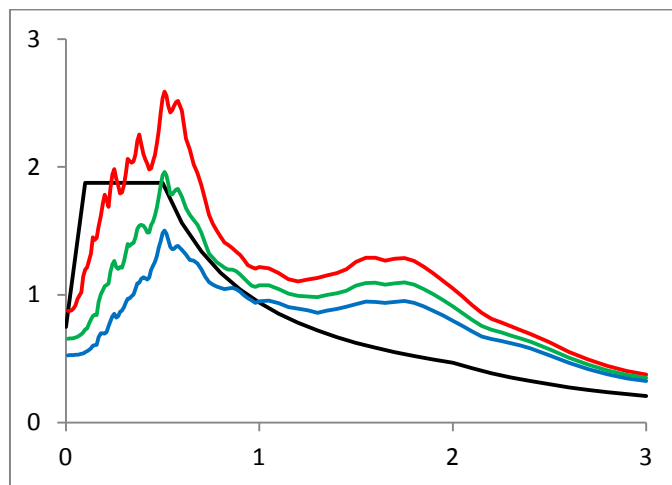
32.5m ($v_{s,G} = 250$ m/s)



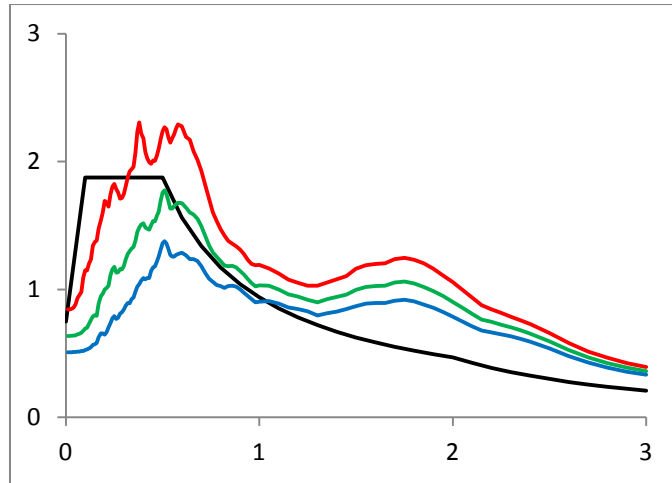
35m ($v_{s,G} = 250$ m/s)



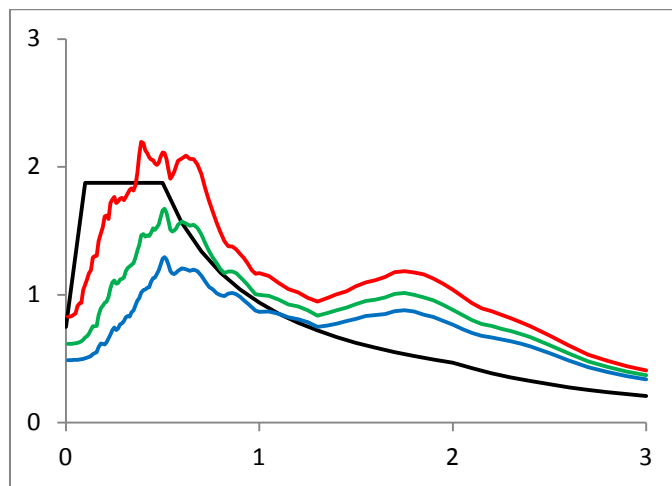
37.5m ($v_{s,G} = 250$ m/s)



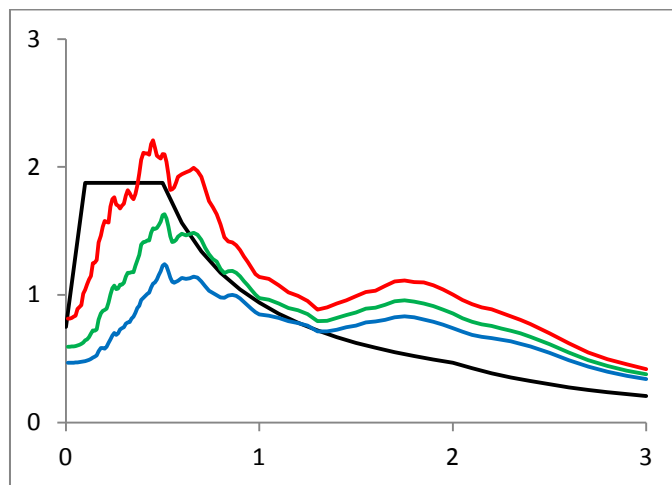
40m ($v_{s,G} = 250$ m/s)



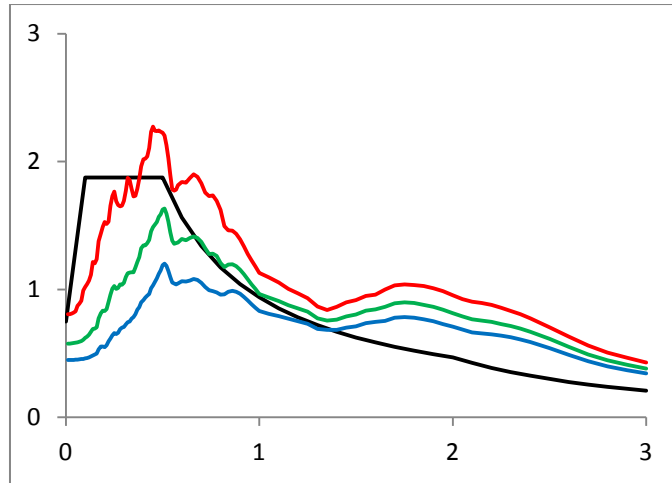
42.5m ($v_{s,G} = 250$ m/s)



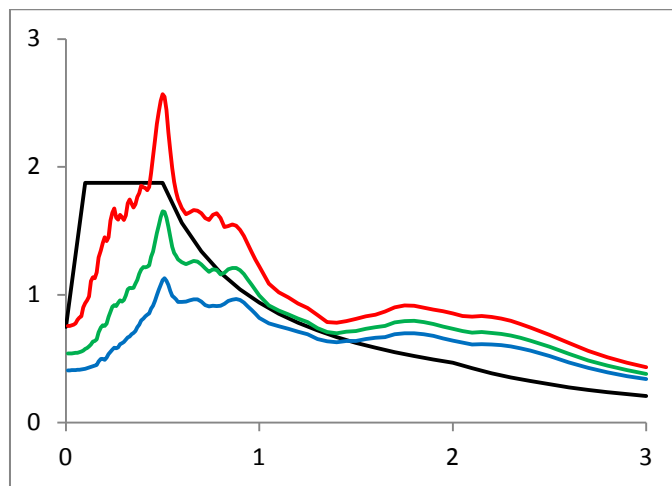
45m ($v_{s,G} = 250$ m/s)



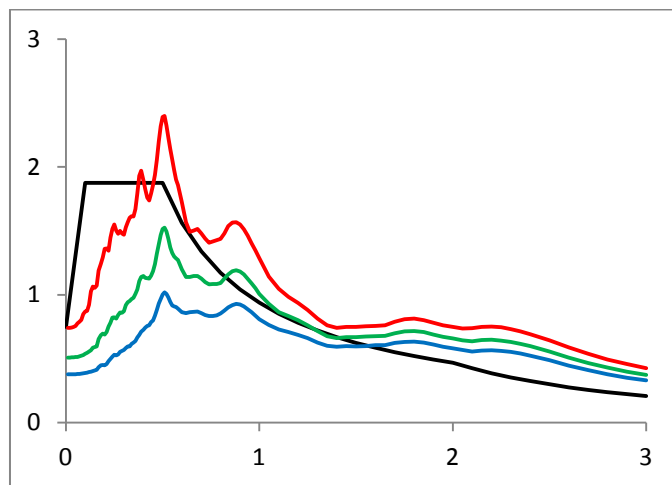
47.5m ($v_{s,G} = 250$ m/s)



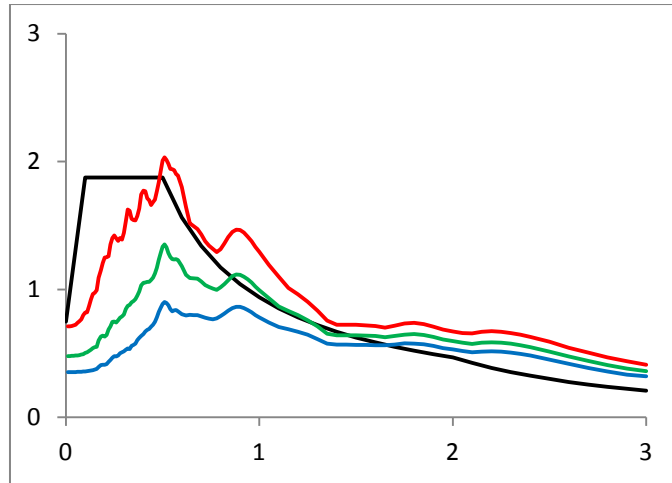
50m ($v_{s,G} = 250$ m/s)



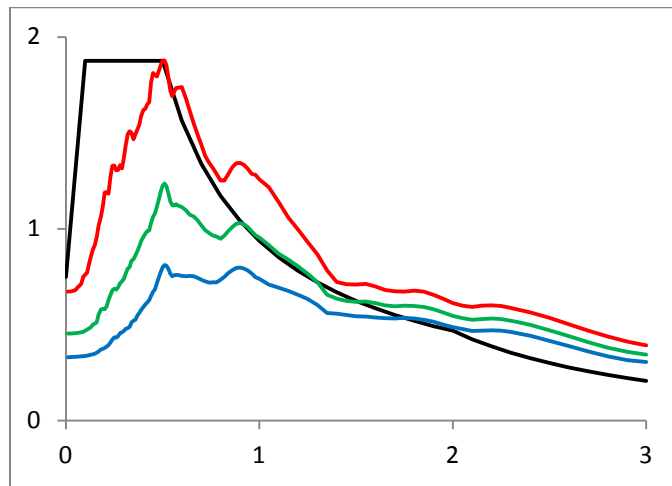
55m ($v_{s,G} = 250$ m/s)



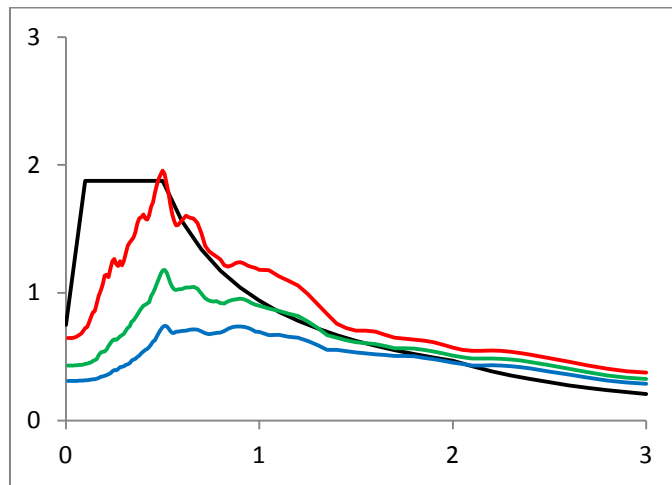
60m ($v_{s,G} = 250$ m/s)



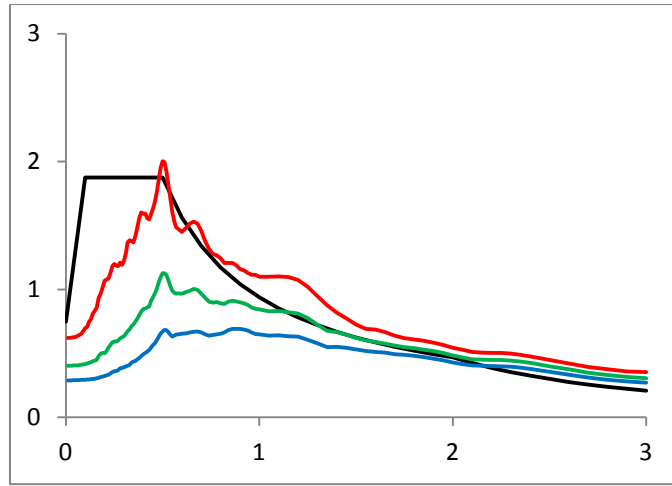
65m ($v_{s,G} = 250$ m/s)



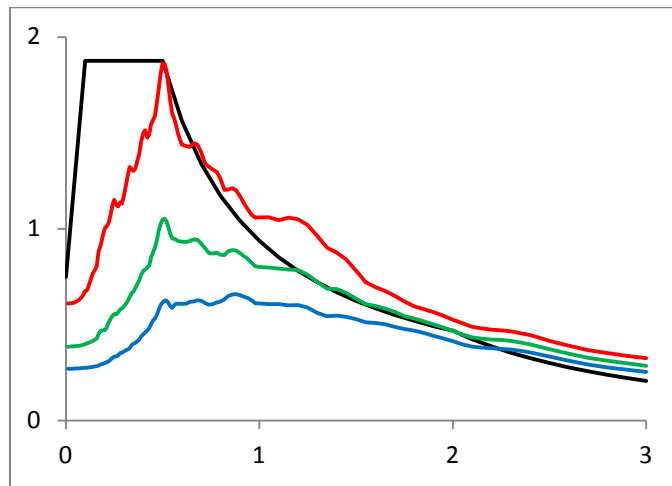
70m ($v_{s,G} = 250$ m/s)



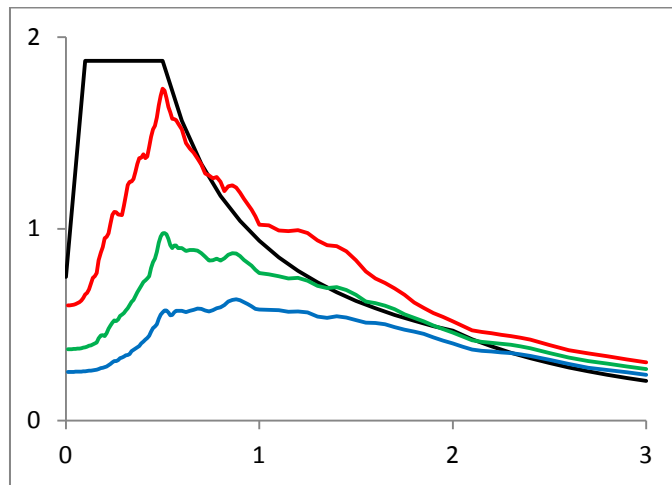
75m ($v_{s,G} = 250$ m/s)



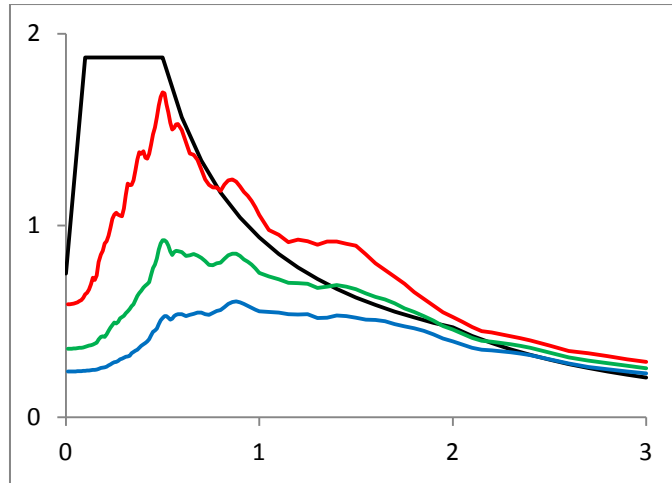
80m ($v_{s,G} = 250$ m/s)



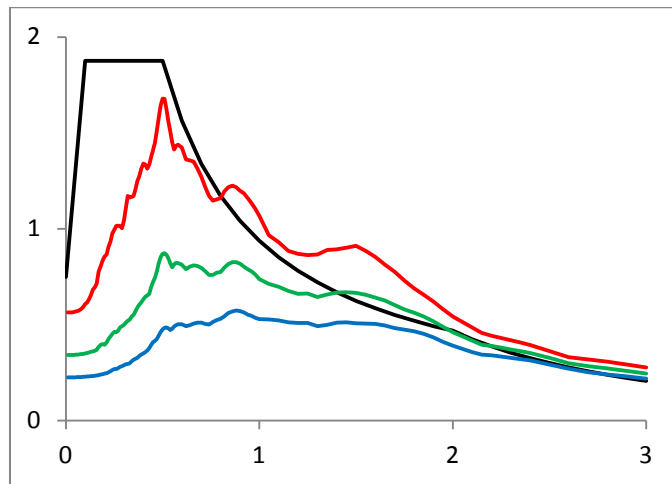
85m ($v_{s,G} = 250$ m/s)



90m ($v_{s,G} = 250$ m/s)

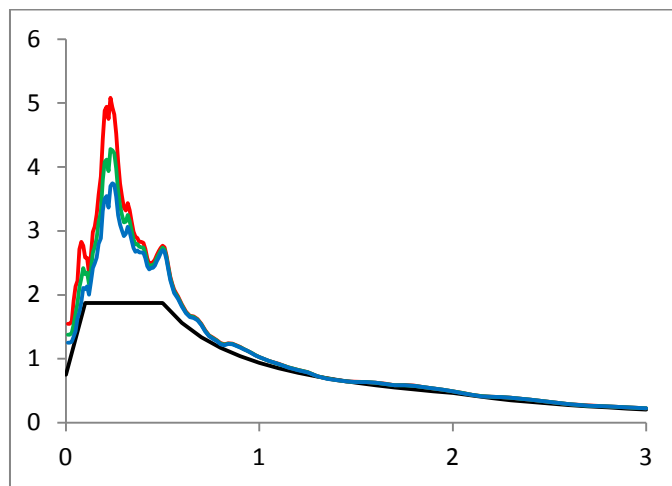


95m ($v_{s,G} = 250$ m/s)

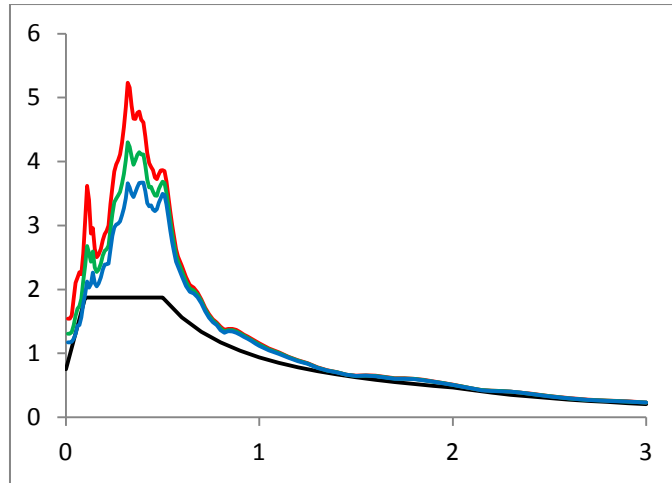


100m ($v_{s,G} = 250$ m/s)

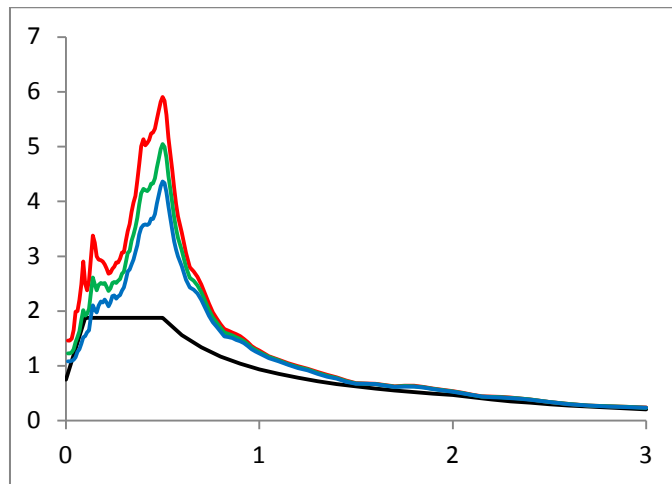
4.3 Bedrock shear wave velocity equal with 350m/s



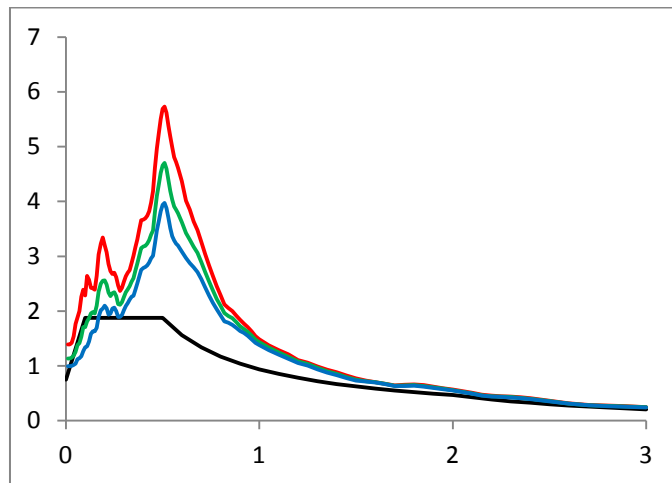
5m ($v_{s,G} = 350$ m/s)



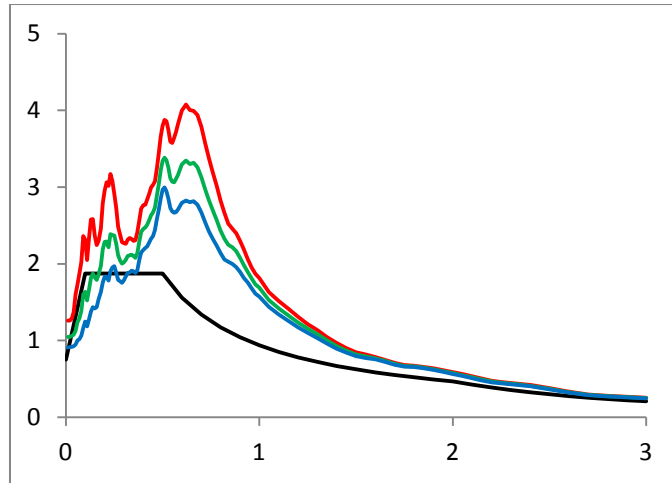
7.5m ($v_{s,G} = 350$ m/s)



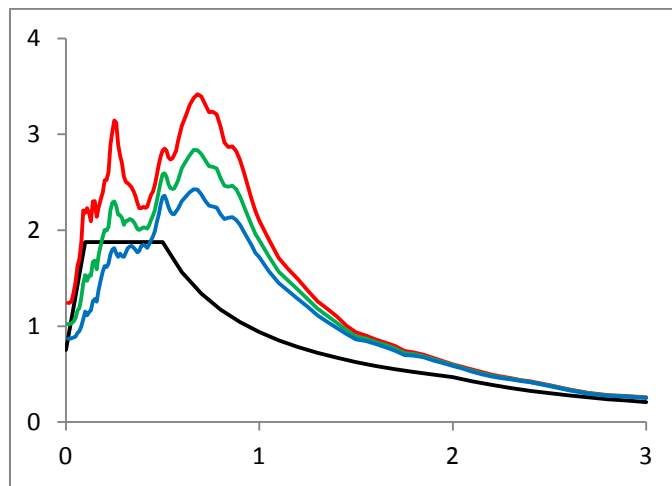
10m ($v_{s,G} = 350$ m/s)



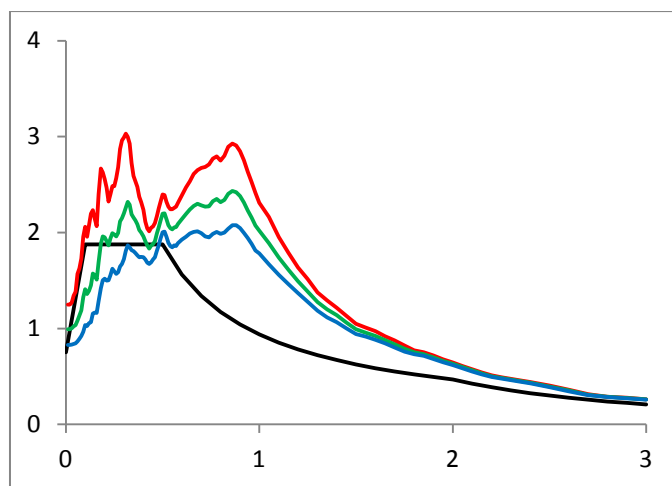
12.5m ($v_{s,G} = 350$ m/s)



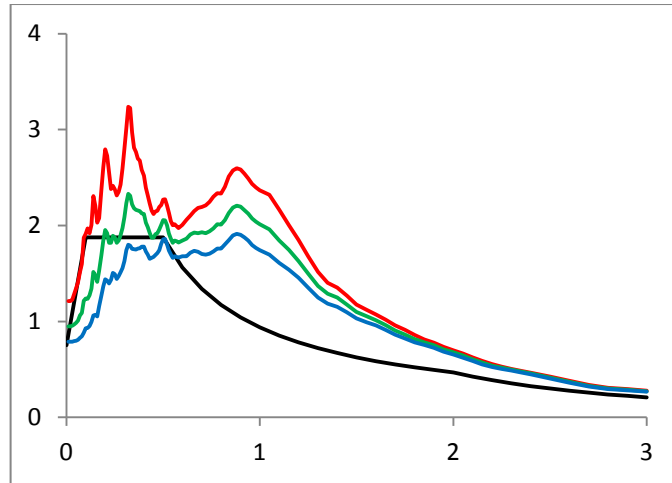
15m ($v_{s,G} = 350$ m/s)



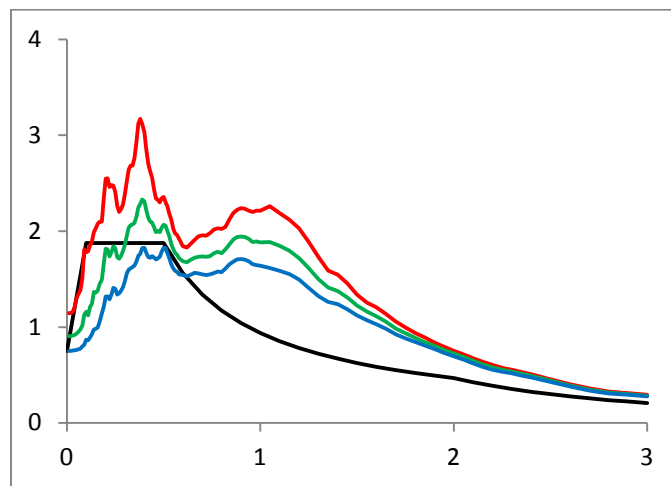
17.5m ($v_{s,G} = 350$ m/s)



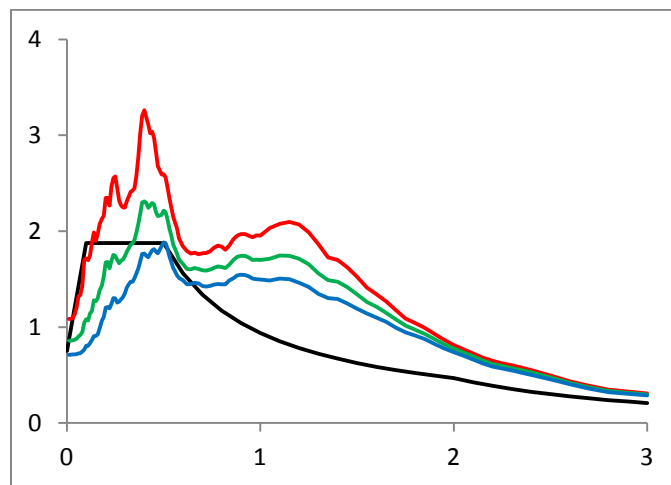
20m ($v_{s,G} = 350$ m/s)



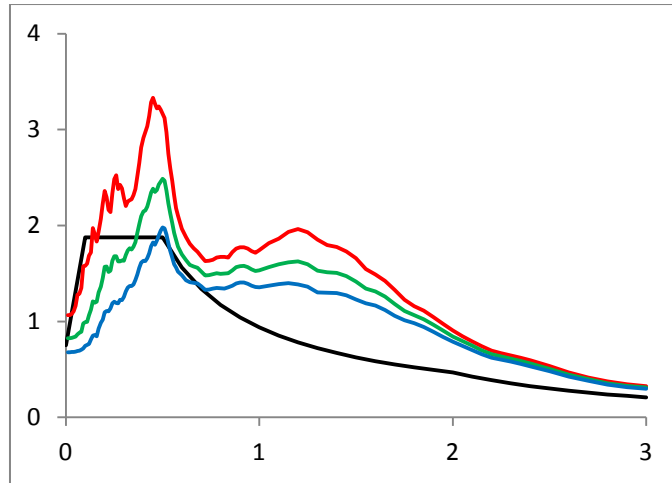
22.5m ($v_{s,G} = 350$ m/s)



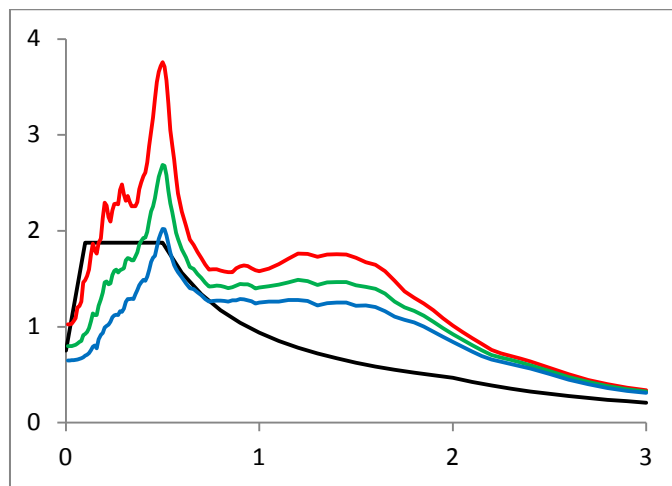
25m ($v_{s,G} = 350$ m/s)



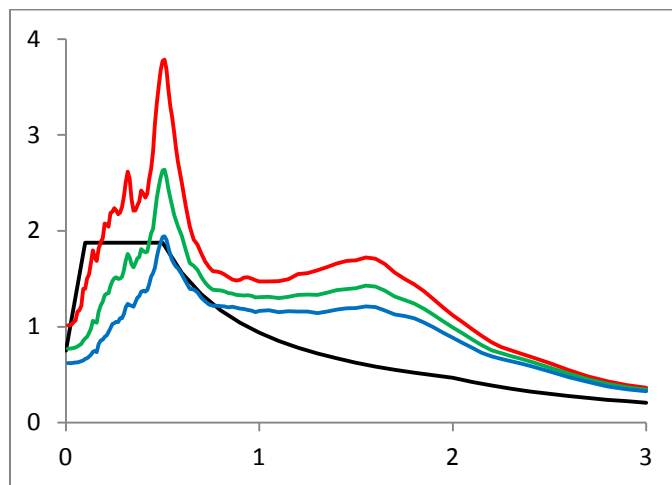
27.5m ($v_{s,G} = 350$ m/s)



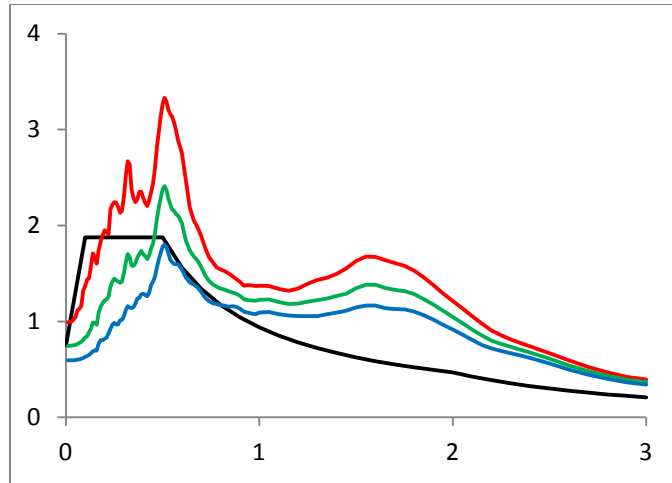
30m ($v_{s,G} = 350$ m/s)



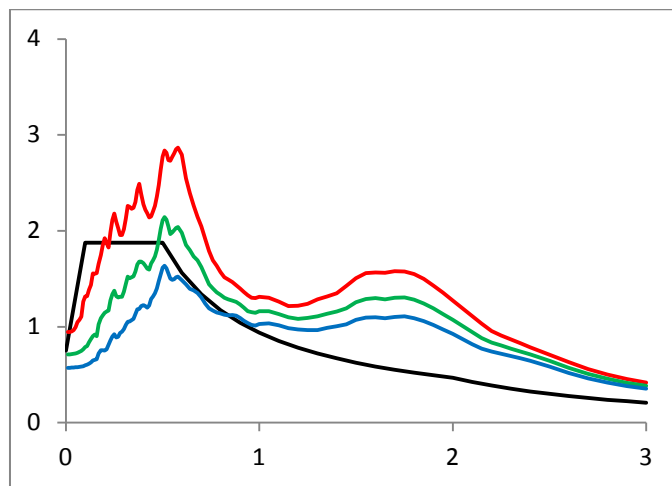
32.5m ($v_{s,G} = 350$ m/s)



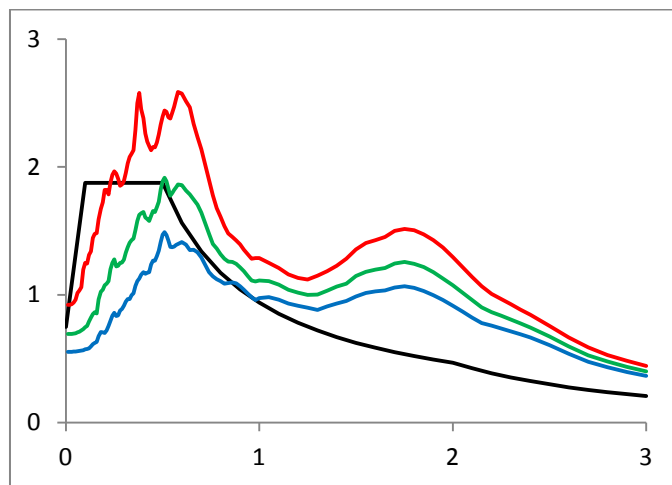
35m ($v_{s,G} = 350$ m/s)



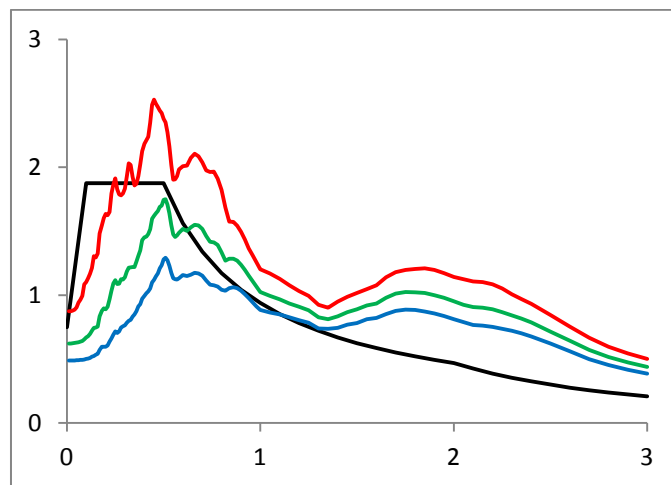
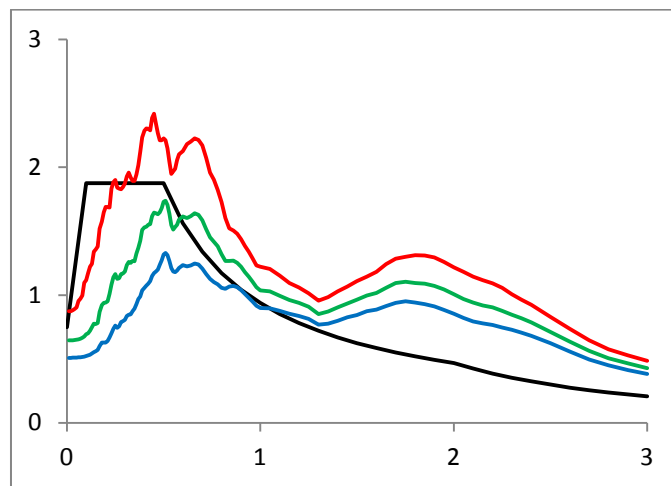
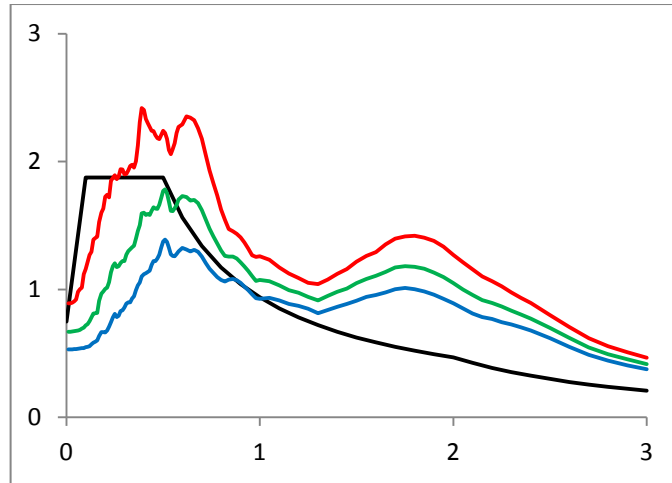
37.5m ($v_{s,G} = 350$ m/s)

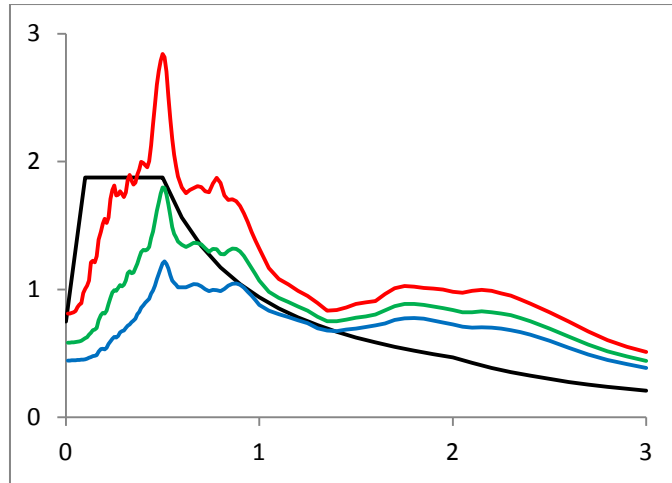


40m ($v_{s,G} = 350$ m/s)

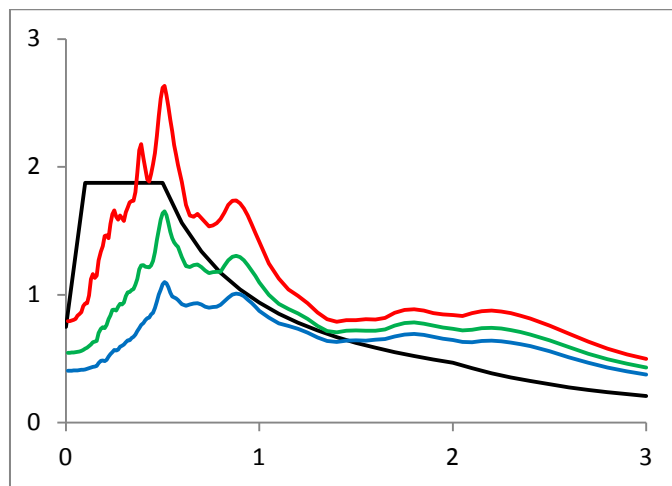


42.5m ($v_{s,G} = 350$ m/s)

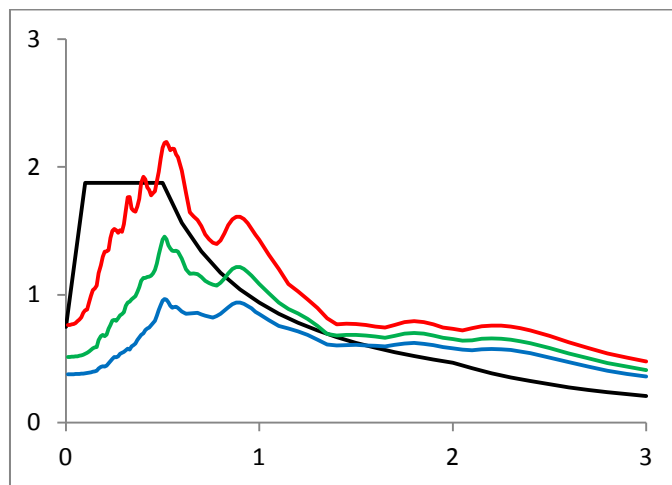




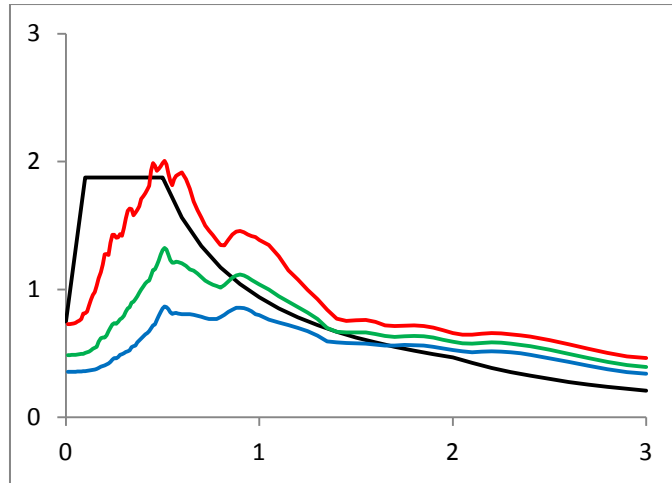
55m ($v_{s,G} = 350$ m/s)



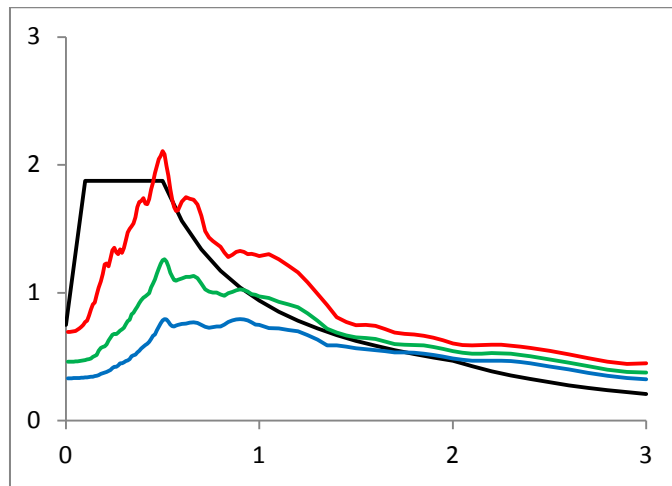
60m ($v_{s,G} = 350$ m/s)



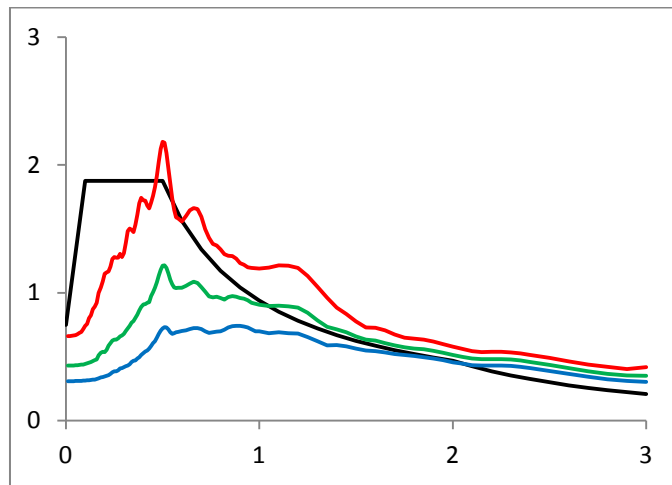
65m ($v_{s,G} = 350$ m/s)



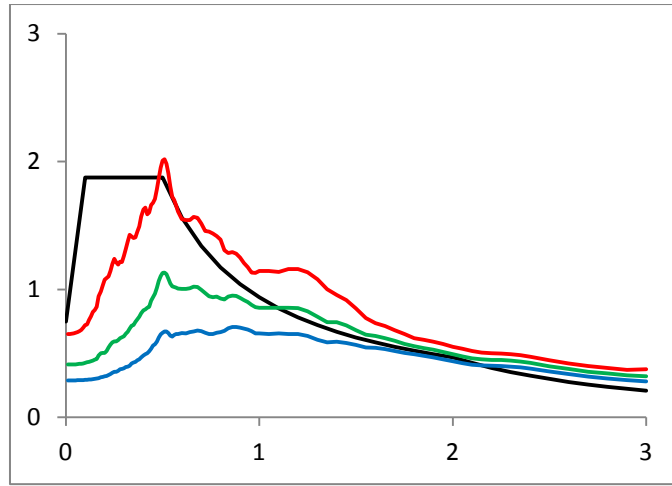
70m ($v_{s,G} = 350$ m/s)



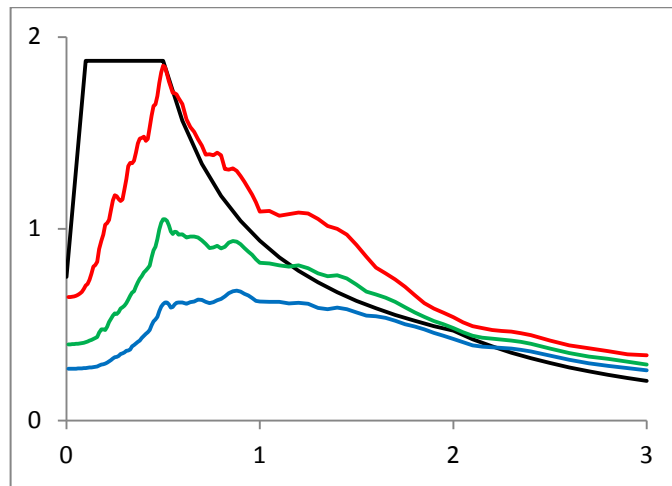
75m ($v_{s,G} = 350$ m/s)



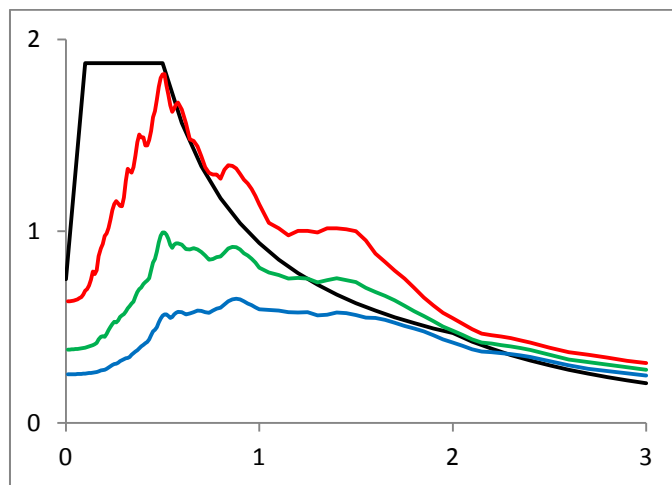
80m ($v_{s,G} = 350$ m/s)



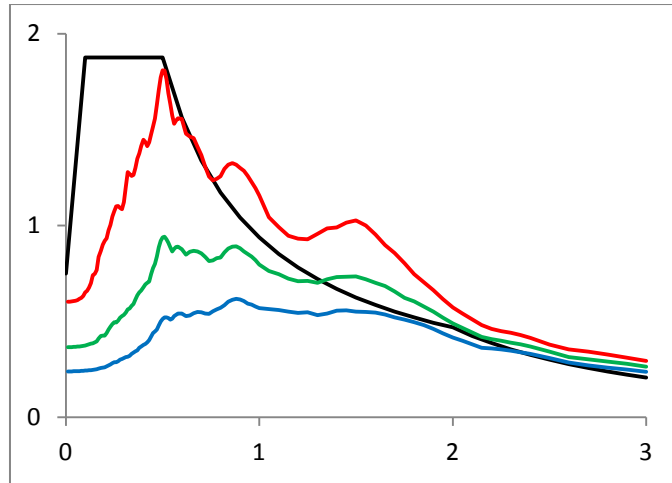
85m ($v_{s,G} = 350$ m/s)



90m ($v_{s,G} = 350$ m/s)

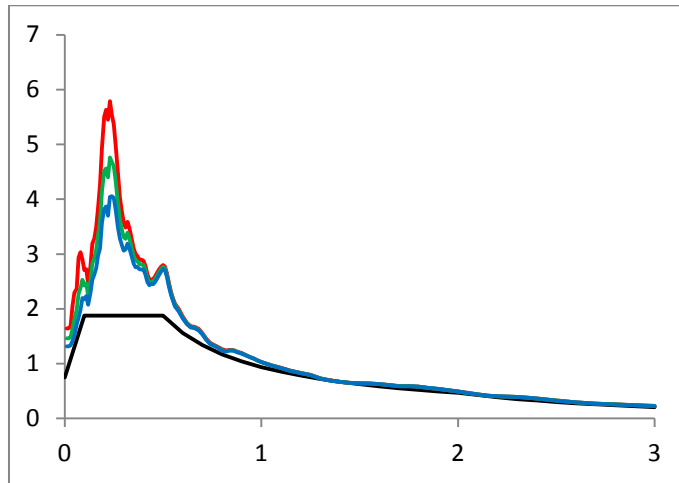


95m ($v_{s,G} = 350$ m/s)

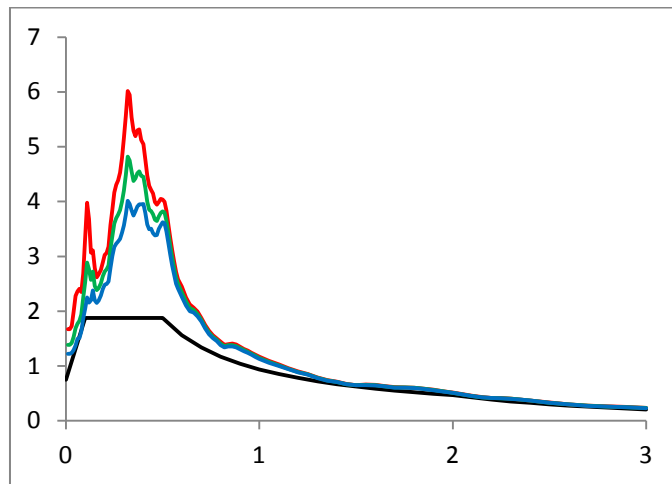


100 m ($v_{s,G} = 350$ m/s)

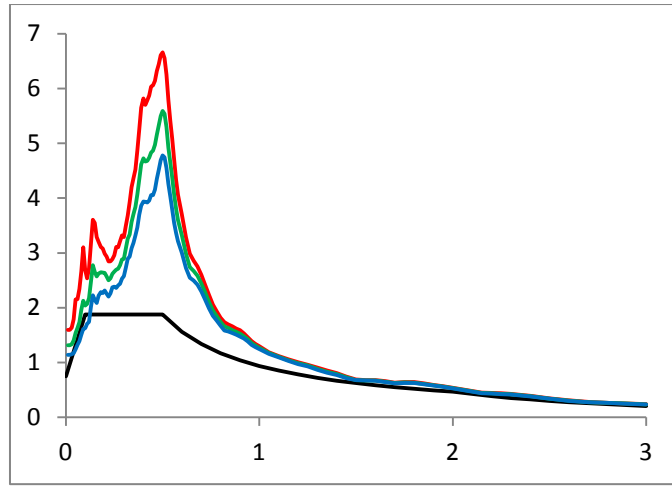
5.4 Bedrock shear wave velocity equal to 450 m/s



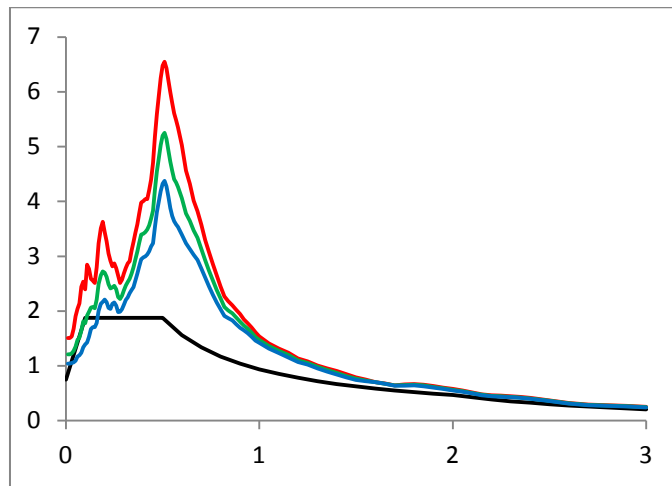
5m ($v_{s,G} = 450$ m/s)



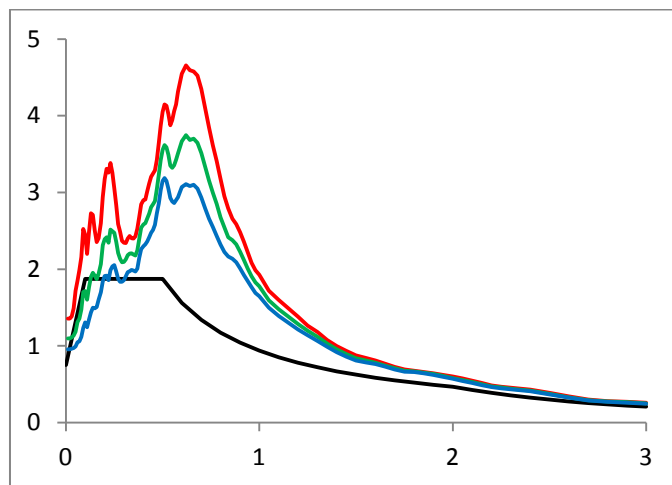
7.5m ($v_{s,G} = 450$ m/s)



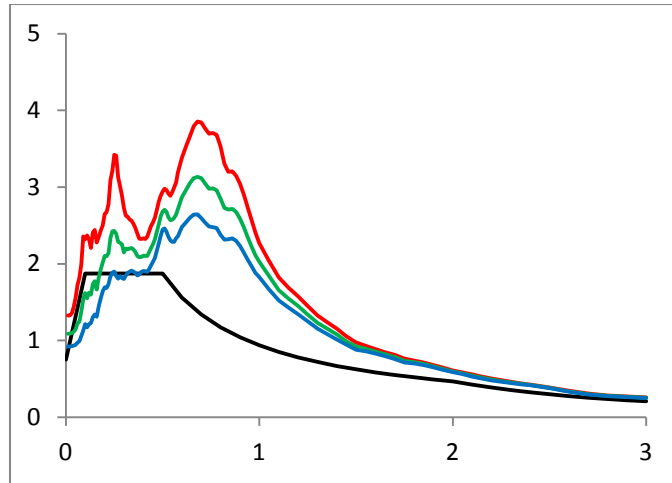
10m ($v_{s,G} = 450$ m/s)



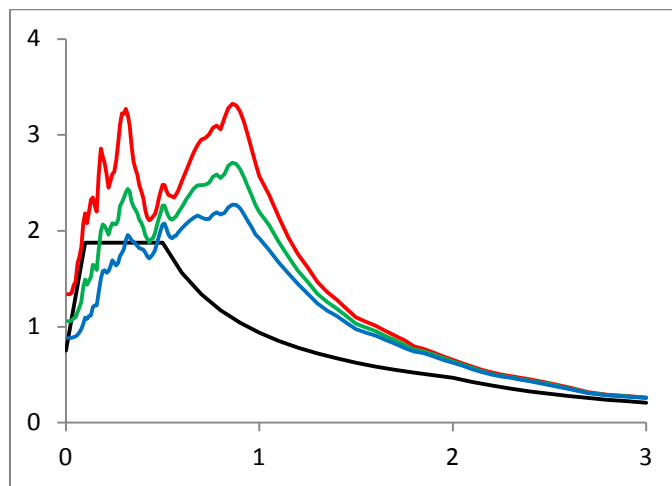
12.5m ($v_{s,G} = 450$ m/s)



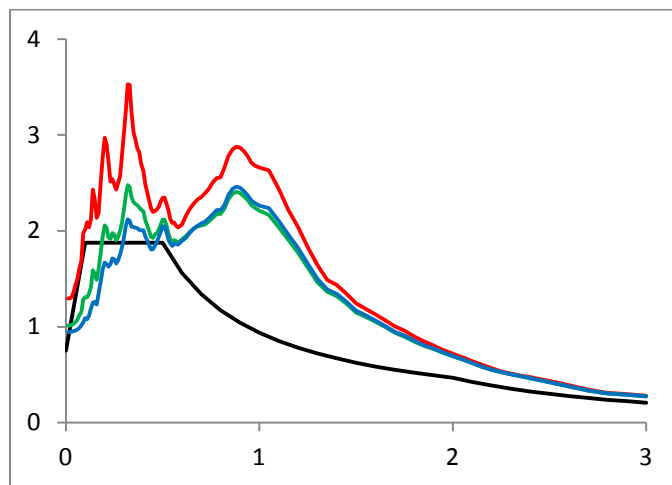
15m ($v_{s,G} = 450$ m/s)



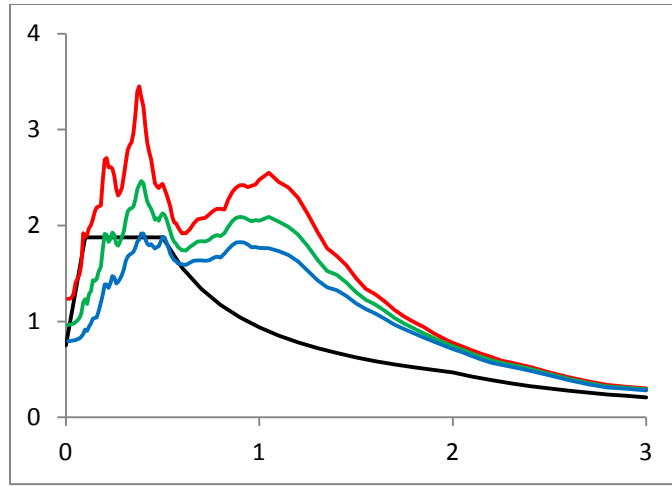
17.5m ($v_{s,G} = 450$ m/s)



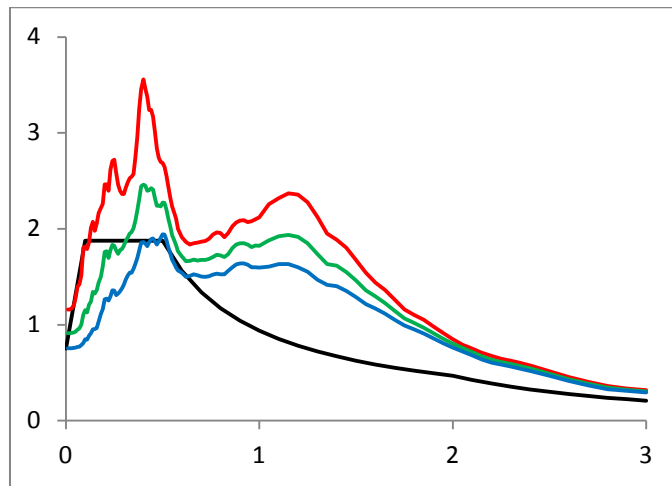
20m ($v_{s,G} = 450$ m/s)



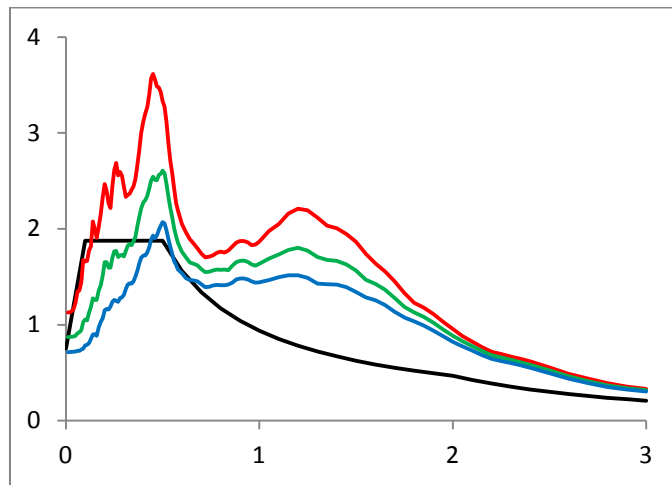
22.5m ($v_{s,G} = 450$ m/s)



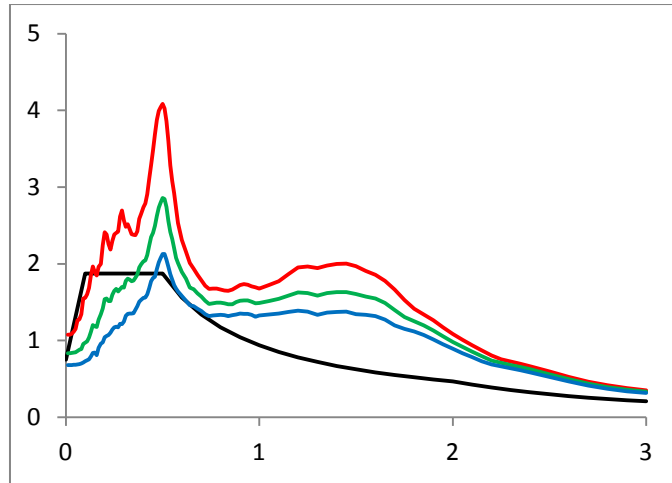
25m ($v_{s,G} = 450$ m/s)



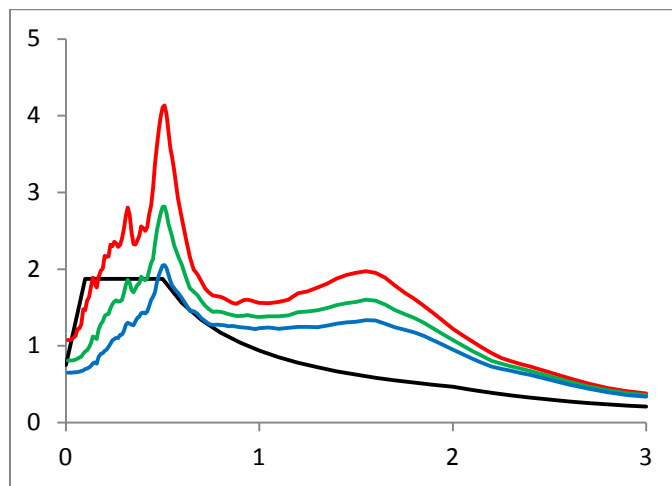
27.5m ($v_{s,G} = 450$ m/s)



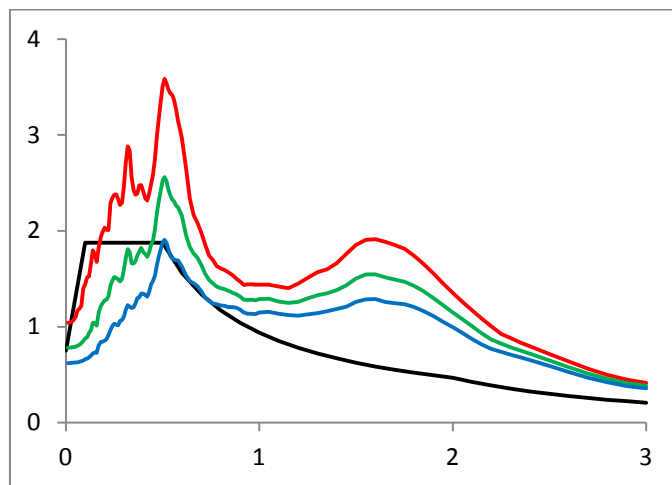
30m ($v_{s,G} = 450$ m/s)



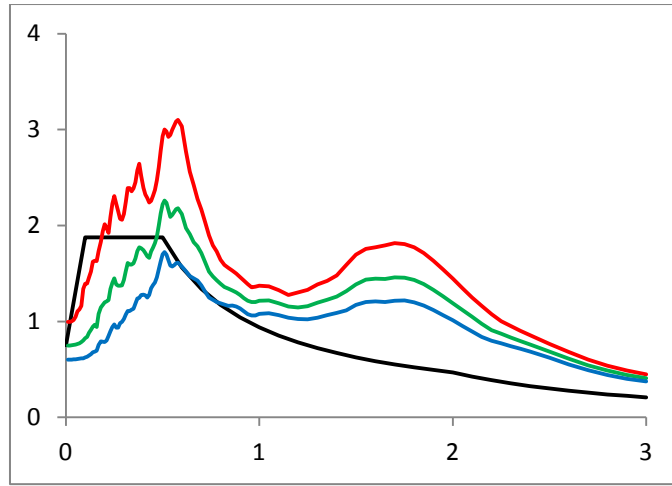
32.5m ($v_{s,G} = 450$ m/s)



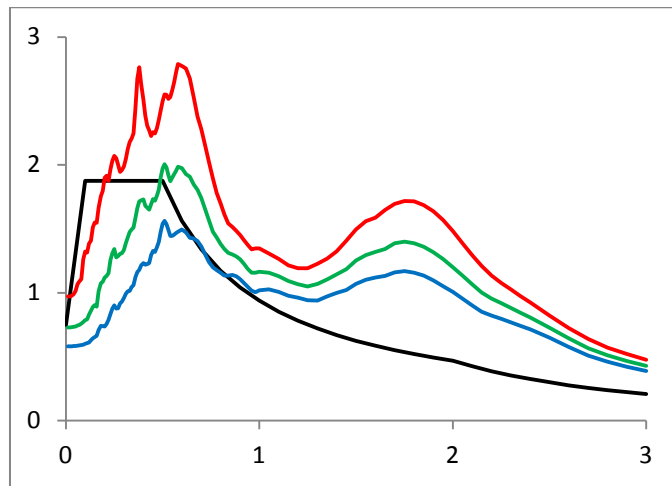
35m ($v_{s,G} = 450$ m/s)



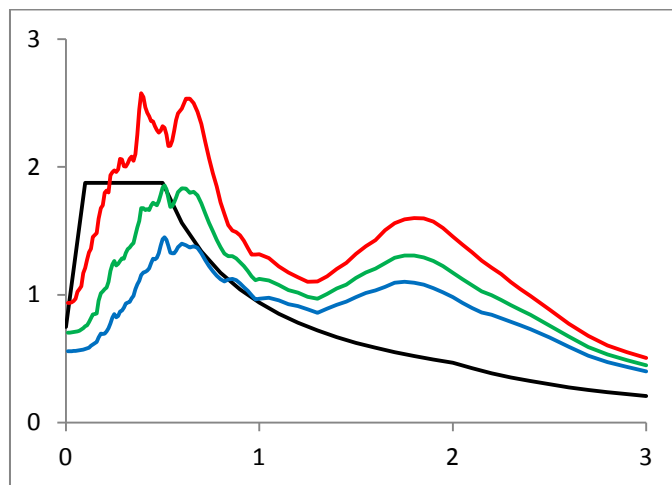
37.5m ($v_{s,G} = 450$ m/s)



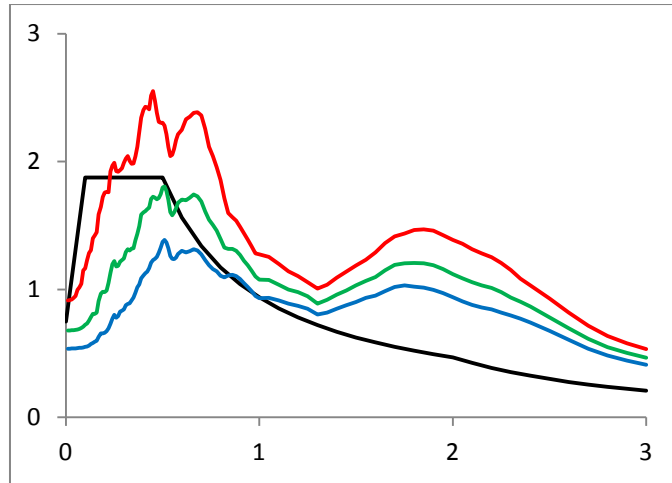
40m ($v_{s,G} = 450$ m/s)



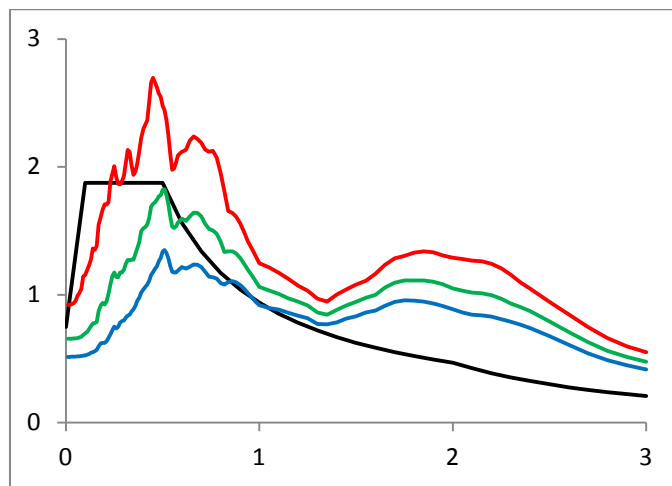
42.5m ($v_{s,G} = 450$ m/s)



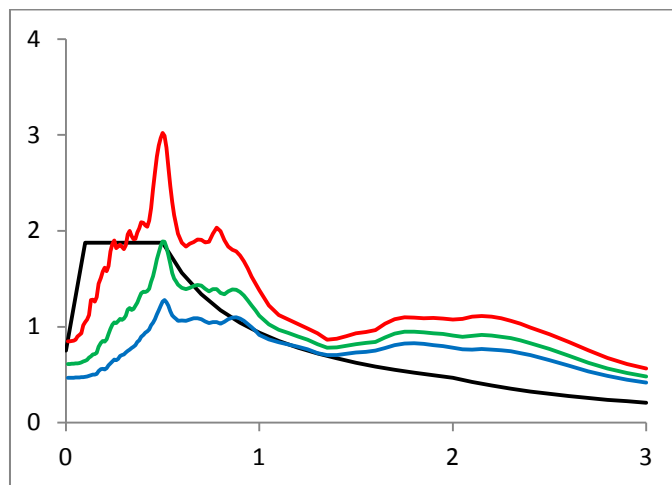
45m ($v_{s,G} = 450$ m/s)



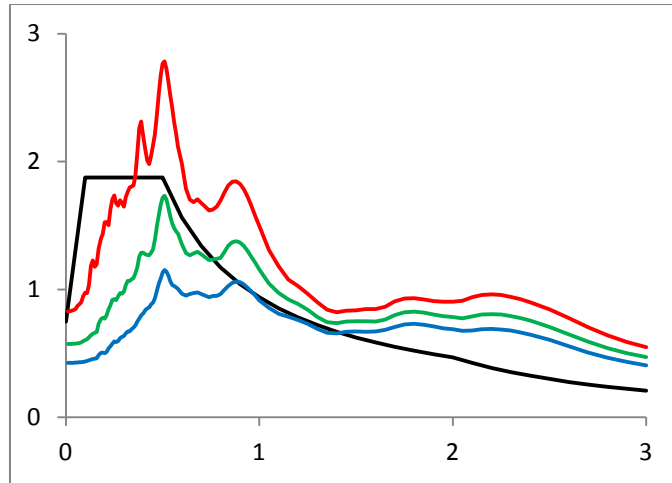
47.5m ($v_{s,G} = 450$ m/s)



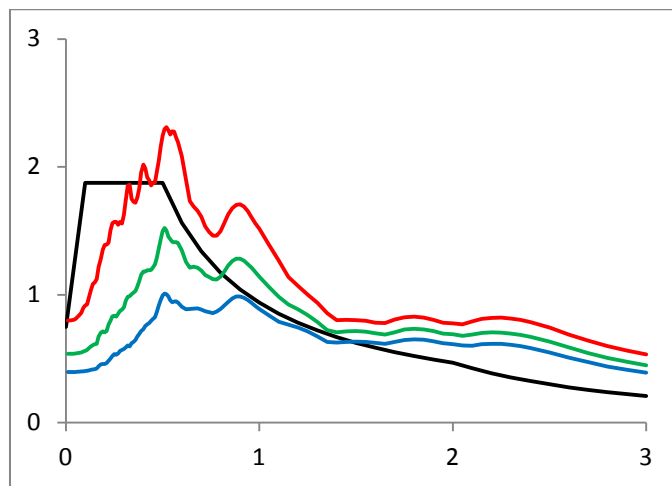
50m ($v_{s,G} = 450$ m/s)



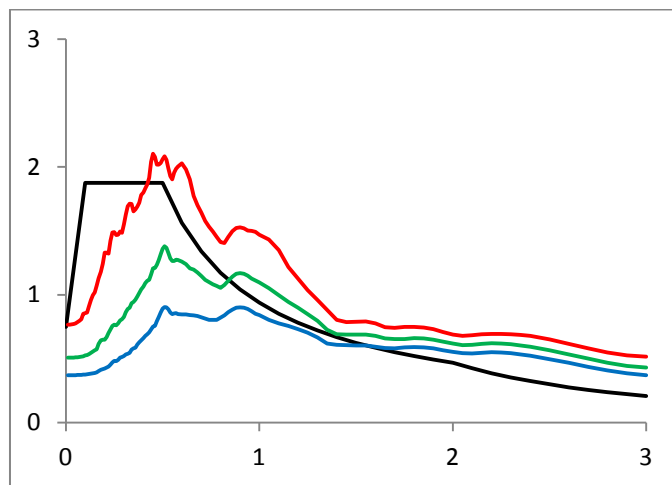
55m ($v_{s,G} = 450$ m/s)



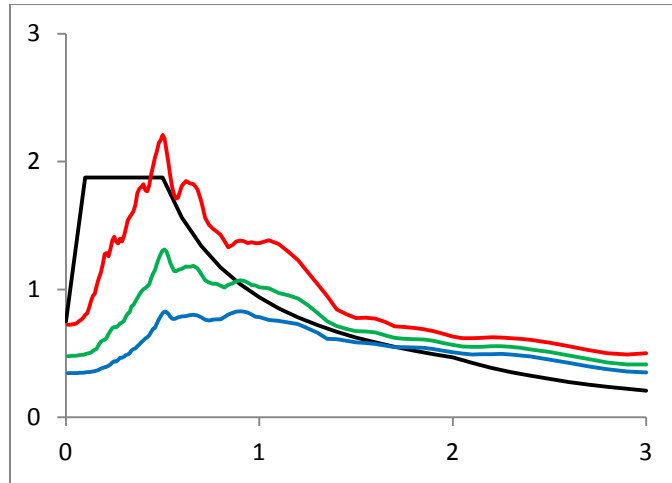
60m ($v_{s,G} = 450$ m/s)



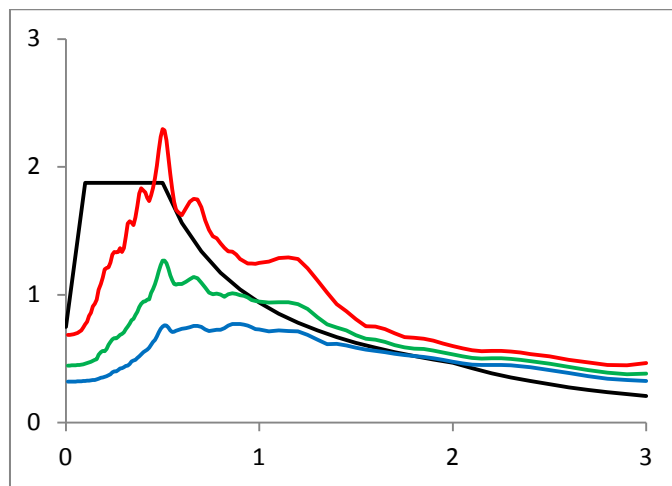
65m ($v_{s,G} = 450$ m/s)



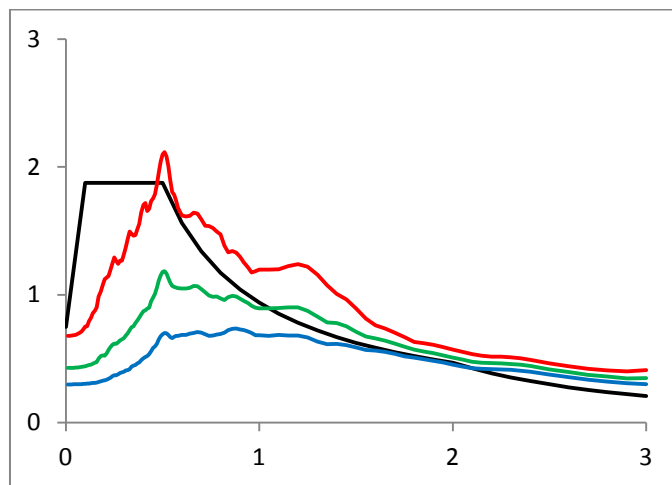
70m ($v_{s,G} = 450$ m/s)



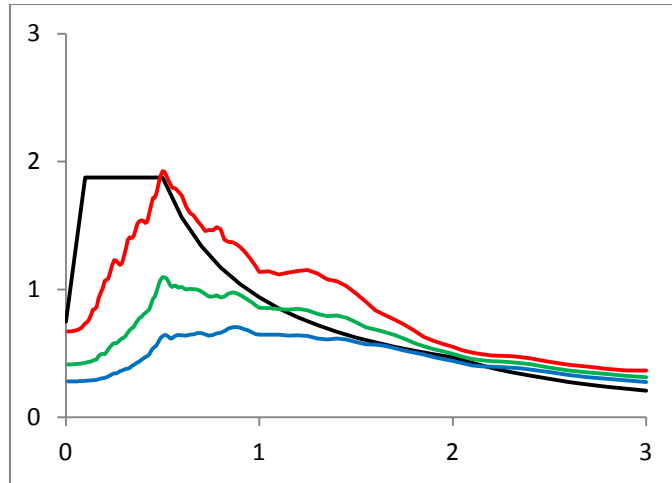
75m ($v_{s,G} = 450$ m/s)



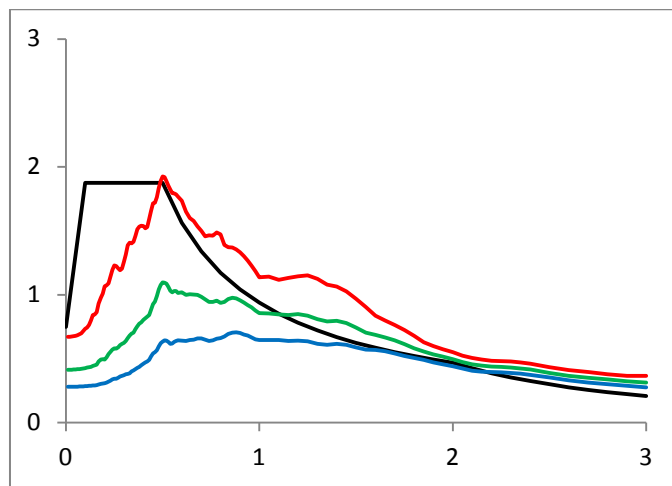
80m ($v_{s,G} = 450$ m/s)



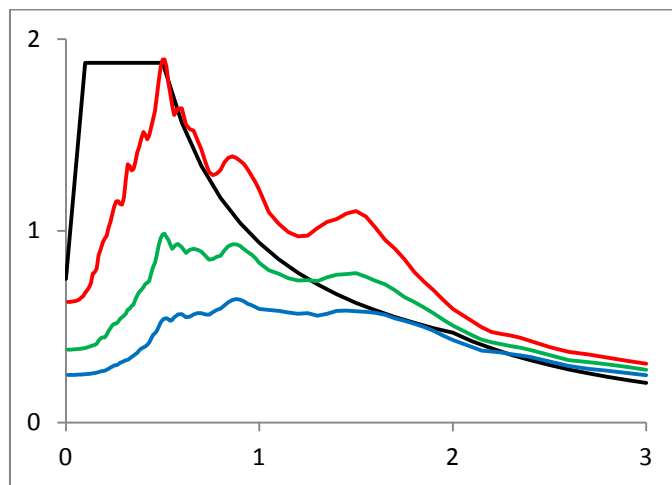
85m ($v_{s,G} = 450$ m/s)



90m ($v_{s,G} = 450$ m/s)

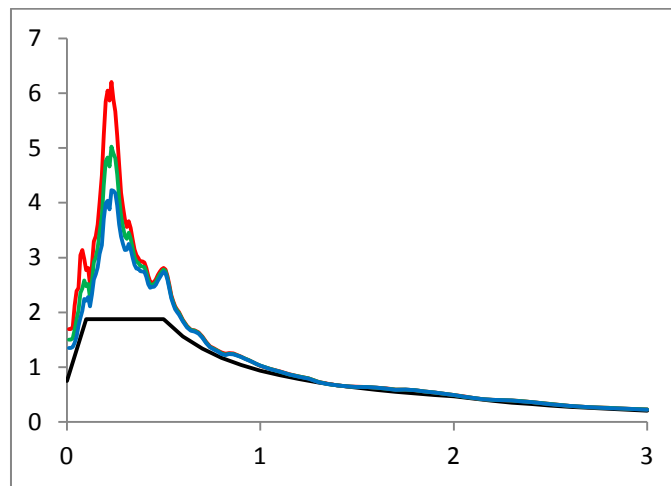


95m ($v_{s,G} = 450$ m/s)

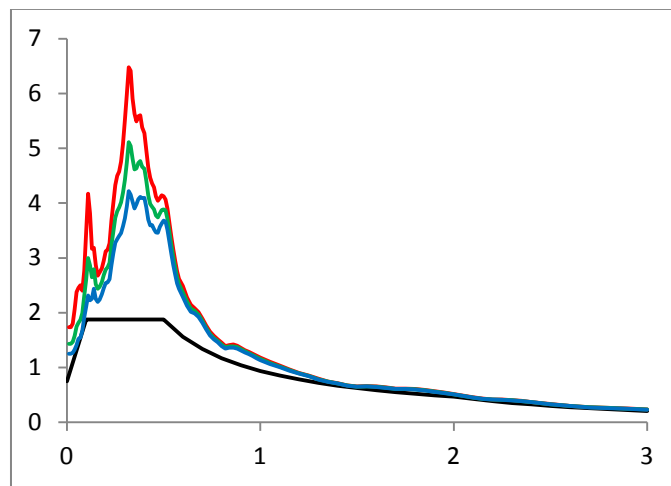


100m ($v_{s,G} = 450$ m/s)

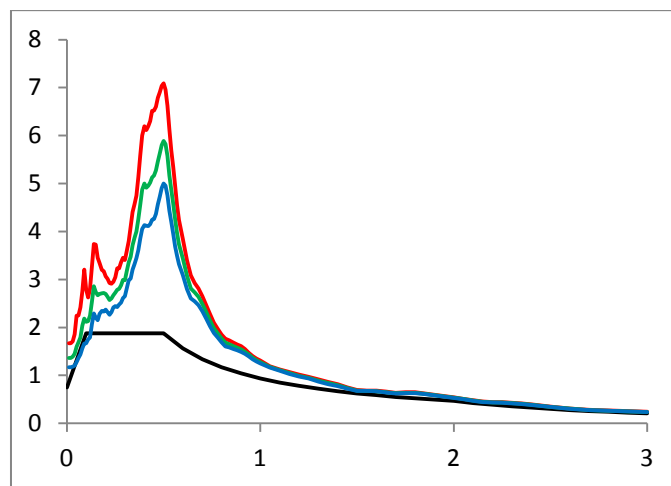
4.5 Bedrock shear wave velocity equal to 520 m/s



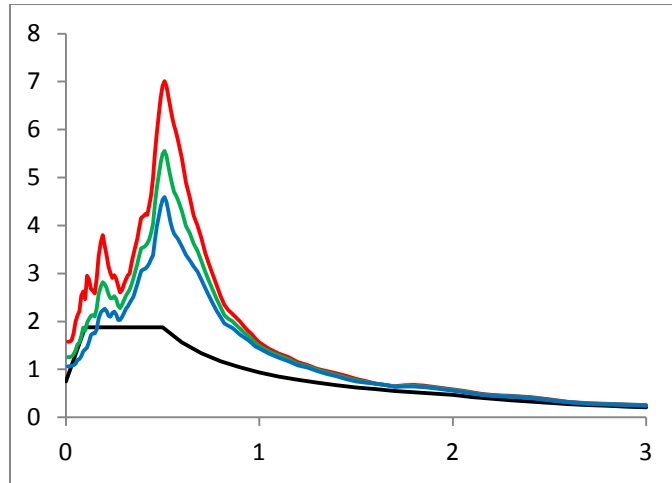
5m ($v_{s,G} = 520$ m/s)



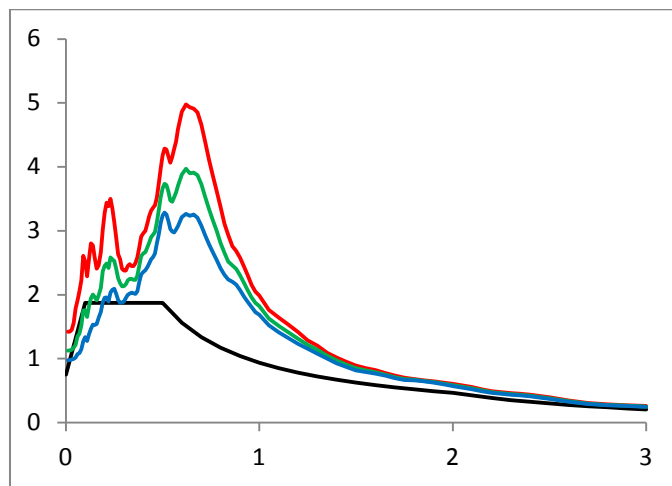
7.5m ($v_{s,G} = 520$ m/s)



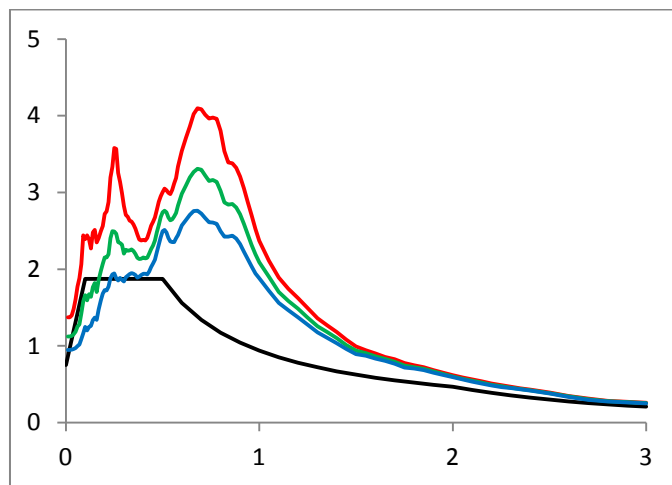
10m ($v_{s,G} = 520$ m/s)



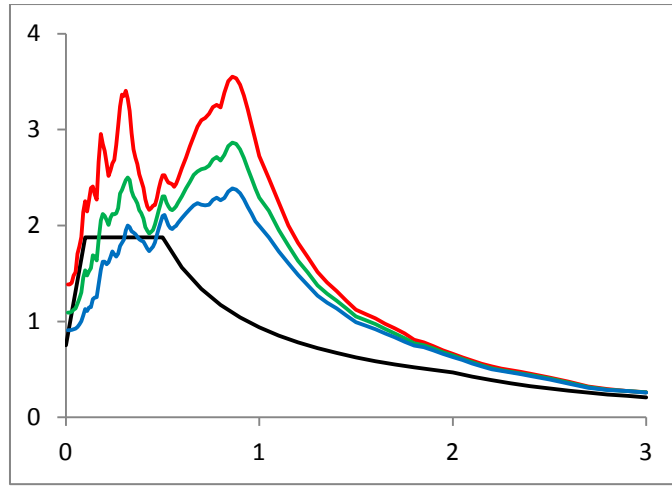
12.5m ($v_{s,G} = 520$ m/s)



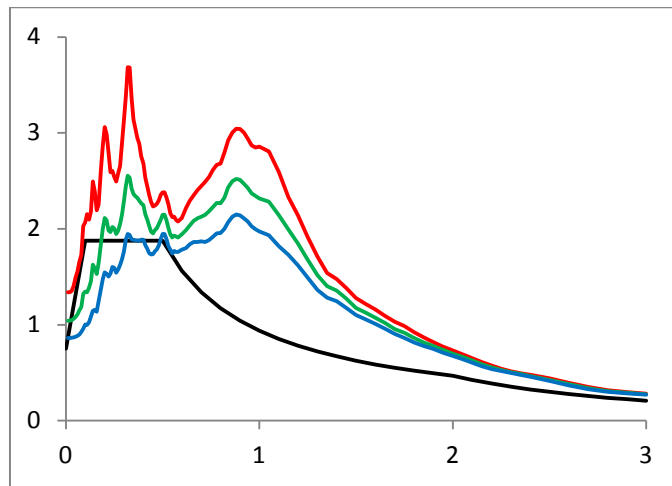
15m ($v_{s,G} = 520$ m/s)



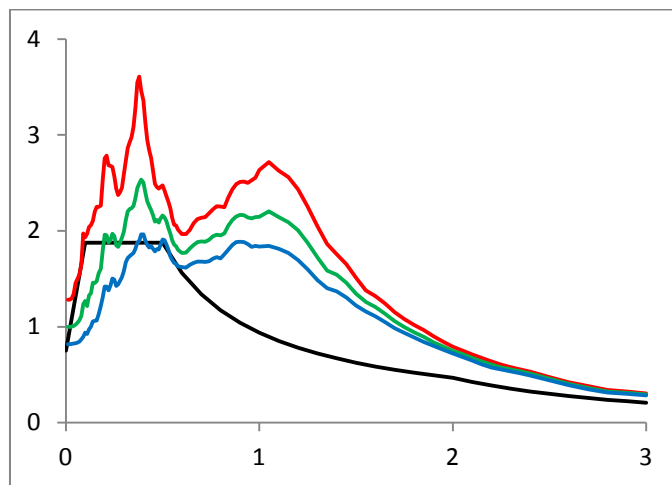
17.5m ($v_{s,G} = 520$ m/s)



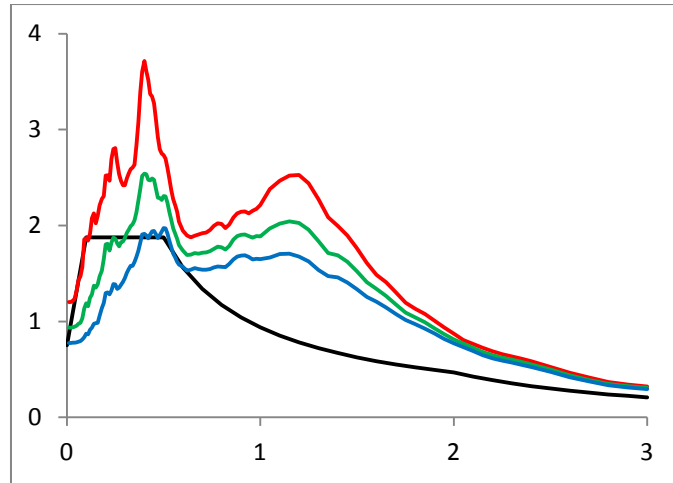
20m ($v_{s,G} = 520$ m/s)



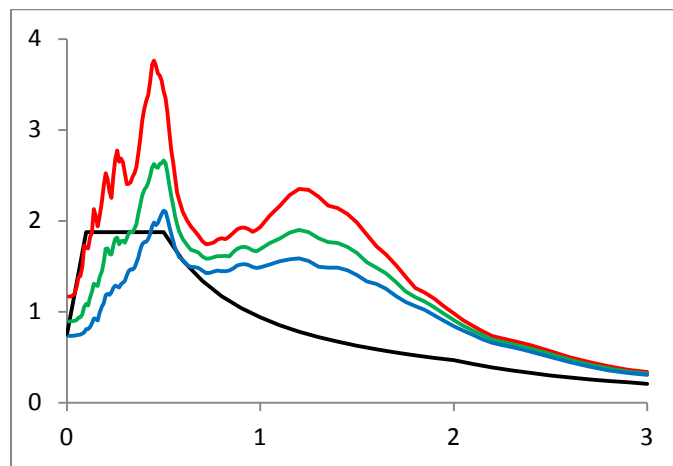
22.5m ($v_{s,G} = 520$ m/s)



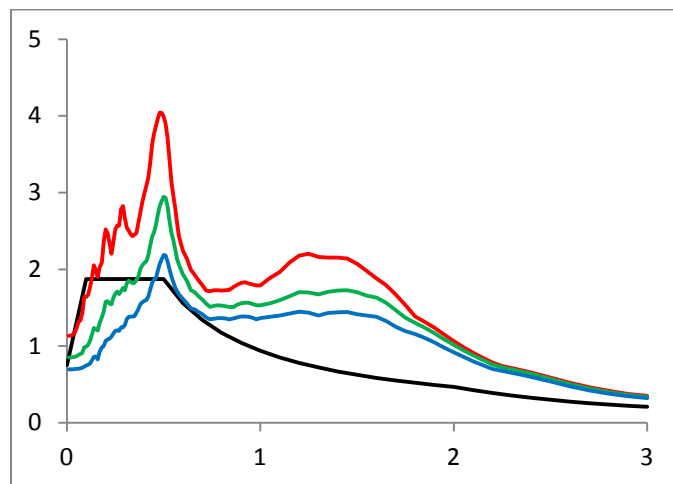
25m ($v_{s,G} = 520$ m/s)



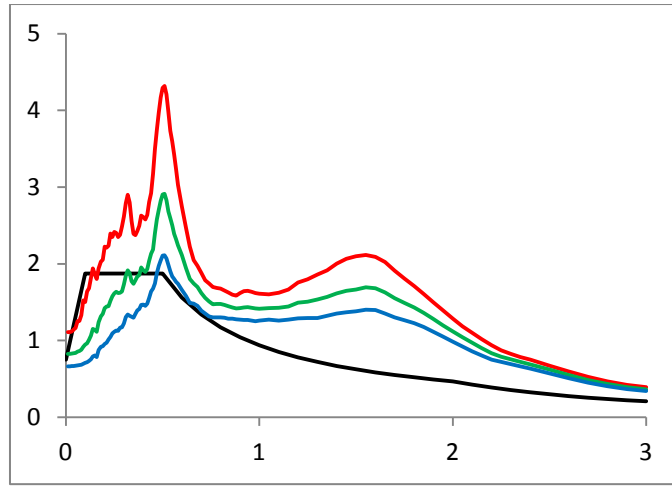
27.5m ($v_{s,G} = 520$ m/s)



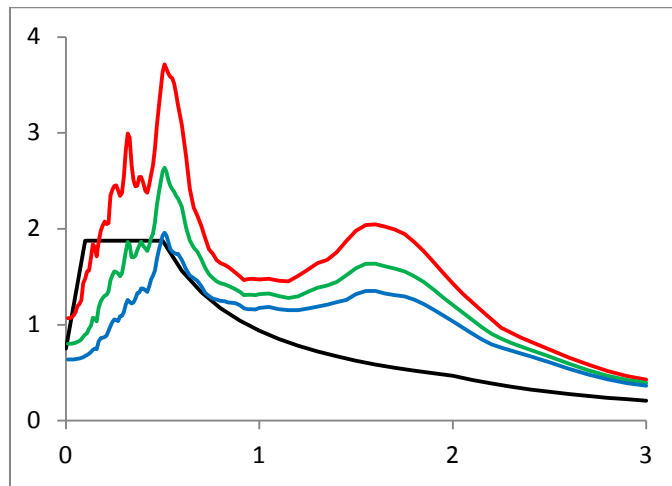
30m ($v_{s,G} = 520$ m/s)



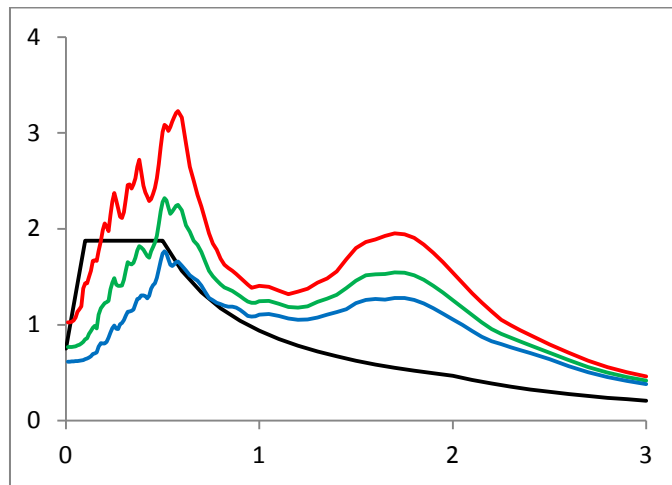
32.5m ($v_{s,G} = 520$ m/s)



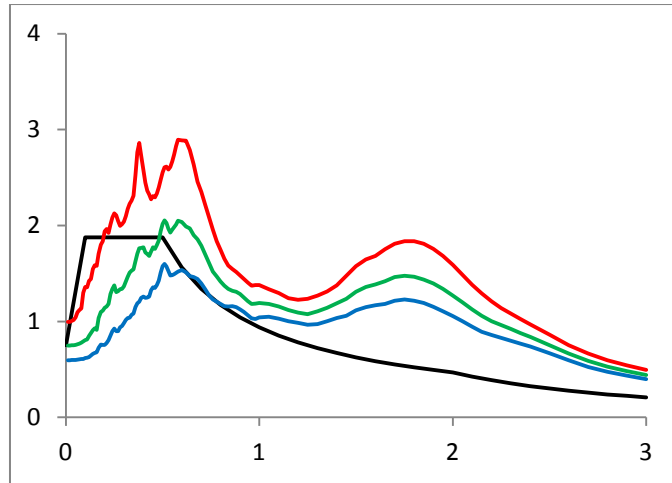
35m ($v_{s,G} = 520$ m/s)



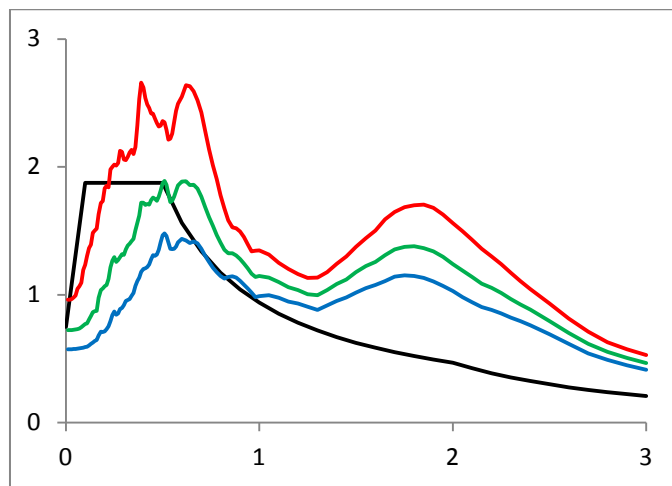
37.5m ($v_{s,G} = 520$ m/s)



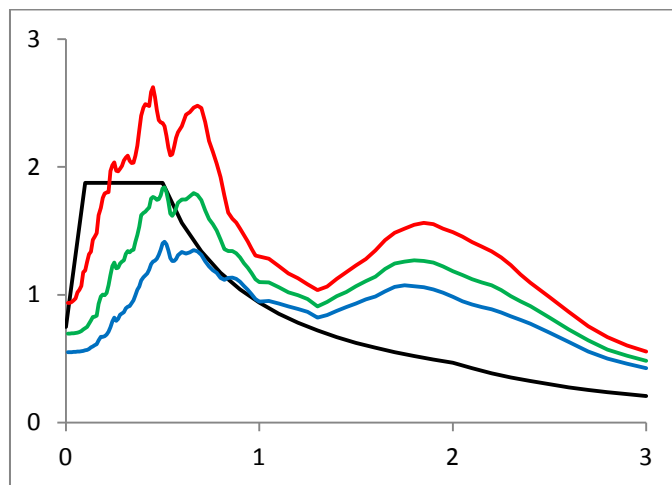
40m ($v_{s,G} = 520$ m/s)



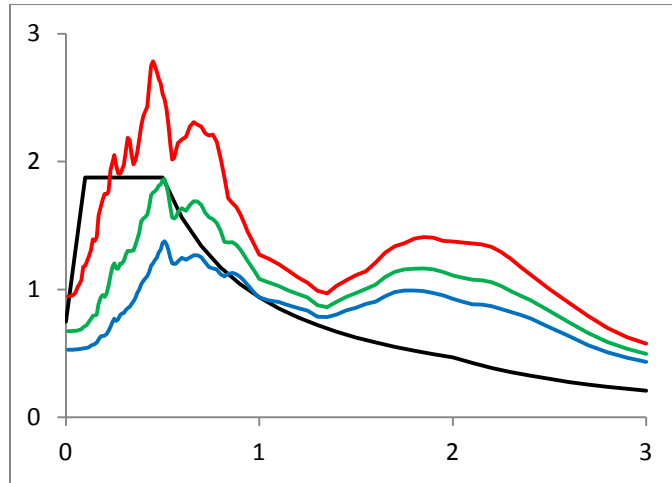
42.5m ($v_{s,G} = 520$ m/s)



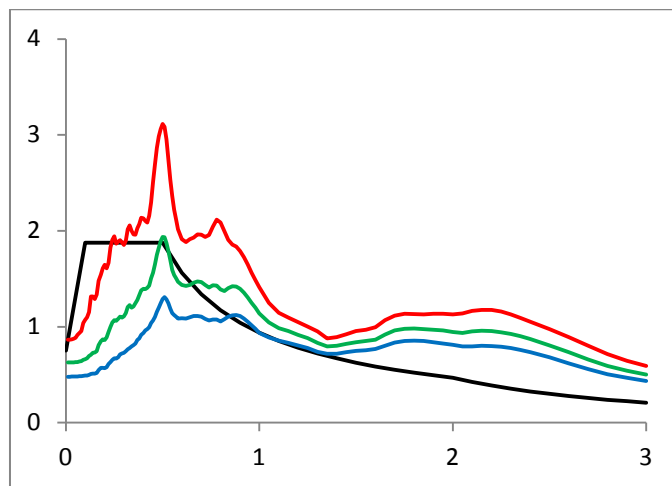
45m ($v_{s,G} = 520$ m/s)



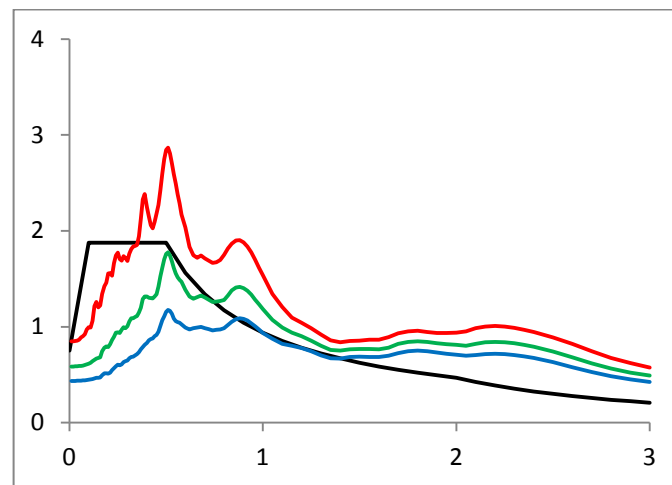
47.5m ($v_{s,G} = 520$ m/s)



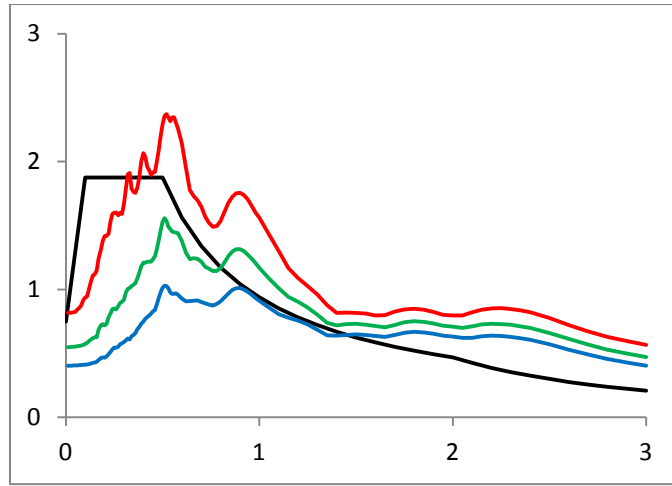
50m ($v_{s,G} = 520$ m/s)



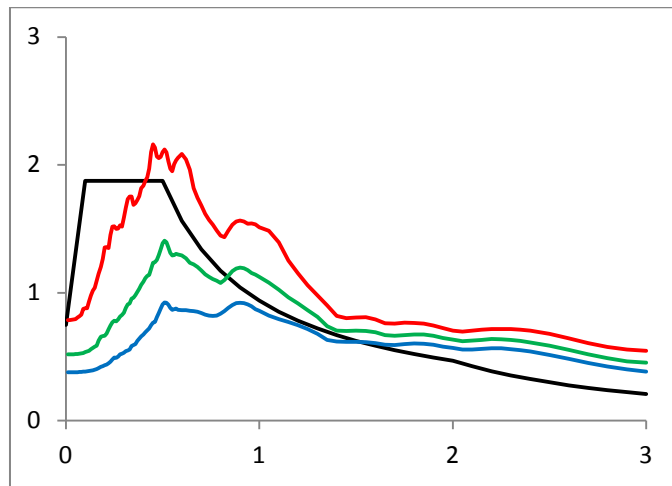
55m ($v_{s,G} = 520$ m/s)



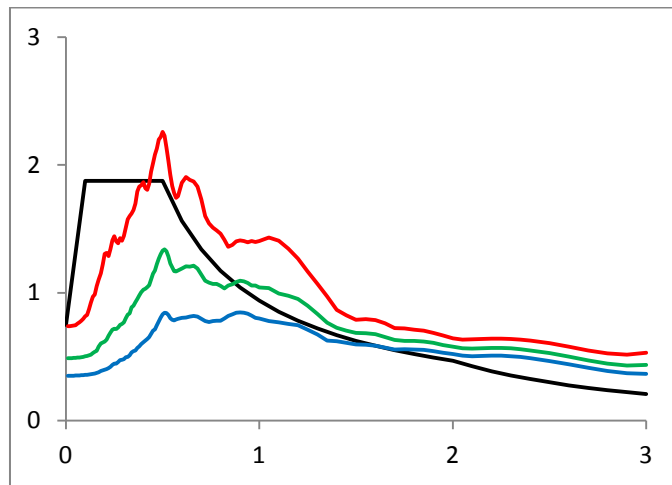
60m ($v_{s,G} = 520$ m/s)



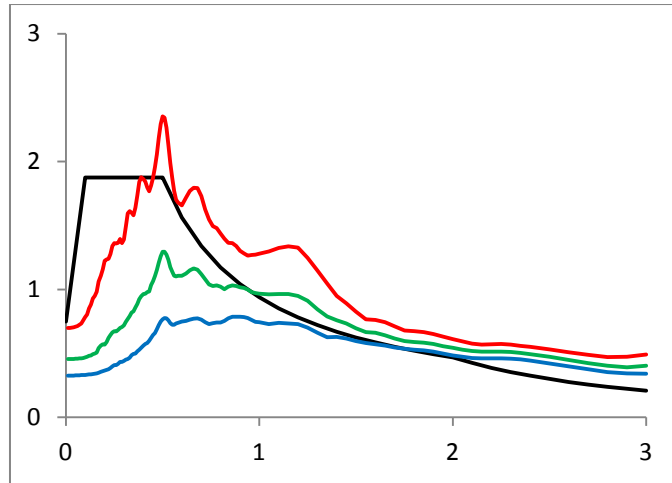
65m ($v_{s,G} = 520$ m/s)



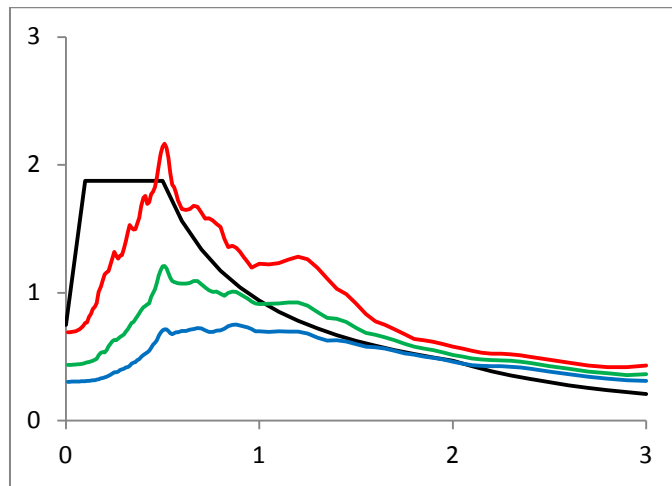
70m ($v_{s,G} = 520$ m/s)



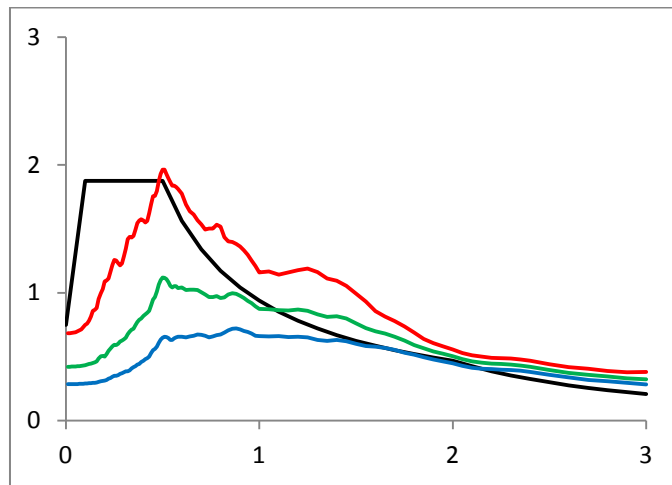
75m ($v_{s,G} = 520$ m/s)



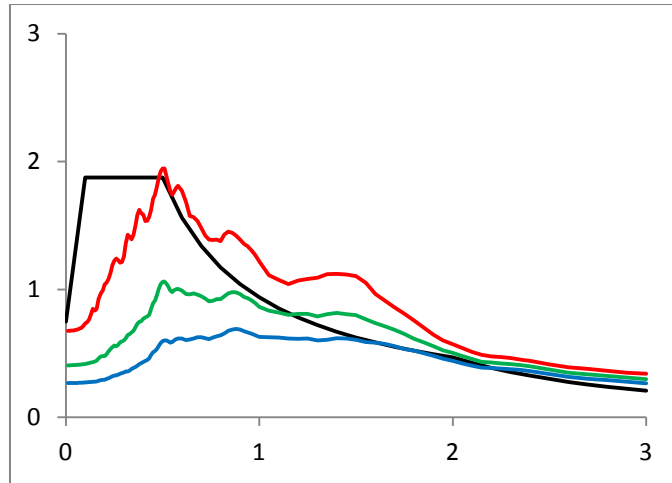
80m ($v_{s,G} = 520$ m/s)



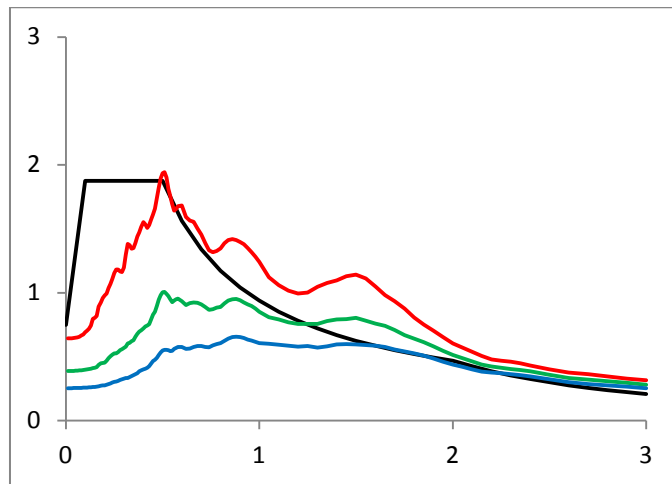
85m ($v_{s,G} = 520$ m/s)



90m ($v_{s,G} = 520$ m/s)

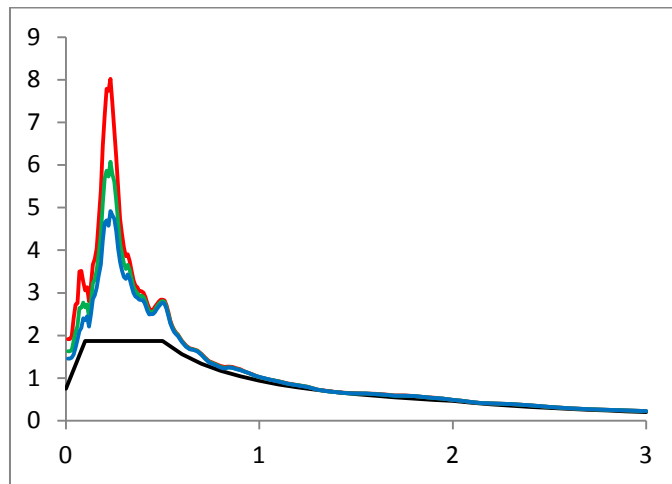


95m ($v_{s,G} = 520$ m/s)

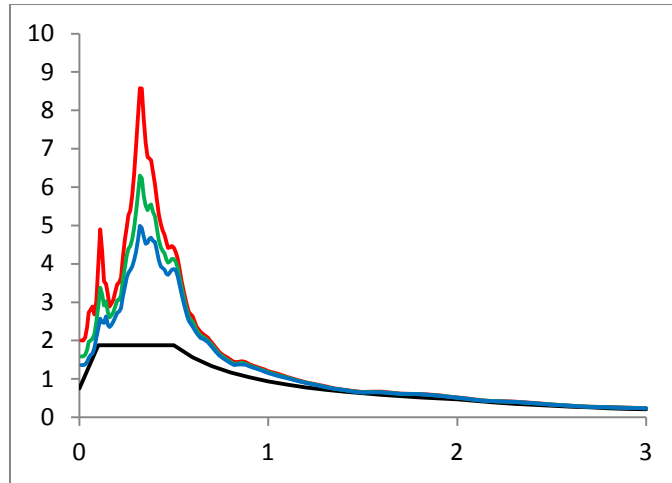


100m ($v_{s,G} = 520$ m/s)

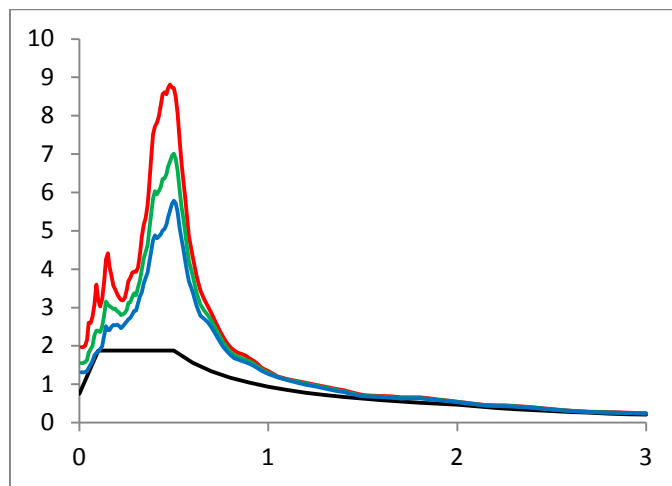
4.6 Bedrock shear wave velocity equal to 1000 m/s



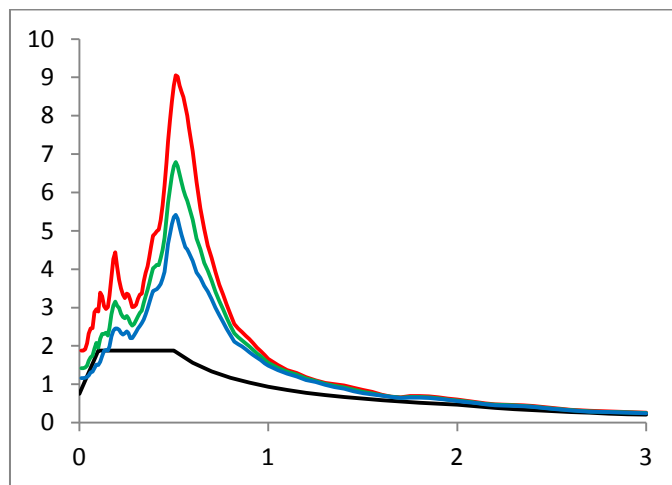
5m ($v_{s,G} = 1000$ m/s)



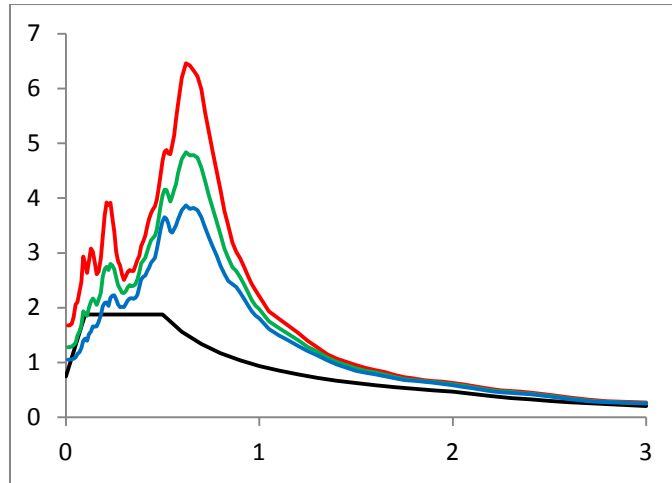
7.5m ($v_{s,G} = 1000$ m/s)



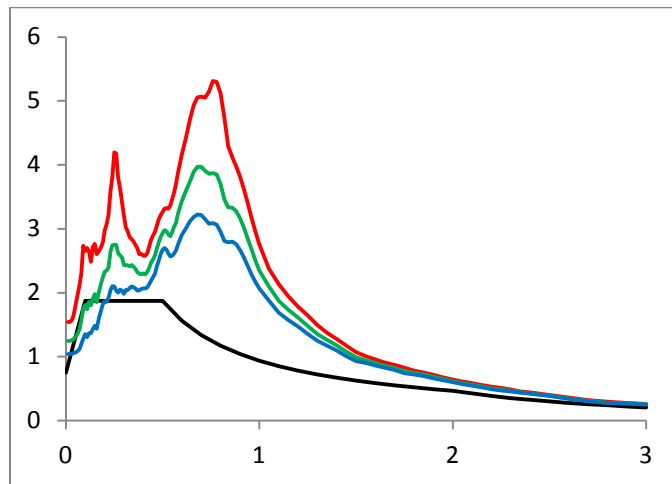
10m ($v_{s,G} = 1000$ m/s)



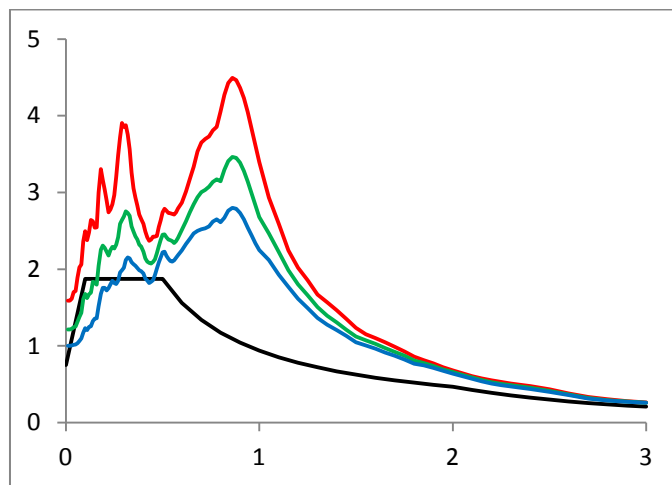
12.5m ($v_{s,G} = 1000$ m/s)



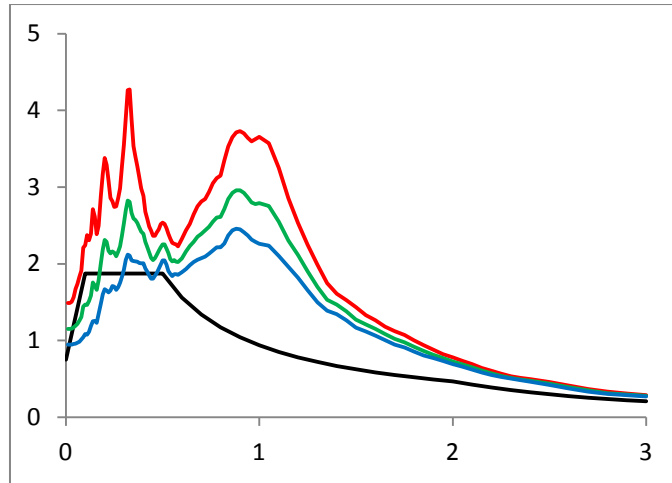
15m ($v_{s,G} = 1000$ m/s)



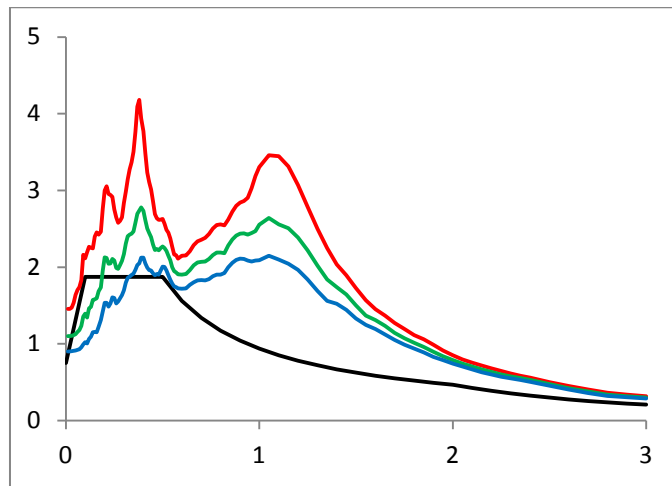
17.5m ($v_{s,G} = 1000$ m/s)



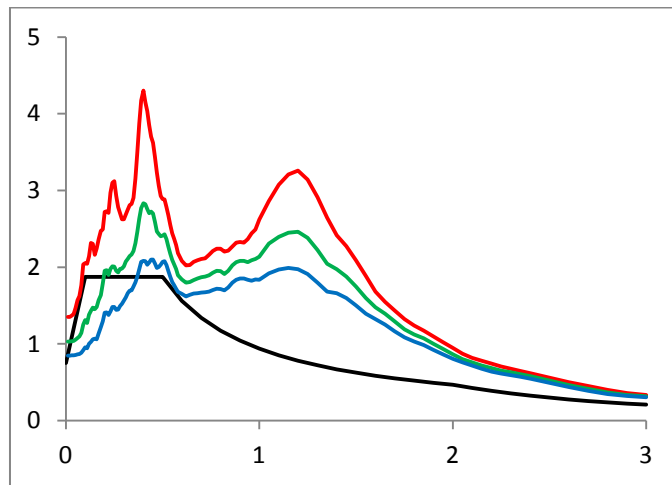
20m ($v_{s,G} = 1000$ m/s)



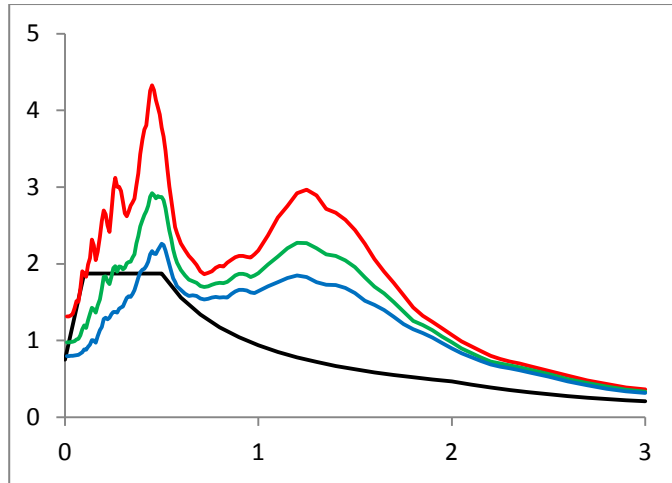
22.5m ($v_{s,G} = 1000$ m/s)



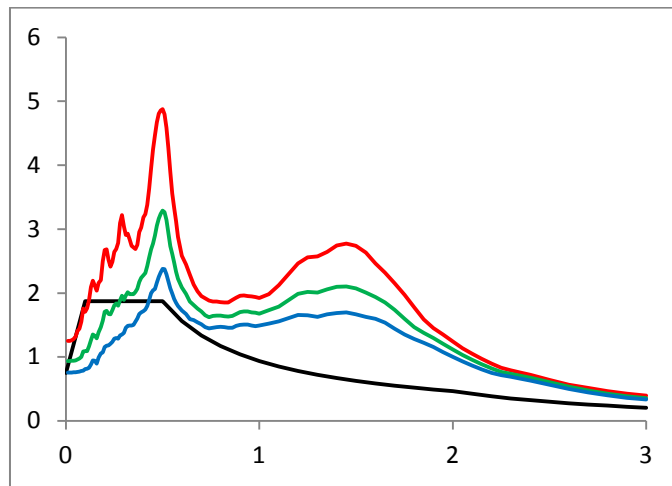
25m ($v_{s,G} = 1000$ m/s)



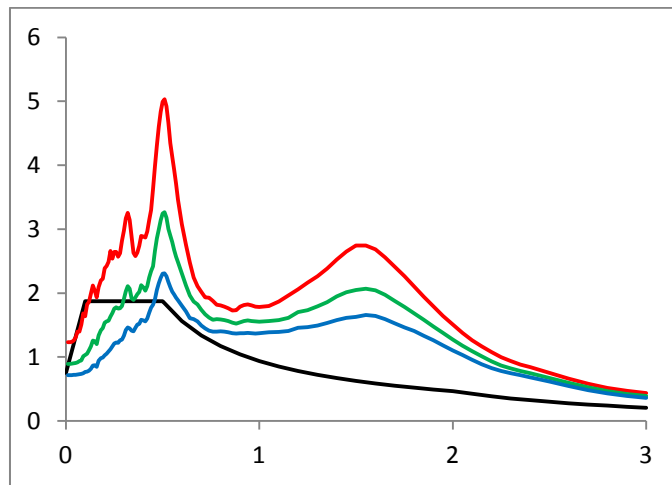
27.5m ($v_{s,G} = 1000$ m/s)



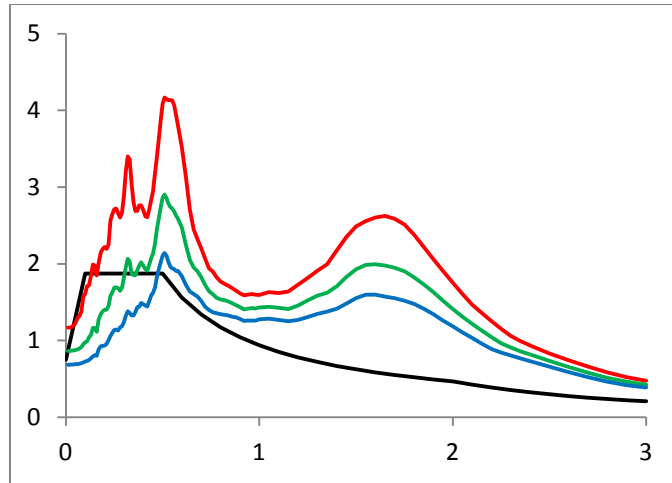
30m ($v_{s,G} = 1000$ m/s)



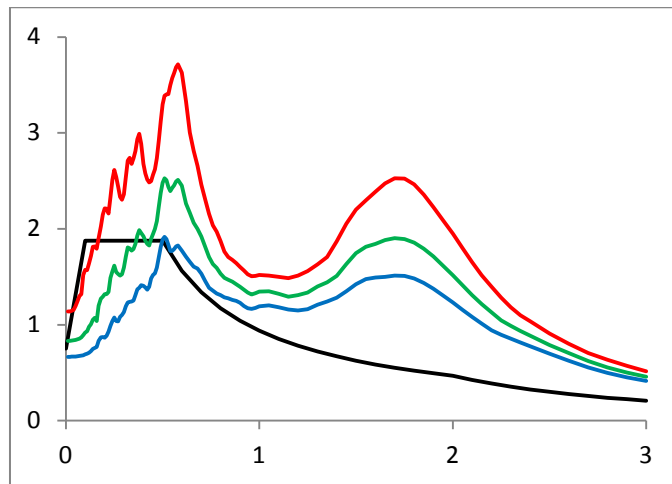
32.5m ($v_{s,G} = 1000$ m/s)



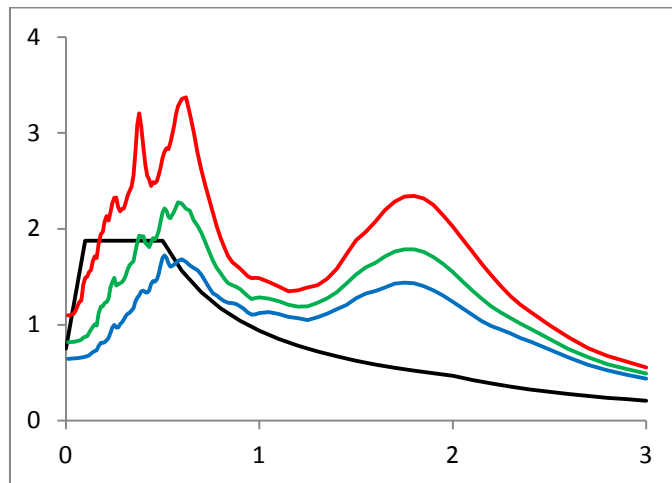
35m ($v_{s,G} = 1000$ m/s)



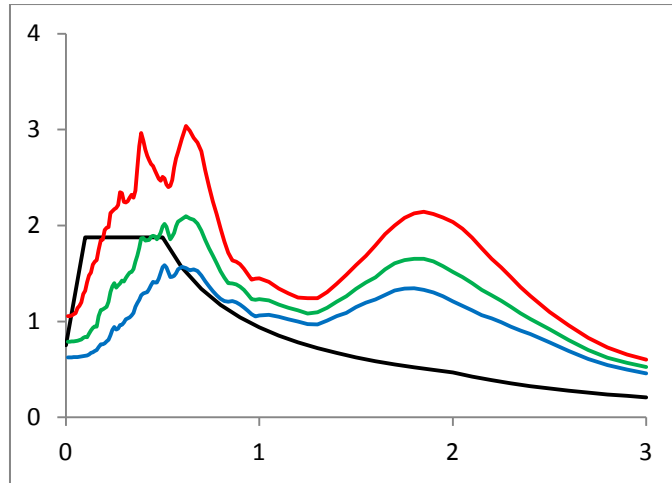
37.5m ($v_{s,G} = 1000$ m/s)



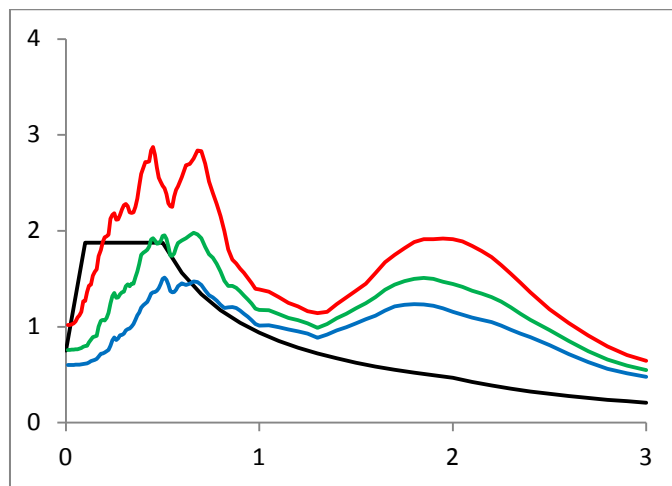
40m ($v_{s,G} = 1000$ m/s)



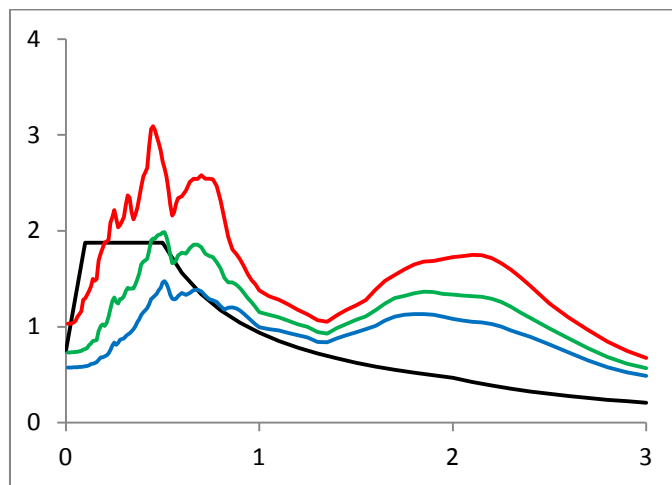
42.5m ($v_{s,G} = 1000$ m/s)



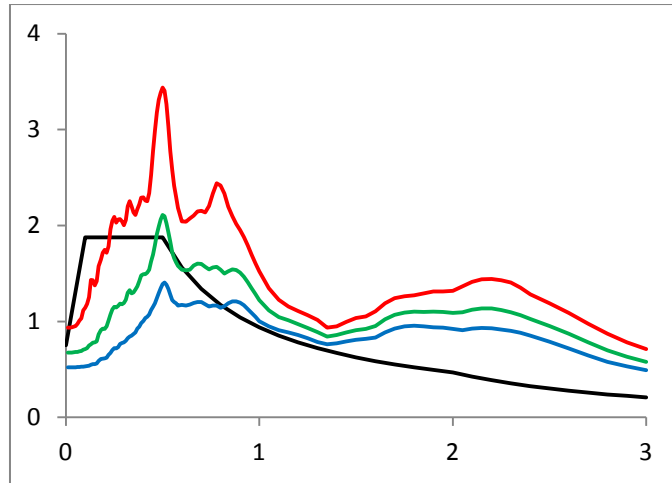
45m ($v_{s,G} = 1000$ m/s)



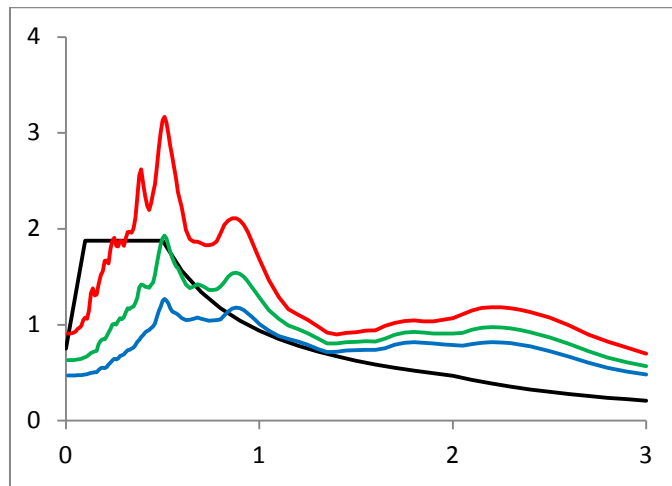
47.5m ($v_{s,G} = 1000$ m/s)



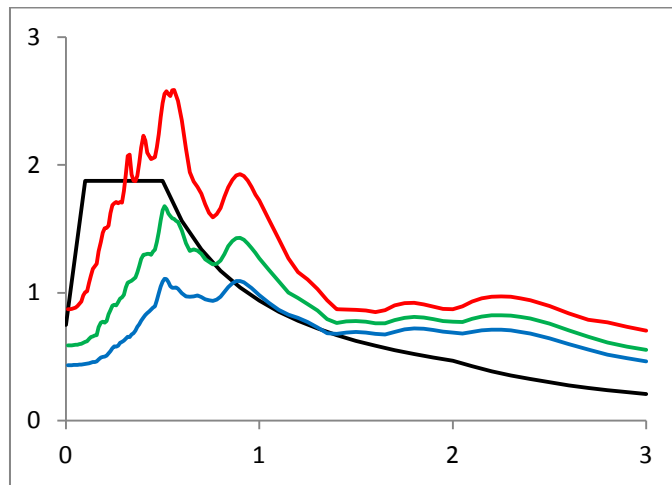
50m ($v_{s,G} = 1000$ m/s)



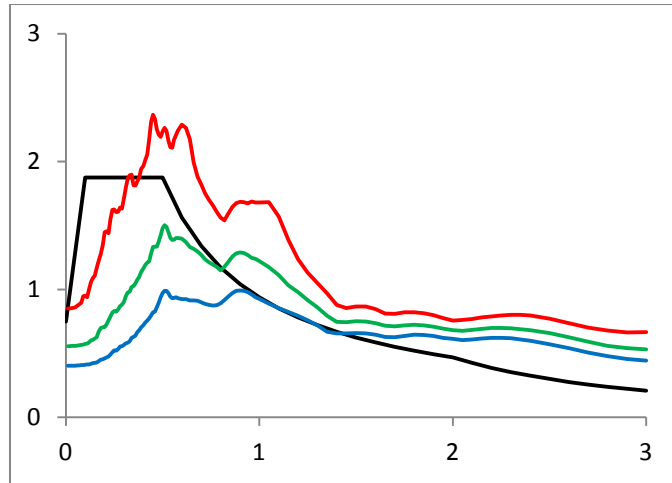
55m ($v_{s,G} = 1000$ m/s)



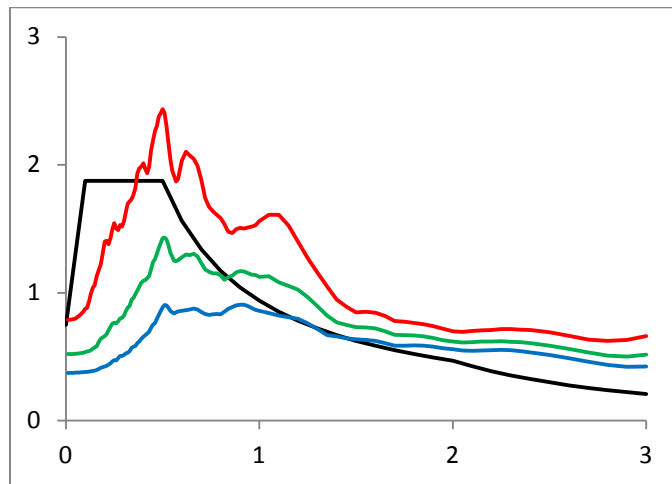
60m ($v_{s,G} = 1000$ m/s)



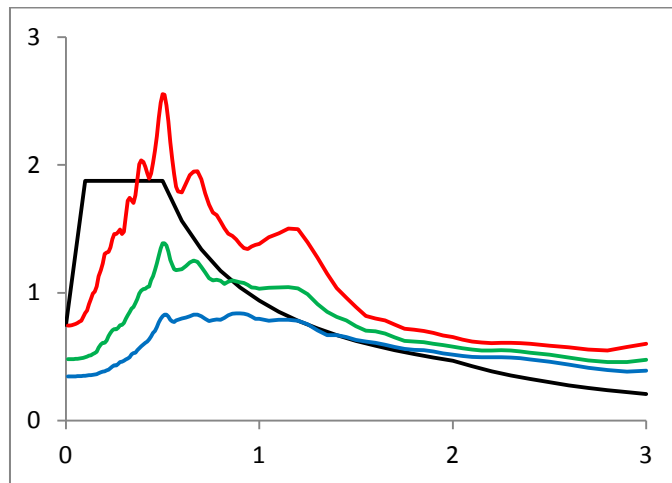
65m ($v_{s,G} = 1000$ m/s)



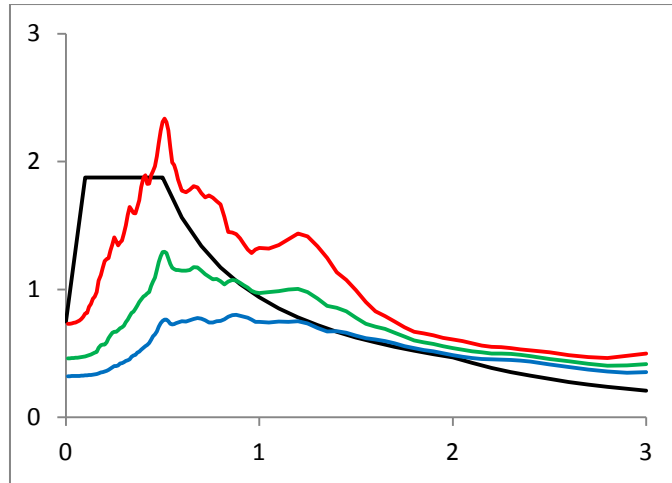
70m ($v_{s,G} = 1000$ m/s)



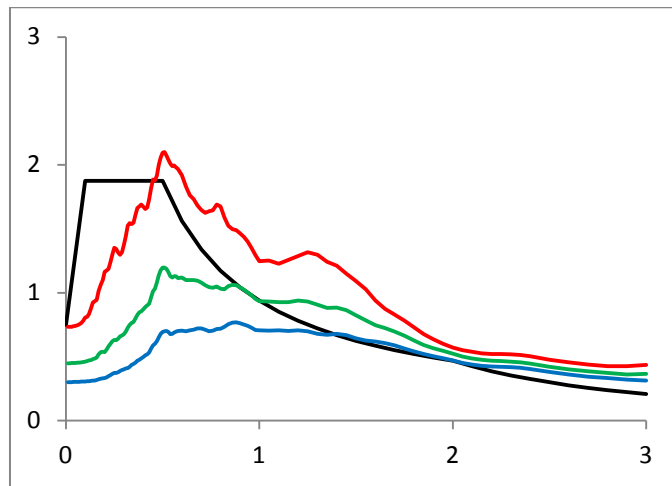
75m ($v_{s,G} = 1000$ m/s)



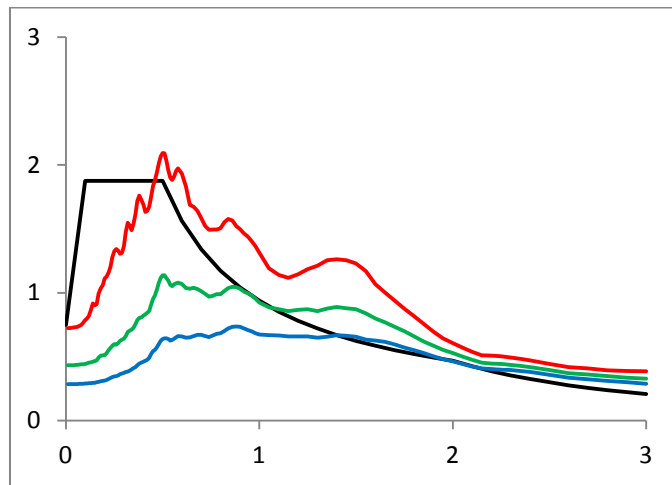
80m ($v_{s,G} = 1000$ m/s)



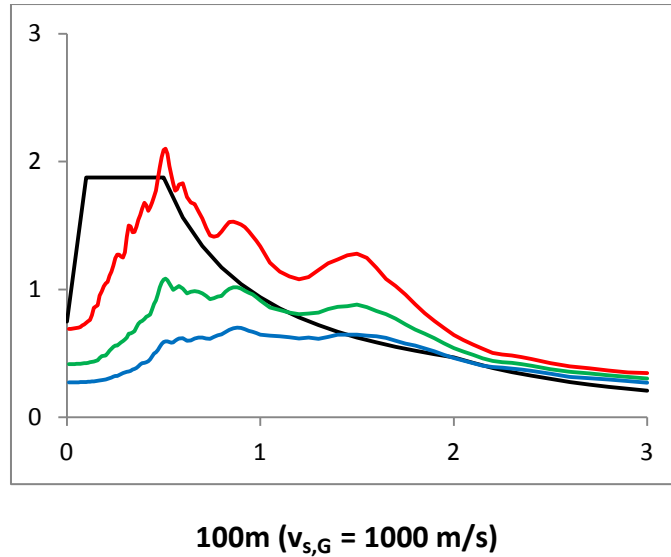
85m ($v_{s,G} = 1000$ m/s)



90m ($v_{s,G} = 1000$ m/s)



95m ($v_{s,G} = 1000$ m/s)



5 EQUIVALENT MODELS

5.1 Generals

Two soil models are considered to be equivalent when the eigenfrequencies of the layers based on a rigid halfspace as well as the damping at the corresponding eigenfrequencies are equal, i.e. when they have the same transfer functions [4].

The model equivalent to the real model to be investigated is denoted as reference model. It is characterized by the layer height h_{ref} giving the same eigenfrequency as the real system and the damping in the layer ξ_{ref} resulting in the same peak value of the transfer function at the first eigenfrequency [4].

5.2 Heights of the reference models

The eigenfrequencies of an elastic layer over a rigid half-space are given by

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

Denoting

h_{ref} – reference height of the actual height,

$v_{s,S_{ref}}$ – reference shear wave velocity of the actual shear wave velocity = 90 m/s,

one obtains for the reference system

$$\frac{h_{ref}}{v_{s,S_{ref}}} = \frac{h}{v_{s,S}} \quad (3)$$

or

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

Assuming a range of shear wave velocities of the soft layer between 50m/s and 150 m/s and $v_{s,S,ref} = 90\text{m/s}$ acc. to table 1 one obtains

$$v_{s,S,min} = 50 \text{ m/s} \rightarrow \frac{v_{s,S,ref}}{v_S} = 1.8 (\approx 2),$$

$$v_{s,S,max} = 150 \text{ m/s} \rightarrow \frac{v_{s,S,ref}}{v_{s,S}} = 0.6$$

This gives the following range of h_{ref}/h :

$$h_{ref} = (0.6 \div 1.8) \cdot h \quad (4)$$

5.3 Damping of the reference models

Equating the peaks of the transfer functions of the real and the reference model gives the equivalent material damping of the layer as [4]

$$\xi_{s,ref} = \frac{2}{\pi \cdot (2j - 1)} (\beta - \beta_{ref}) + \xi_s \quad (5)$$

Here j denotes the mode (see eq. 3) and β, β_{ref} the impedance ratio of the real and the reference model, respectively. The impedance ratios are given as

$$\beta = \frac{\rho_S \cdot v_{s,S}}{\rho_G \cdot v_{s,G}} \quad (6)$$

and

$$\beta_{ref} = \frac{\rho_{S,ref} \cdot v_{s,S,ref}}{\rho_{G,ref} \cdot v_{s,G,ref}} \quad (7)$$

For the first mode ($j=1$) one obtains

$$\xi_{ref} = \frac{2}{\pi} (\beta - \beta_{ref}) + \xi_s = \Delta\xi_\beta + \xi_s \quad (8)$$

with

$$\Delta\xi_\beta = \frac{2}{\pi} (\beta - \beta_{ref}) \quad (9)$$

This means that in the reference system the damping of the layer has to be augmented by $\Delta\xi_\beta$.

The densities of the real system are assumed to be equal to those of the reference system, i.e.

$$Q_S = Q_{S,ref}, \quad Q_G = Q_{G,ref}$$

With

$$v_{s,S} = 50 \dots 120 \text{ m/s} \rightarrow \beta_{\min} = \frac{50}{350} = 0.14$$

$$v_{s,G} = 150 \dots 350 \text{ m/s} \rightarrow \beta_{\max} = \frac{150}{200} = 0.75$$

the possible range of the impedance ratios is obtained as

$$0.14 < \beta < 0.75 \tag{10}$$

The impedance ratio β_{ref} depends on the shear wave velocity in the bedrock of the reference model chosen (see table 1). For $v_{s,G,ref} = 350 \text{ m/s}$ e.g. one obtains

$$\beta_{ref} = \frac{1.9 \cdot 90}{2.2 \cdot 350} = 0.22$$

This gives for the range of $\Delta\xi_{\beta} = \frac{2}{\pi}(\beta - \beta_{ref})$:

$$\Delta\xi_{\beta,min} = \frac{2}{\pi}(0.14 - 0.22) = -0.008 \cdot \frac{2}{\pi} = -0.05$$

$$\Delta\xi_{\beta,max} = \frac{2}{\pi}(0.75 - 0.22) = 0.53 \cdot \frac{2}{\pi} = 0.34$$

This means that in the case of $\beta = 0,14$ of the real model the material damping in the layer of the reference model has to be diminished by 5%, and for $\beta = 0,75$ it has to be increased by 34%. E.g. if the material damping of the real model is 10% and $\beta = 0,14$, the damping in the layer of the reference model will be 5%.

The impedance ratios and ranges for the reference models acc. to table 1 are given in table 3. As the reference models have been computed for damping ratios of 5%, 10% and 15% only (table 1), as suitable reference model has to be selected acc. to the parameters $\Delta\xi_{\beta,min}$, $\Delta\xi_{\beta,max}$ given in table 3.

Table 3: Ranges of parameters of the reference model ($v_{s,S,ref} = 90 \text{ m/s}$)

$v_{s,G,ref}$ [m/s]	β_{ref}	$\Delta\xi_{\beta,min}(j=1)$	$\Delta\xi_{\beta,max}(j=1)$
154	0,50	-0,23	0,16
250	0,31	-0,11	0,28
350	0,22	-0,05	0,34
450	0,17	-0,02	0,37
520	0,15	-0,01	0,38
1000	0,08	0,04	0,43

5.4 Verification of the equivalent model

The application of the equivalent soil model is demonstrated for the examples given in table 4. The results of the equivalent models are compared with those of a computation of the real model. The analyses for the real models as well as for the equivalent models have been performed using SHAKE2000.

Table 4: Soil models

	Soil model					Equivalent soil model						
	$v_{s,S}$ [m/s]	$v_{s,G}$ [m/s]	h [m]	β	ξ_S [%]	v_{s,S_ref}	v_{s,G_ref}	h_{ref}	β_{ref}	ξ_1 [%]	ξ_2 [%]	ξ_3 [%]
A	50	500	10	0.09	10	90	1000	18	0.08	10.5	10.2	10.1
B	150	250	10	0.52	10	90	154	6	0.50	10.9	10.3	10.2
C	150	250	20	0.52	10	90	154	12	0.50	10.9	10.3	10.2
D	150	250	40	0.52	10	90	154	24	0.50	10.9	10.3	10.2
E	150	250	20	0.52	5	90	154	12	0.50	5.9	5.3	5.2
F	150	250	40	0.52	5	90	154	24	0.50	5.9	5.3	5.2

5.4.1 Soil model A

Soil model properties:

$$v_{s,S} = 50 \text{ m/s}; \quad h = 10 \text{ m}; \quad \xi_S = 10 \%;$$

$$v_{s,G} = 500 \text{ m/s}; \quad \beta = 0.09;$$

Equivalent soil model properties:

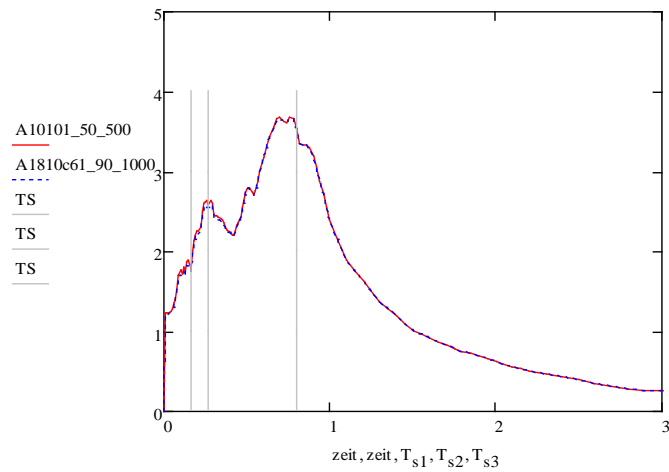
$$v_{s_ref} = 90 \text{ m/s}; \quad h_{ref} = 18 \text{ m};$$

Soil model A may be represented by six equivalent models with different shear wave velocities v_{s,G_ref} given in table 5. It can be seen that the models with $v_{s,G_ref} = 154, 250$ and 350 m/s are not suitable since they require very small or negative damping values (see eq. (4)). The model with $v_{s,G_ref} = 1000$ m/s is selected as equivalent model since the three damping values fit together quite well. The corresponding column is shadowed in gray.

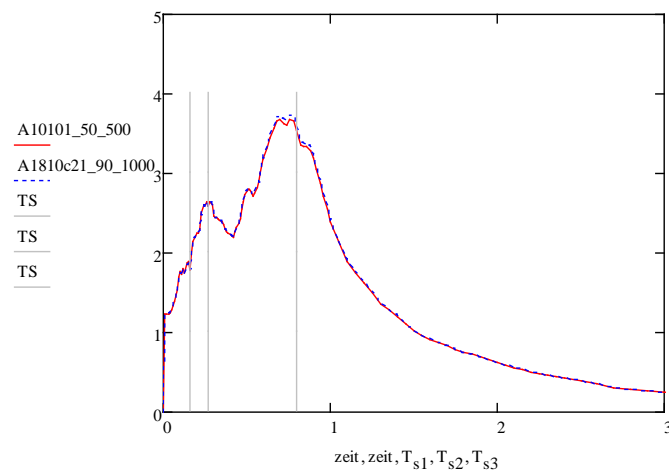
Table 5: Damping values of equivalent models for soil model A

v_{s,G_ref} [m/s]		154	250	350	450	520	1000
β_{ref}		0.50	0.31	0.22	0.20	0.15	0.08
j	1	-16.6%	-4.3%	1.4%	4.5%	6.0%	10.5%
	2	-1.1%	5.2%	7.1%	8.2%	8.7%	10.2%
	3	4.7%	7.1%	8.3%	8.9%	9.2%	10.1%

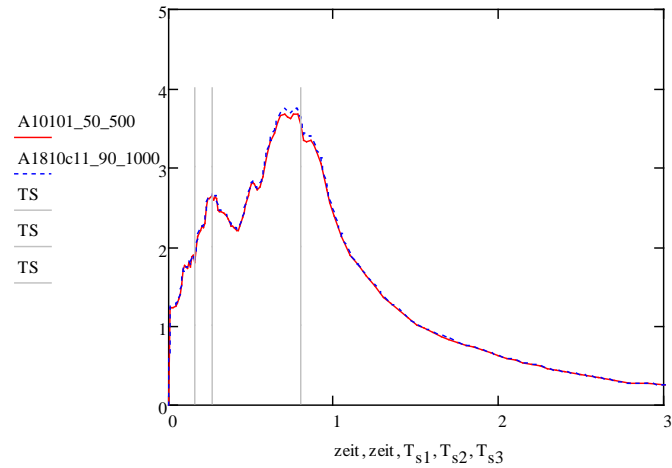
The response spectra of the equivalent models with three different damping values given in table 5) are shown in fig. 5a. The red line represents the response spectrum of the real model computed by a SHAKE2000 analysis while the blue line represents the response spectrum for the equivalent soil model. The green lines represent the first three periods of vibration for the soil layer on a rigid half-space.



(a) $\xi_{S,ref} = 10,5\%$



(b) $\xi_{S,ref} = 10.2\%$



(c) $\xi_{s,ref} = 10.1 \%$

Figure 5 a-c: Response spectra of the real and the equivalent soil models; soil model A

5.4.2 Soil model B

Soil model properties:

$$v_s = 150 \text{ m/s}; \quad h = 10 \text{ m}; \quad \xi = 10 \%;$$

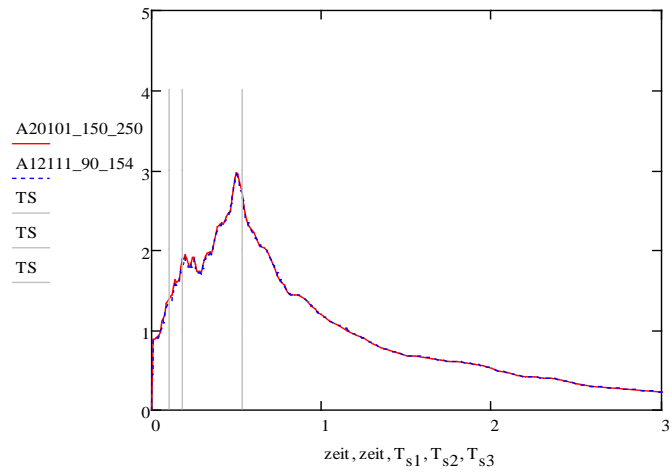
$$v_{s,G} = 250 \text{ m/s}; \quad \beta = 0.52.$$

Equivalent soil model properties:

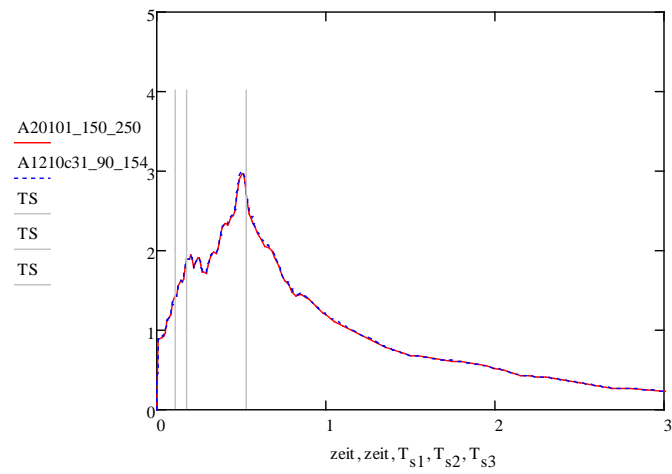
$$v_{s,ref} = 90 \frac{\text{m}}{\text{s}}; \quad h_{ref} = 6 \text{ m}.$$

Table 6: Damping values of equivalent models for soil models B, C and D

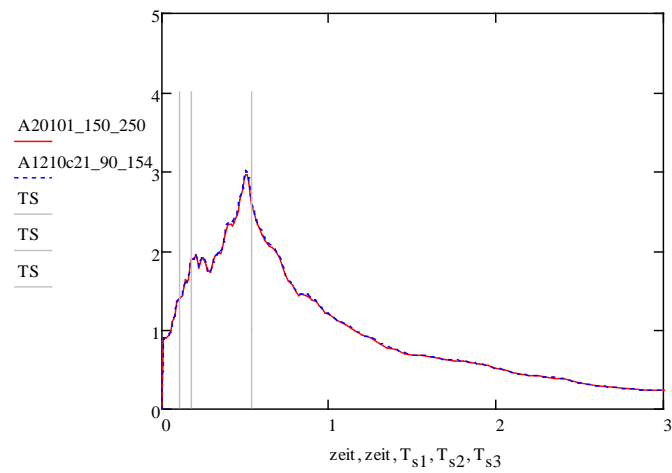
$v_{s,G,ref} \text{ [m/s]}$		154	250	350	450	520	1000
β_{ref}		0.50	0.31	0.22	0.17	0.15	0.08
j	1	10.9%	23.2%	28.9%	32.0%	33.5%	38.0%
	2	10.3%	14.4%	16.3%	17.3%	17.8%	19.3%
	3	10.2%	12.6%	13.8%	14.4%	14.7%	15.6%



(a) $\xi_{S,ref} = 10.9 \%$



(b) $\xi_{S,ref} = 10.3 \%$



(c) $\xi_{S,ref} = 10.2 \%$

Figure 6 a-c: Response spectra of the real and the equivalent soil models; soil model B

5.4.4 Soil model C

Soil model properties:

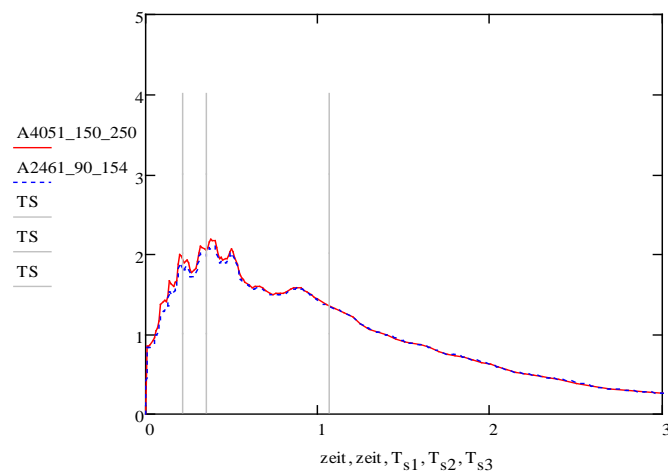
$$v_s = 150 \text{ m/s}; \quad h = 20 \text{ m}; \quad \xi = 10 \%;$$

$$v_{s,G} = 250 \text{ m/s}; \quad \beta = 0.52;$$

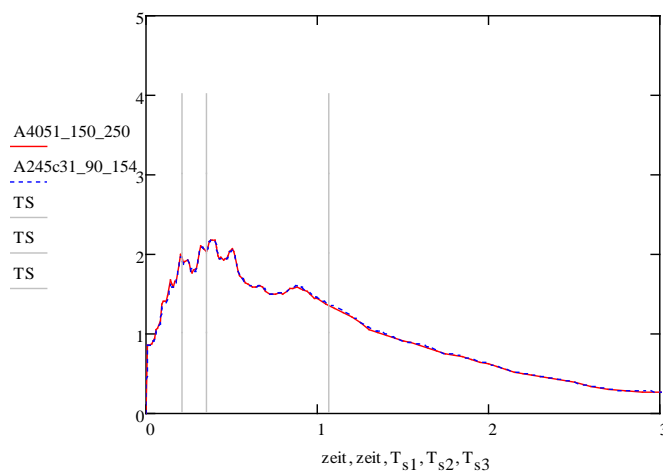
Equivalent soil model properties:

$$v_{s,\text{ref}} = 90 \frac{\text{m}}{\text{s}}; \quad h_{\text{ref}} = 12 \text{ m}.$$

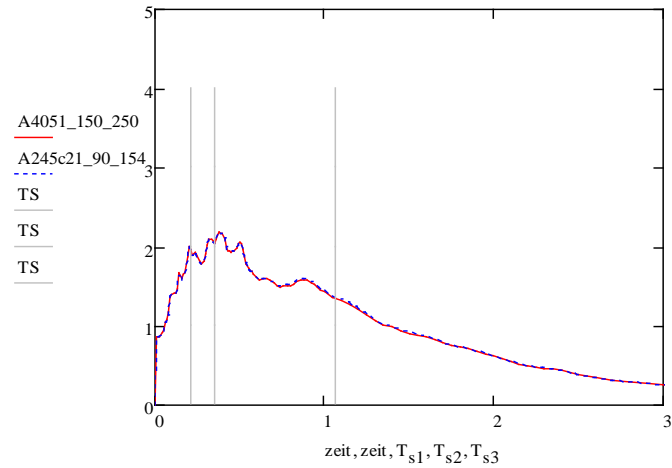
The damping values of the equivalent models for soil are given in table 6



(a) $\xi_{S,\text{ref}} = 10.9 \%$



(b) $\xi_{S,\text{ref}} = 10.3 \%$



(c) $\xi_{S,ref} = 10.2 \%$

Figure 7 a-c: Response spectra of the real and the equivalent soil models; soil model C

5.4.6 Soil model D

Soil model properties:

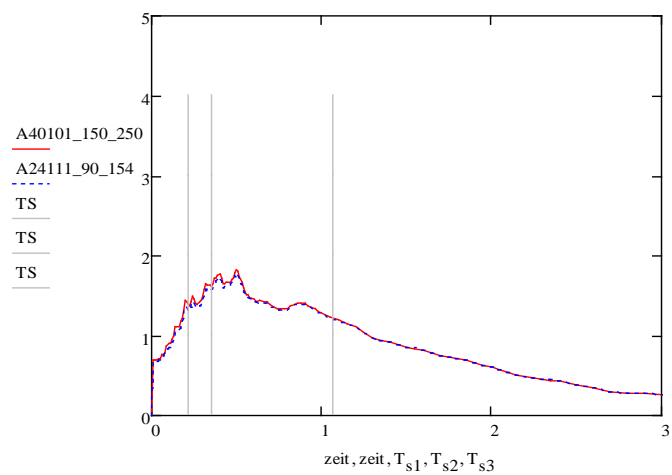
$$v_s = 150 \text{ m/s}; \quad h = 40 \text{ m}; \quad \xi = 10 \%;$$

$$v_{s,G} = 250 \text{ m/s}; \quad \beta = 0.52;$$

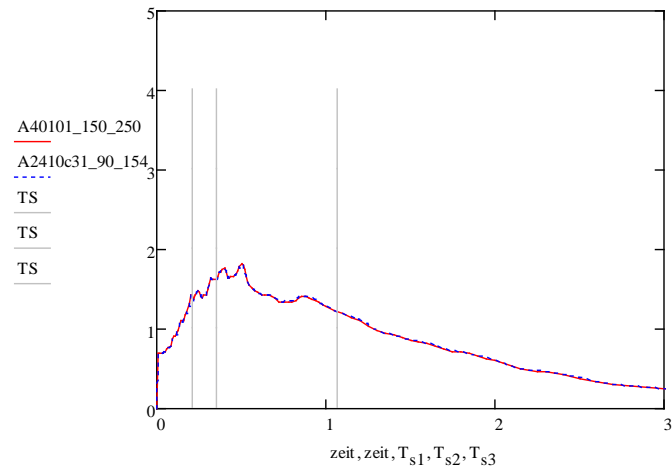
Equivalent soil model properties:

$$v_{s,ref} = 90 \frac{\text{m}}{\text{s}}; \quad h_{ref} = 24 \text{ m}.$$

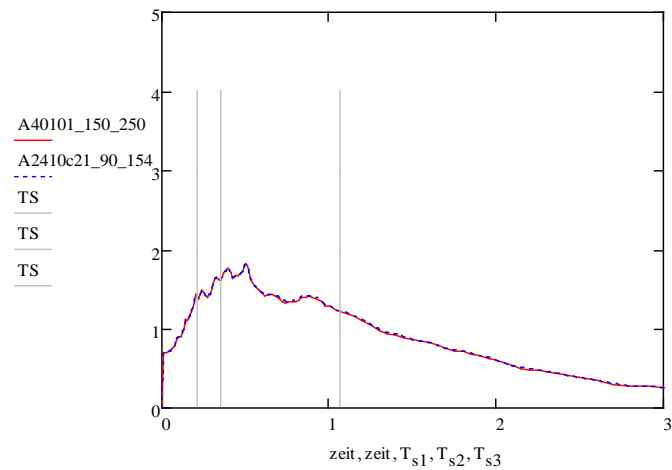
The damping values of the equivalent models for soil are given in table 6



(a) $\xi_{S,ref} = 10.9 \%$



(b) $\xi_{S,ref} = 10.3 \%$



(c) $\xi_{S,ref} = 10.2 \%$

Figure 8 a-c: Response spectra of the real and the equivalent soil models; soil model D

5.4.3 Soil model E

Soil model properties:

$$v_s = 150 \text{ m/s}; \quad h = 20 \text{ m}; \quad \xi = 5 \%;$$

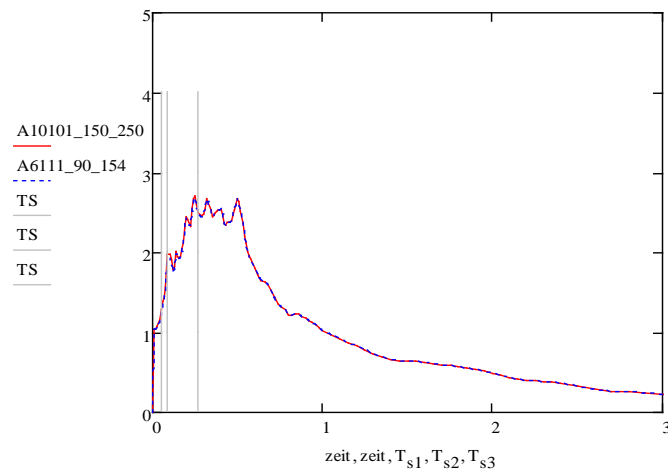
$$v_{s,G} = 250 \text{ m/s}; \quad \beta = 0.52;$$

Equivalent soil model properties:

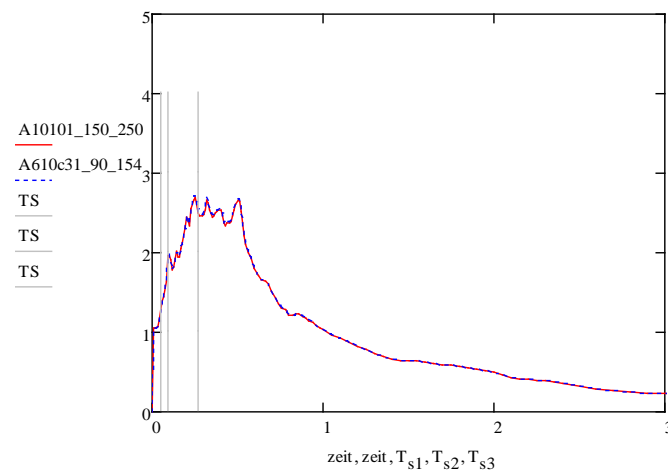
$$v_{s,ref} = 90 \text{ m/s}; \quad h_{ref} = 12 \text{ m}$$

Table 7: Damping values of equivalent models for soil models E and F

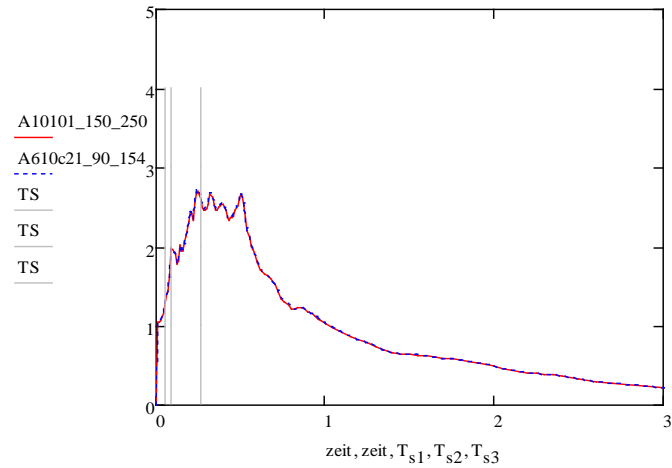
v_{s,G_ref} [m/s]		154	250	350	450	520	1000
β_{ref}		0.50	0.31	0.22	0.17	0.15	0.08
j	1	5.9%	18.2%	23.9%	27.0%	28.5%	33.0%
	2	5.3%	9.4%	11.3%	12.3%	12.8%	14.3%
	3	5.2%	7.6%	8.8%	9.4%	9.7%	10.6%



(a) $\xi_{S,ref} = 5.9 \%$



(b) $\xi_{S,ref} = 5.3 \%$



(c) $\xi_{S,ref} = 5.2 \%$

Figure 9 a-c: Response spectra of the real and the equivalent soil models; soil model E

5.4.5 Soil model F

Soil model properties:

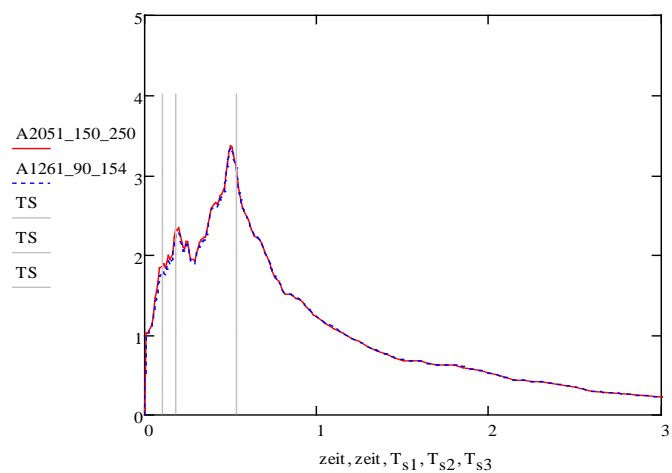
$$v_s = 150 \text{ m/s}; \quad h = 40 \text{ m}; \quad \xi = 5 \%;$$

$$v_{s,G} = 250 \text{ m/s}; \quad \beta = 0.52.$$

Equivalent soil model properties:

$$v_{s,ref} = 90 \text{ m/s}; \quad h_{ref} = 24 \text{ m};$$

The damping values of the equivalent models are given in table 7.



(a) $\xi_{S,ref} = 5.9 \%$

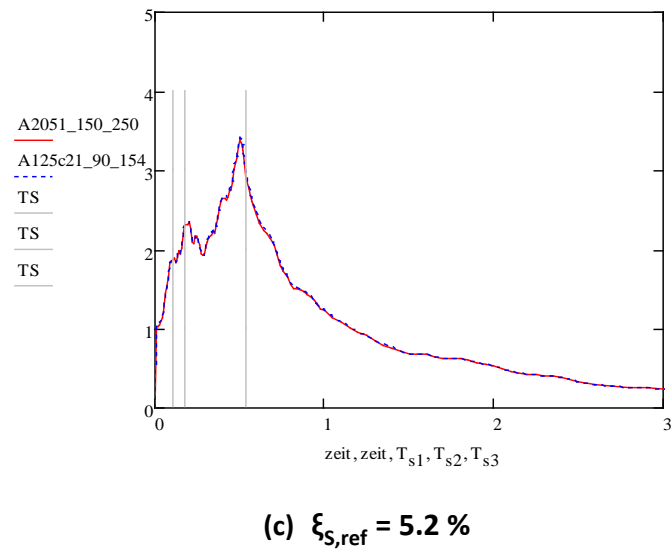
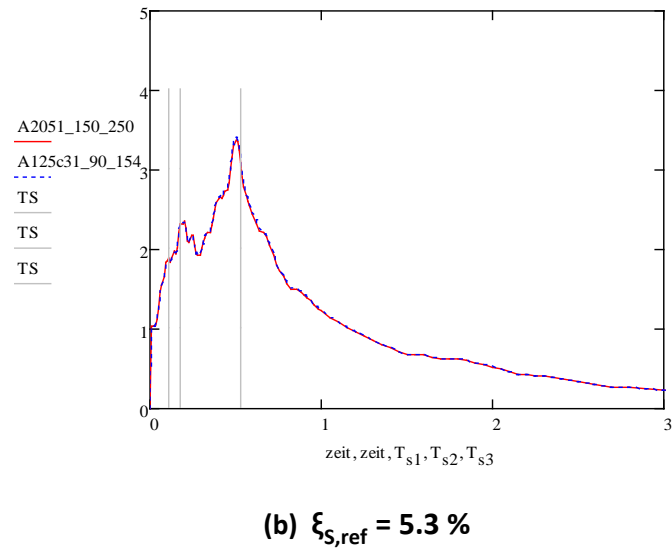


Figure 10 a-c: Response spectra of the real and the equivalent soil models; soil model F

6 SIMPLIFIED RESPONSE SPECTRA

Based on the parameter study described in section 4, simplified formulas for response spectra of a layer over a half-space have been developed. Taking the resonance behavior of the layer into account two response spectra are defined separately, one for the first and one for the second period of the layer. The final response spectrum is the envelope of both spectra.

6.1 Basic formula for acceleration response spectra

The formula of the response spectrum for the i -th natural vibration of the layer is adapted to EC8 acc. to eq. 1 and given by

$$\begin{aligned}
S_{S,e,i} &= 0.75 + \frac{T}{T_{B,i}} \cdot (a_{g,i} - 0.75), & T_{A,i} \leq T \leq T_{B,i} \\
S_{S,e,i} &= a_{g,i}, & T_{B,i} \leq T \leq T_{C,i} \\
S_{S,e,i} &= a_{g,i} \cdot \left(\frac{T_{C,i}}{T}\right)^{n_i}, & T_{C,i} \leq T \leq T_{D,i} \\
S_{S,e,i} &= a_{g,i} \cdot \left(\frac{T_{C,i}}{T}\right)^{n_i} \cdot \frac{T_{D,i}}{T}, & T_{D,i} \leq B
\end{aligned} \tag{11}$$

where

$S_{S,e,i}$ - is the elastic response spectrum for the i -th period of the layer (on a rigid base);

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

$a_{g,i}$ - is the design ground acceleration;

$T_{B,i}$ - is the lower limit of the period of the constant spectral acceleration branch;

$T_{C,i}$ - is the upper limit of the period of the constant spectral acceleration branch;

$T_{D,i}$ - is the value defining the beginning of the constant displacement response range of the spectrum.

As in EC8 the response spectrum is related to 5% damping of the one-degree-of-freedom system.

The maximum values of the response acceleration are given by

$$a_{g,i} = \alpha_i \cdot a_{gR} \cdot \gamma_I \cdot S_e(T_{S,i}). \tag{12}$$

The parameters α_i corresponding the i -th natural mode of vibration are evaluated in section 6.3. They are related to the "optimized" $T_{S,i}$ acc. to section 6.2. The evaluation of the parameter n_1 is presented in section 6.4. In the following investigations all spectra are normalized to $a_g = 1.0 \text{ m/s}^2$ and $\gamma_I = 1.0$.

Two response spectra having the presented form are computed for the first two modes of vibration where $i=1$ and $i=2$, respectively. The resulting response spectrum is given by the maximum of these two spectra as

$$S_{S,e} = \max(S_{S,e,1}, S_{S,e,2}). \tag{13}$$

6.2 Control periods of the response spectrum

The control periods are derived from the natural vibration periods of the layer:

$$T_{A,i} = 0; \quad T_{B,i} = T_{S,i+1}; \quad T_{C,i} = T_{S,i}; \quad T_{D,i} = \max(T_{C,i}, T_D) \quad \text{with } T_D = 2.0 \text{ [s]}. \tag{13}$$

Natural periods of vibrations for an elastic layer over a rigid base are given by eq. 2 as

$$T_j = \frac{4 \cdot h}{v_{s,S} \cdot (2 \cdot j - 1)} \quad (14)$$

or

$$T_1 = \frac{4 \cdot h}{v_{s,S}}; \quad T_2 = \frac{4 \cdot h}{3 \cdot v_{s,S}}; \quad T_3 = \frac{4 \cdot h}{5 \cdot v_{s,S}}; \quad T_4 = \frac{4 \cdot h}{7 \cdot v_{s,S}}; \quad T_5 = \frac{4 \cdot h}{9 \cdot v_{s,S}}; \quad (15)$$

During the investigations it has been noticed that for all the layer heights the response spectra show a pronounced peak takes at a period of $T=0.5s$ due to the initial spectra from EC8. In order to take this fact into account, for the control periods the following adjustments were performed:

$$T_1 = \max \left(0.5, \frac{4h}{v_{s,S}} \right); \quad T_2 = \begin{cases} \max \left(0.5, \frac{4h}{3v_{s,S}} \right) & \text{if } \frac{4h}{v_{s,S}} > 0.5 \\ \frac{4h}{3v_{s,S}} & \text{otherwise} \end{cases}$$

Height [m]	$T_1 = \frac{4 \cdot h}{v_s}$	T_1 - optimal	$T_2 = \frac{4 \cdot h}{3 \cdot v_s}$	T_2 - optimal
5	0.22	0.2	0.07	0.2
7.5	0.33	0.3	0.111	0.3
10	0.444	0.4	0.148	0.4
12.5	0.55	0.45	0.185	0.45
15	0.667	0.5	0.222	0.5
20	0.887	0.5	0.296	0.5
25	1.11	0.5	0.37	0.5
30	1.33	0.5	0.44	0.5
35	1.56	0.5	0.519	0.519
40	1.77	0.5	0.59	0.59
45	2	0.5	0.667	0.667
50	2.22	0.5	0.741	0.741

6.3 Parameter α_i

The ratio between the accelerations obtained from Shake2000 analyses at the top of the layer and the ones at the top of the half-space (fig. 2) at the frequencies given above are defined by a parameter α_i . As mentioned in the previous section, two parameters α_i (α_1 and α_2) are required in order to define the spectra for the first two modes of vibrations. For each investigated shear wave velocity of the half space a different set of α_1 and α_2 parameters for $\xi_s = 5\%, 10\%, 15\%$ is to be fixed.

The evaluation of the parameters is done for $h < 50$ m. For $50 \text{ m} < h < 100$ m the third and fourth eigenfrequencies become relevant. This would require a corresponding extension of eq. 11 for higher values i .

a) $v_{s,G} = 154 \text{ m/s}$

α						
	$\xi_s = 5\%$		$\xi_s = 10\%$		$\xi_s = 15\%$	
h	T_1	T_2	T_1	T_2	T_1	T_2
5	1.50	1.23	1.35	1.00	1.23	0.86
10	1.61	1.21	1.44	0.98	1.29	0.82
15	1.64	1.15	1.46	0.92	1.30	0.76
20	1.66	1.12	1.48	0.88	1.34	0.72
25	1.58	1.17	1.42	0.91	1.28	0.73
30	1.55	1.19	1.37	0.92	1.23	0.73
35	1.64	1.38	1.46	1.04	1.31	0.80
40	1.74	1.25	1.54	0.94	1.38	0.73
45	1.59	1.19	1.40	0.92	1.25	0.72
50	1.66	1.08	1.47	0.85	1.32	0.67
Average	1.62	1.20	1.44	0.94	1.29	0.75

	T_1	T_2
5%	1.62	1.20
10%	1.44	0.94
15%	1.29	0.75

$\alpha_{1_5} = 1.62$; $\alpha_{1_{15}} = 1.29$ – Alfa parameter corresponding to the first equivalent spectra (1st mode of vibration) having a damping equal to 5% and 15%, respectively.

$\alpha_{2_5} = 1.20$; $\alpha_{2_{15}} = 0.75$ – Alfa parameter corresponding to the second equivalent spectra (2nd mode of vibration) having a damping equal to 5% and 15%, respectively.

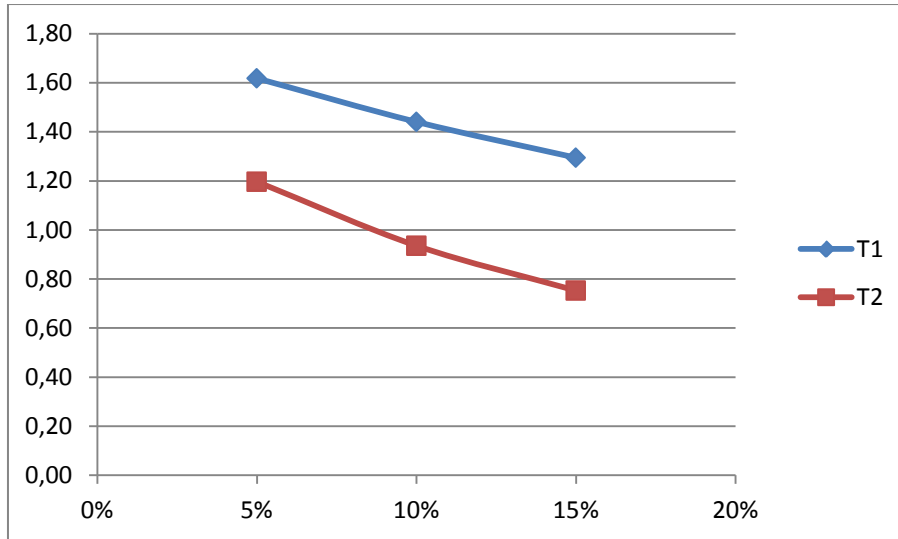


Figure 11: Parameters α_1 and α_2 for $v_{s,G} = 154$ m/s

b) $v_{s,G} = 250$ m/s

α						
	$\xi_s = 5\%$		$\xi_s = 10\%$		$\xi_s = 15\%$	
h	T1	T2	T1	T2	T1	T2
5	2.06	1.52	1.77	1.20	1.56	0.99
10	2.26	1.52	1.94	1.19	1.69	0.98
15	2.33	1.42	1.98	1.08	1.71	0.88
20	2.26	1.41	1.95	1.05	1.71	0.84
25	2.16	1.45	1.86	1.09	1.64	0.85
30	2.11	1.53	1.82	1.12	1.59	0.87
35	2.32	1.77	1.98	1.27	1.72	0.96
40	2.40	1.54	2.05	1.12	1.78	0.86
45	2.21	1.44	1.88	1.08	1.63	0.84
50	2.31	1.37	1.96	1.01	1.71	0.79
Average	2.24	1.50	1.92	1.12	1.68	0.89

	T1	T2
5%	2.24	1.50
10%	1.92	1.12
15%	1.68	0.89

$$\alpha_{1_5} = 2.24; \alpha_{1_{15}} = 1.68$$

$$\alpha_{2_5} = 1.50; \alpha_{2_{15}} = 0.89$$

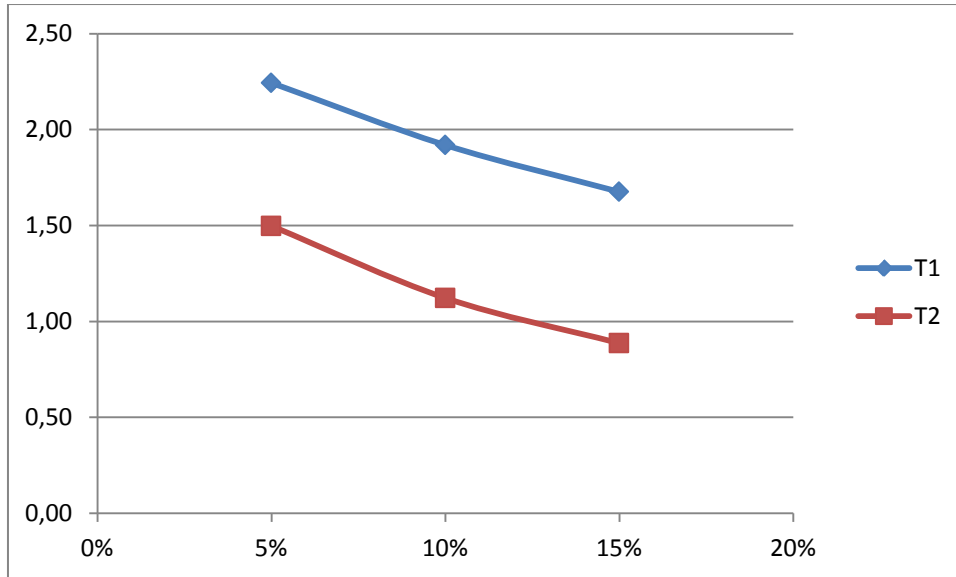


Figure 12: Parameters α_1 and α_2 for $v_{s,G} = 250$ m/s

c) $v_{s,G} = 350$ m/s

h	α					
	$\xi_s = 5\%$		$\xi_s = 10\%$		$\xi_s = 15\%$	
	T1	T2	T1	T2	T1	T2
5	2.54	1.8	2.1	1.38	1.8	1.13
10	2.79	1.8	2.3	1.33	1.97	1.08
15	2.82	1.61	2.34	1.14	1.99	0.95
20	2.78	1.6	2.31	1.2	1.89	0.94
25	2.59	1.67	2.18	1.33	1.87	0.93
30	2.64	1.79	2.29	1.26	2.06	1.09
35	2.88	2.04	2.43	1.21		0.98
40	2.93	1.77	2.46	1.77	2.06	0.95
45	2.7	1.65	2.23	1.2	1.89	0.92
50	2.79	1.55	2.28	1.12	1.92	0.85
Average	2.75	1.73	2.29	1.29	1.94	0.98

	T1	T2
5%	2.75	1.73
10%	2.29	1.29
15%	1.94	0.98

$$\alpha_{1_5} = 2.75; \alpha_{1_{15}} = 1.94$$

$$\alpha_{2_5} = 1.73; \alpha_{2_{15}} = 0.98$$

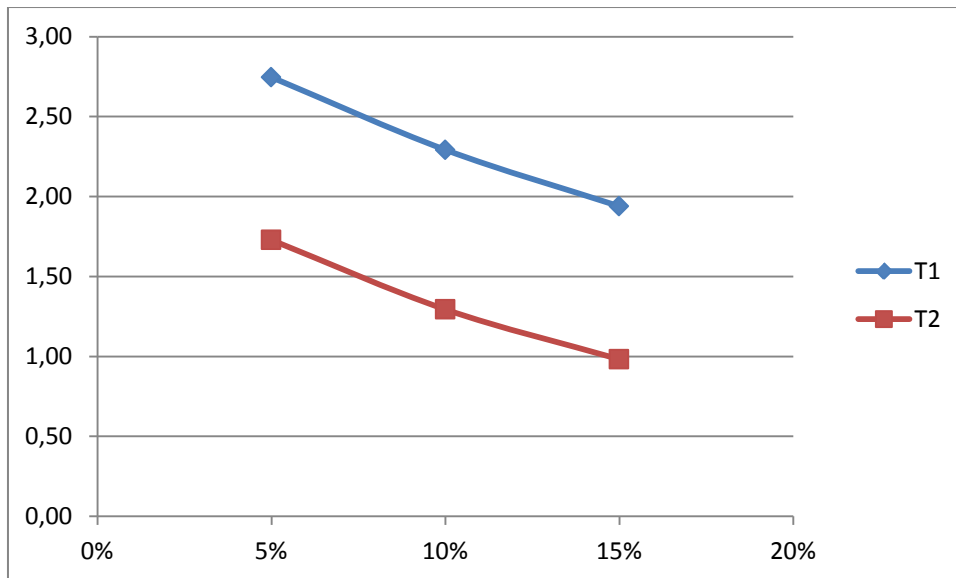


Figure 13: Parameters α_1 and α_2 for $v_{s,G} = 350$ m/s

d) $v_{s,G} = 450$ m/s

h	α					
	$\xi_s = 5\%$		$\xi_s = 10\%$		$\xi_s = 15\%$	
	T1	T2	T1	T2	T1	T2
5	2.91	1.85	2.35	1.44	1.97	1.16
10	3.22	1.89	2.58	1.41	2.16	1.14
15	3.22	1.74	2.59	1.25	2.17	0.99
20	3.14	1.72	2.56	1.25	2.15	0.96
25	2.91	1.81	2.42	1.27	2.05	0.98
30	2.51	1.44	2.17	1.16	1.93	0.96
35	3.27	2.23	2.65	1.51	2.22	1.12
40	3.37	1.92	2.72	1.34	2.27	1.00
45	3.10	1.73	2.50	1.26	2.09	0.97
50	3.27	1.67	2.62	1.20	2.18	0.90
Average	3.09	1.80	2.52	1.31	2.12	1.02

	T1	T2
5%	3.09	1.80
10%	2.52	1.31
15%	2.12	1.02

$$\alpha_{1_5} = 3.09; \alpha_{1_{15}} = 2.12$$

$$\alpha_{2_5} = 1.80; \alpha_{2_{15}} = 1.02$$

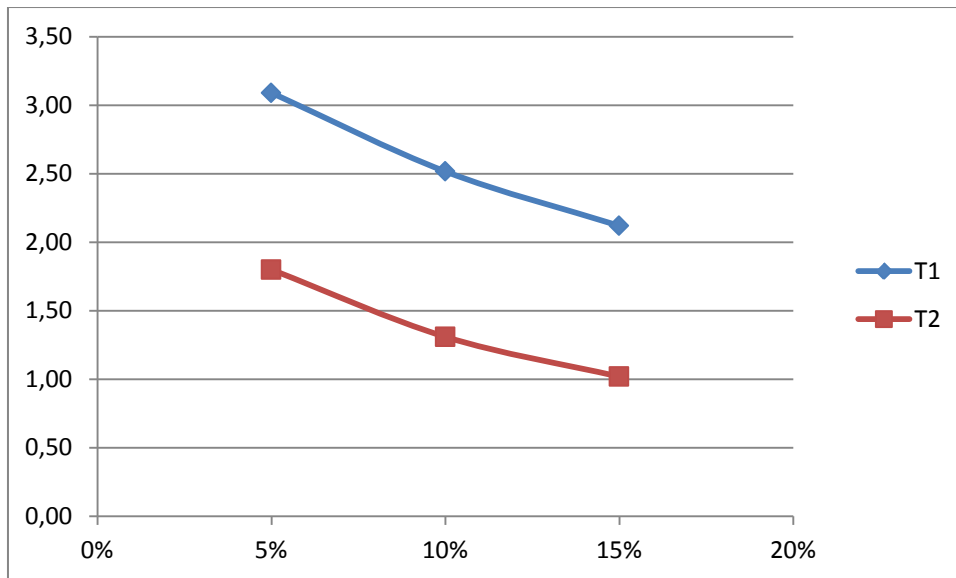


Figure 14: Parameters α_1 and α_2 for $v_{s,G} = 450$ m/s

e) $v_{s,G} = 520$ m/s

	α					
	$\xi_s = 5\%$		$\xi_s = 10\%$		$\xi_s = 15\%$	
h	T1	T2	T1	T2	T1	T2
5	3.13	1.92	2.49	1.49	2.07	1.20
10	3.48	1.99	2.73	1.46	2.27	1.18
15	3.49	1.80	2.78	1.29	2.31	1.01
20	3.35	1.79	2.70	1.29	2.25	0.99
25	3.11	1.89	2.54	1.31	2.15	1.00
30	3.22	1.98	2.57	1.38	2.13	1.03
35	3.51	2.33	2.81	1.57	2.33	1.15
40	3.61	2.04	2.88	1.42	2.39	1.05
45	3.33	1.84	2.64	1.32	2.19	1.01
50	3.50	1.74	2.78	1.24	2.29	0.93
Average	3.37	1.93	2.69	1.38	2.24	1.05

	T1	T2
5%	3.37	1.93
10%	2.69	1.38
15%	2.24	1.05

$$\alpha_{1_5} = 3.37; \alpha_{1_{15}} = 2.24$$

$$\alpha_{2_5} = 1.93; \alpha_{2_{15}} = 1.05$$

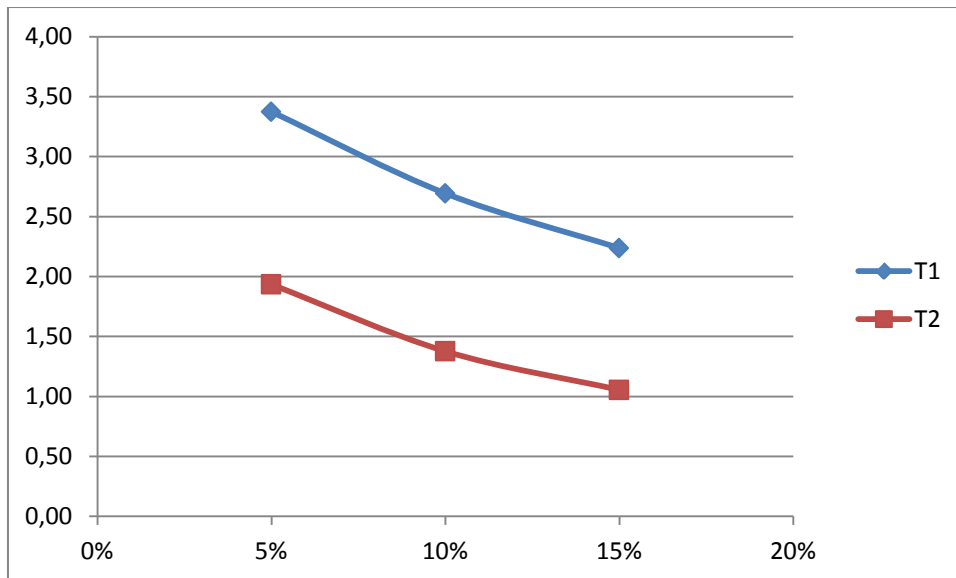


Figure 15: Parameters α_1 and α_2 for $v_{s,G} = 520$ m/s

f) $v_{s,G} = 1000$ m/s

h	α					
	$\xi_s = 5\%$		$\xi_s = 10\%$		$\xi_s = 15\%$	
	T1	T2	T1	T2	T1	T2
5.00	4.13	2.21	3.06	1.67	2.44	1.33
10.00	4.57	2.36	3.39	1.64	2.67	1.29
15.00	4.50	2.07	3.40	1.43	2.72	1.08
20.00	4.23	2.06	3.27	1.43	2.59	1.08
25.00	4.09	2.18	3.03	1.44	2.49	1.08
30.00	3.86	2.27	3.02	1.53	2.46	1.13
35.00	4.55	2.72	3.43	1.76	2.75	1.25
40.00	4.68	2.30	3.52	1.55	2.81	1.12
45.00	4.34	2.04	3.23	1.44	2.58	1.09
50.00	4.52	2.01	3.40	1.38	2.71	1.02
Average	4.35	2.22	3.28	1.53	2.62	1.15

	T1	T2
5%	4.35	2.22
10%	3.28	1.53
15%	2.62	1.15

$$\alpha_{1_5} = 4.35; \alpha_{1_{15}} = 2.62$$

$$\alpha_{2_5} = 2.22; \alpha_{2_{15}} = 1.15$$

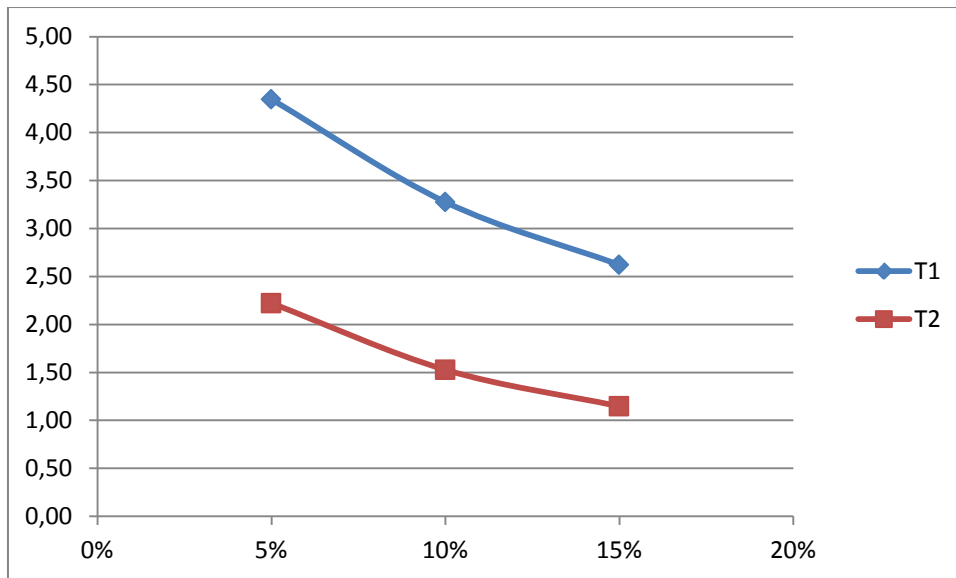


Figure 16: Parameters α_1 and α_2 for $v_{s,G} = 1000$ m/s

f) Summary

The parameters α_1 and α_2 for all shear wave velocities $v_{s,G}$ of the bedrock investigated are given in table 8 and Fig. 17.

Table 8: Variation of the parameters α_1 and α_2 with $v_{s,G}$ and material damping ξ_s

	$v_{s,G}$					
	154	250	350	450	520	1000
α_{1_5}	1.62	2.24	2.75	3.09	3.37	4.35
$\alpha_{1_{10}}$	1.46	1.96	2.35	2.61	2.81	3.49
$\alpha_{1_{15}}$	1.29	1.68	1.94	2.12	2.24	2.62
α_{2_5}	1.20	1.50	1.73	1.80	1.93	2.22
$\alpha_{2_{10}}$	0.98	1.20	1.36	1.41	1.49	1.69
$\alpha_{2_{15}}$	0.75	0.89	0.98	1.02	1.05	1.15

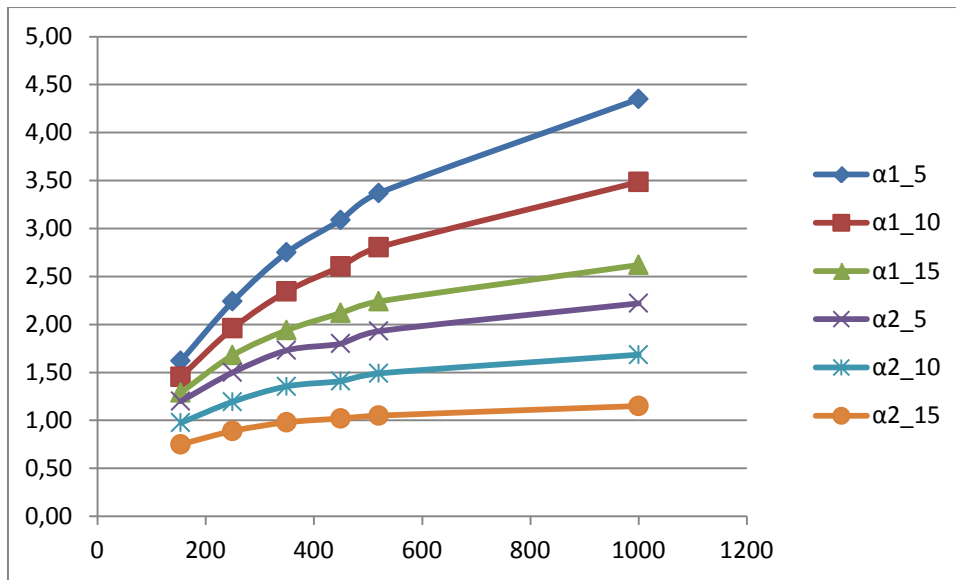


Figure 17: Variation of the parameters α_1 and α_2 with $v_{s,G}$ and material damping ξ_S

6.4 Parameter 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 for different values $v_{s,G}$ and ξ_S .

The results are summarized in Table 9 and Fig. 25.

a) $v_{s,G} = 154 \text{ m/s}$

	$\xi_S \%$		
	5	10	15
n_1	1.30	1.18	1.05
n_2	1.20	1.00	0.80

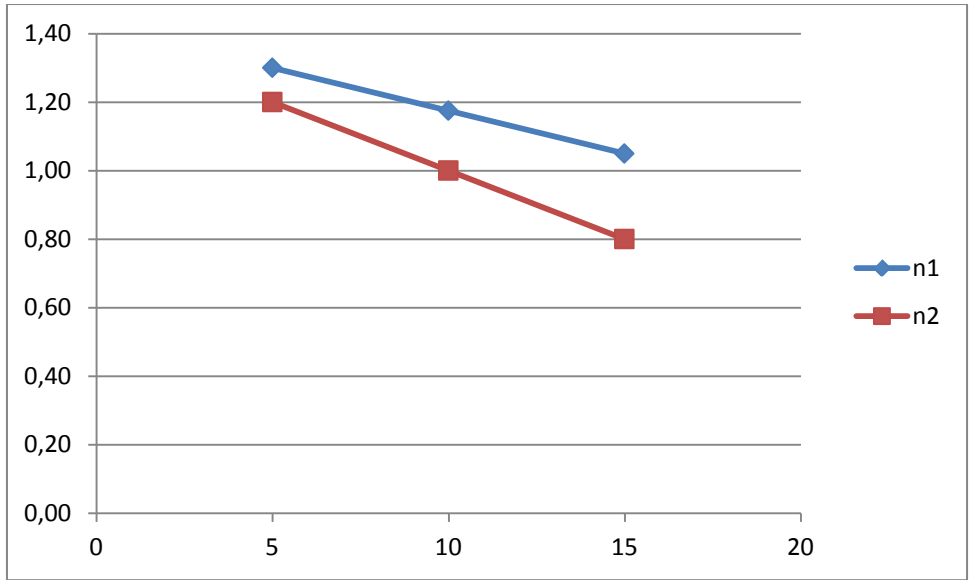


Figure 18: Parameters n_1 and n_2 vs. ξ_s for $v_{s,G} = 154$ m/s

b) $v_{s,G} = 250$ m/s

	ξ_s %		
	5	10	15
n_1	1.50	1.35	1.20
n_2	1.40	1.10	0.80

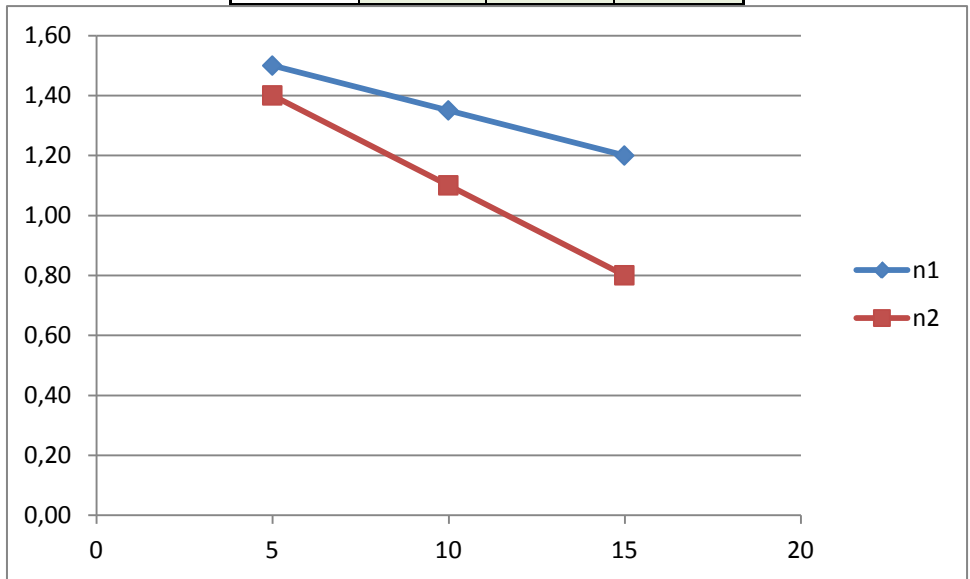


Figure 19: Parameters n_1 and n_2 vs. ξ_s for $v_{s,G} = 250$ m/s

c) $v_{s,G} = 350 \text{ m/s}$

	$\xi_s \%$		
	5	10	15
n_1	1.70	1.50	1.30
n_2	1.50	1.20	0.90

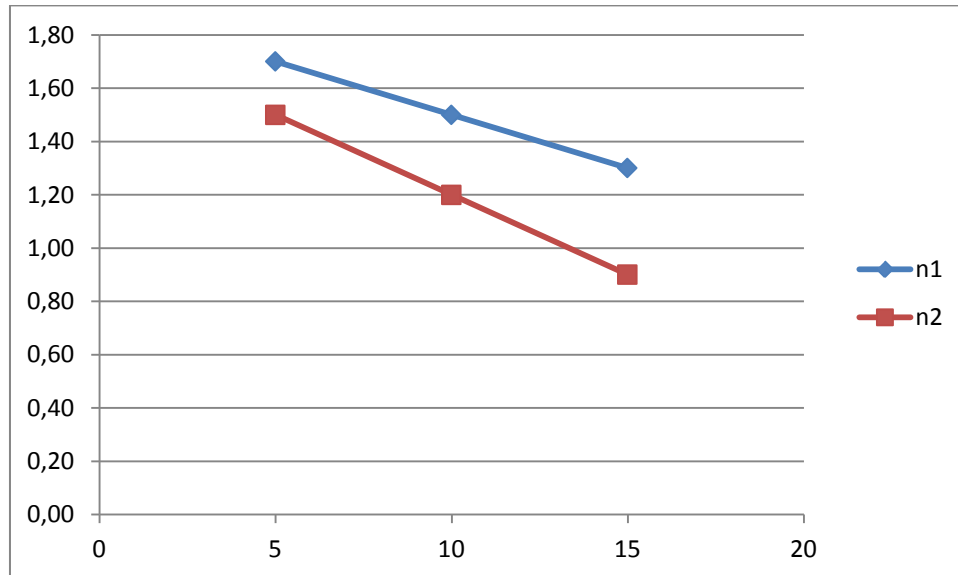


Figure 20: Parameters n_1 and n_2 vs. ξ_s for $v_{s,G} = 350 \text{ m/s}$

d) $v_{s,G} = 450 \text{ m/s}$

	$\xi_s \%$		
	5	10	15
n_1	1.70	1.55	1.40
n_2	1.50	1.25	1.00

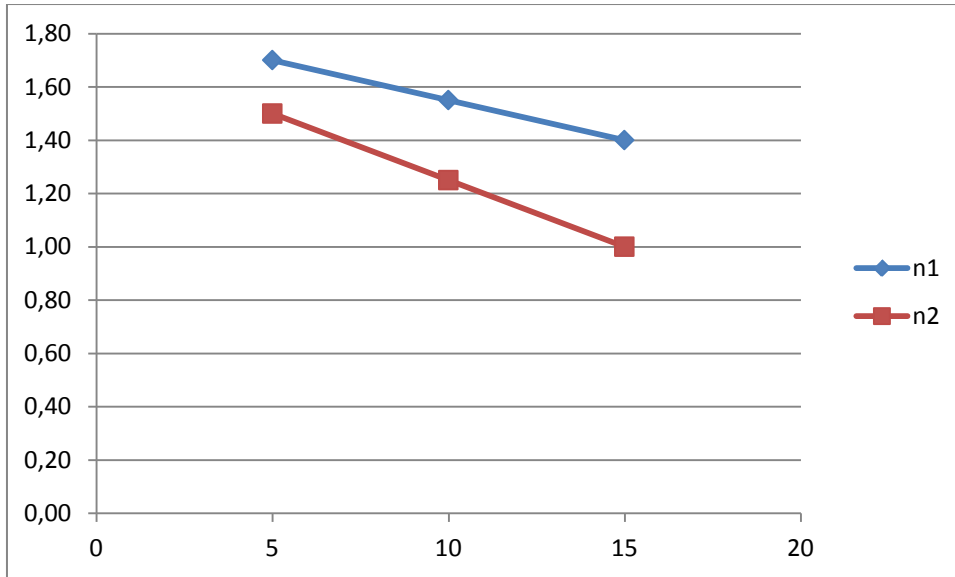


Figure 21: Parameters n_1 and n_2 vs. ξ_s for $v_{s,G} = 450$ m/s

e) $v_{s,G} = 520$ m/s

	ξ_s %		
	5	10	15
n_1	1.90	1.65	1.40
n_2	1.60	1.30	1.00

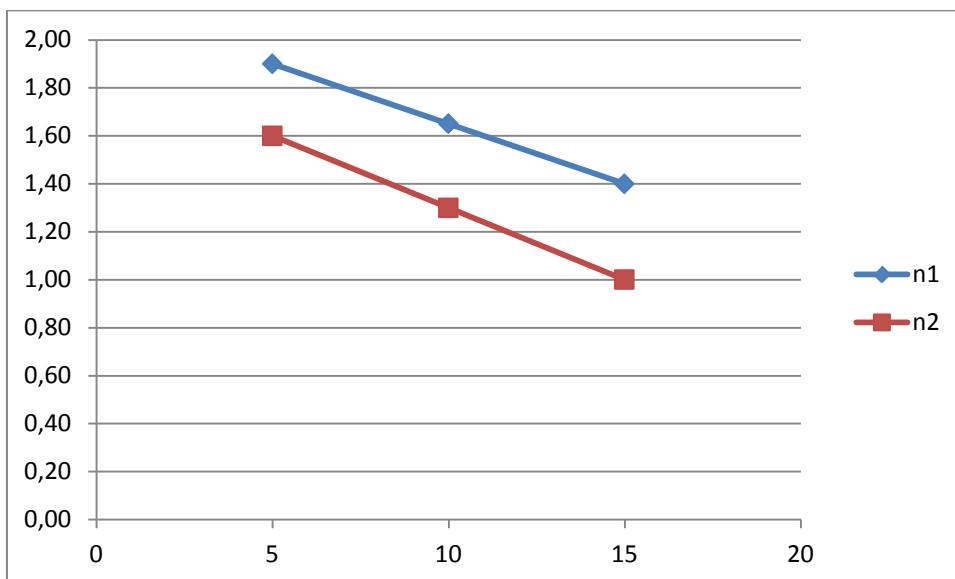


Figure 22: Parameters n_1 and n_2 vs. ξ_s for $v_{s,G} = 520$ m/s

f) $v_{s,G} = 1000 \text{ m/s}$

	$\xi_s \%$		
	5	10	15
n_1	2.10	1.85	1.60
n_2	1.50	1.25	1.00

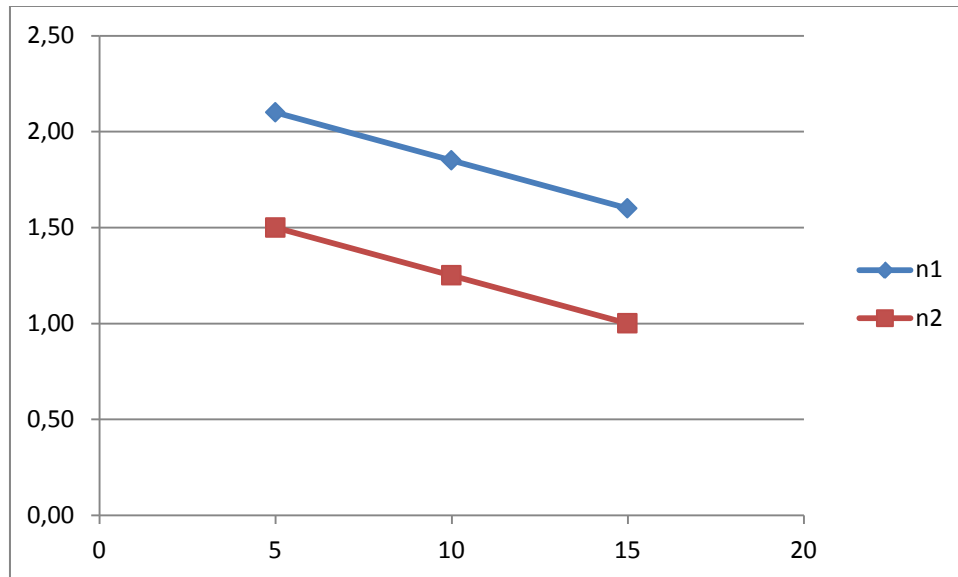


Figure 24: Parameters n_1 and n_2 vs. ξ_s for $v_{s,G} = 1000 \text{ m/s}$

g) Summary

The parameters n_1 and n_2 for all shear wave velocities $v_{s,G}$ of the bedrock investigated are given in table 9 and Fig. 25.

Table 9: Variation of the parameter n_1 and n_2 with $v_{s,G}$ and material damping ξ_s

	vs_halfspace					
	154	250	350	450	520	1000
n_{1_5}	1.30	1.50	1.70	1.70	1.90	2.10
n_{1_10}	1.18	1.35	1.50	1.55	1.65	1.85
n_{1_15}	1.05	1.20	1.30	1.40	1.40	1.60
n_{2_5}	1.20	1.40	1.50	1.50	1.60	1.50
n_{2_10}	1.00	1.10	1.20	1.25	1.30	1.25
n_{2_15}	0.80	0.80	0.90	1.00	1.00	1.00

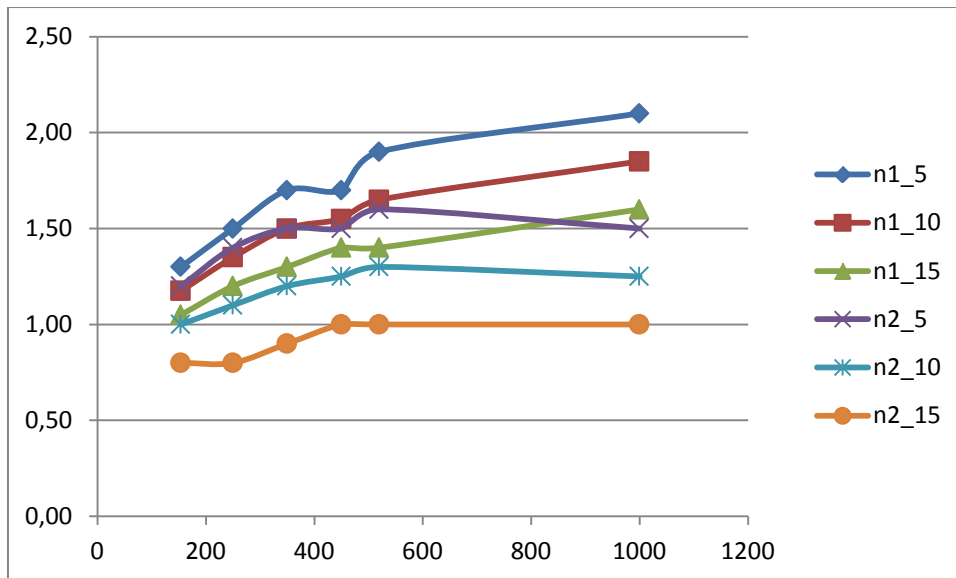
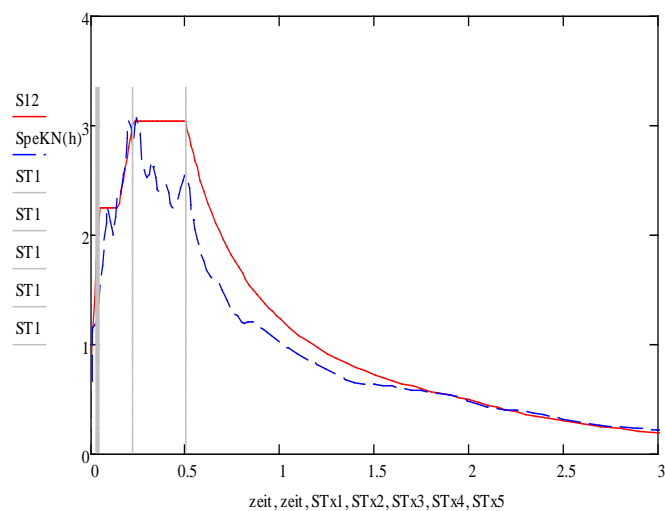


Figure 25: Parameters n_1 and n_2 vs. $v_{s,G}$ for $\xi_s = 5\%$; 10% ; 15%

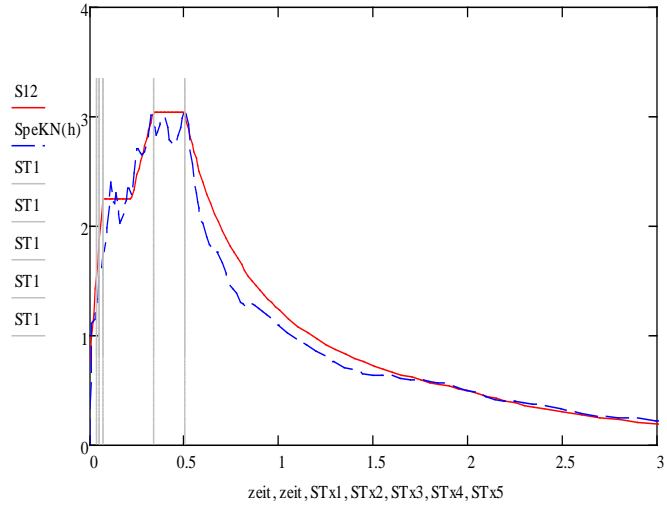
6.5 Verification of the simplified spectra

In order to verify the simplified spectra for all investigated shear wave velocities the graphs are plotted in this section for 5, 10 and 15 % damping, respectively. They are compared with the exact spectra acc. to section 4. The results of the simplified method show a good agreement with more precise one-dimensional shear wave propagation analyses.

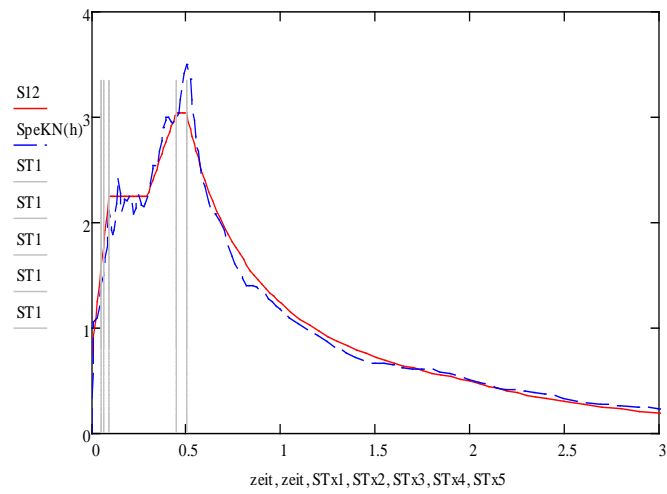
6.5.1 Bedrock shear wave velocity equal to 154 m/s



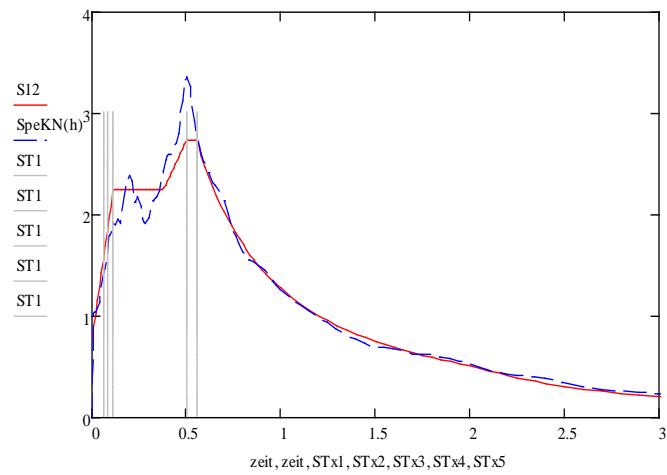
5m ($\xi_s = 5\%$)



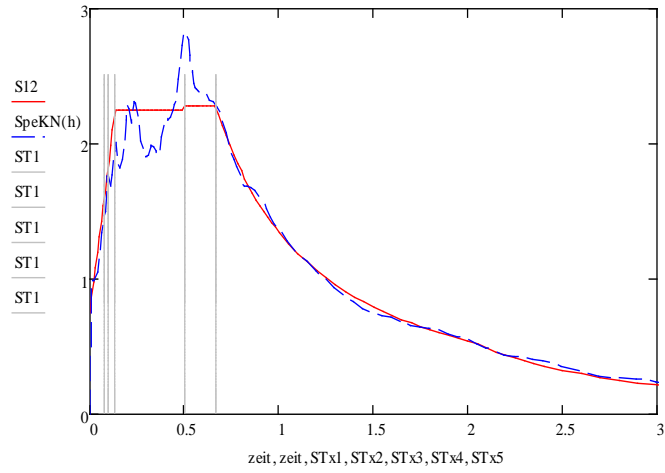
7.5m ($\xi_s = 5\%$)



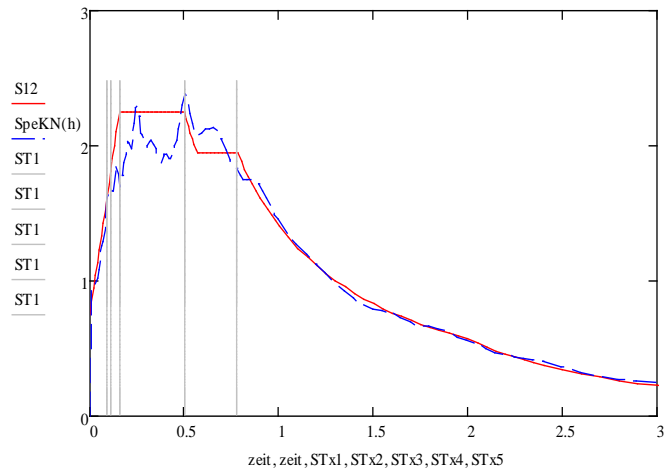
10m ($\xi_s = 5\%$)



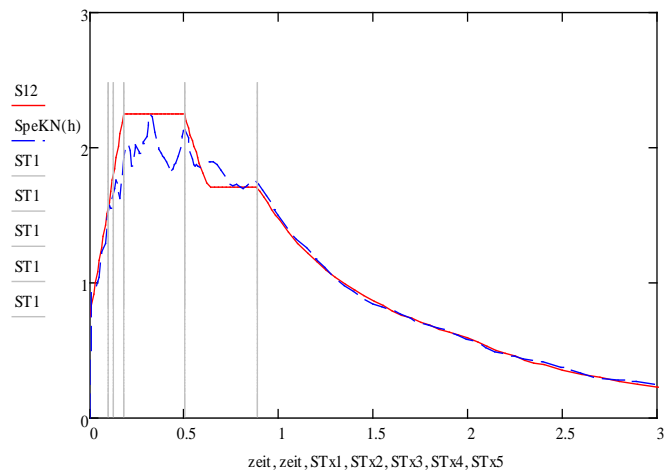
12.5m ($\xi_s = 5\%$)



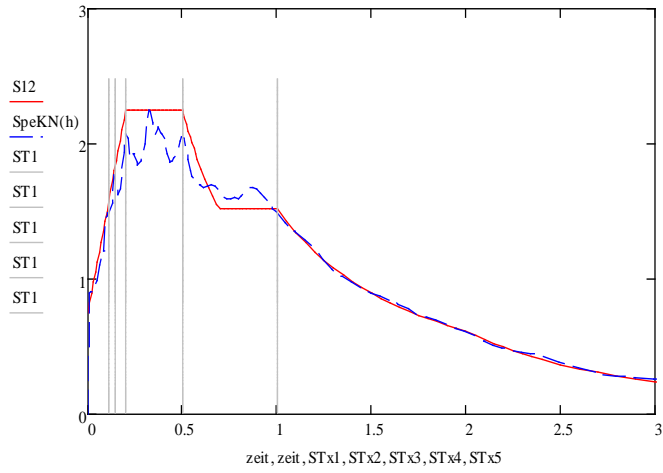
15m ($\xi_s = 5\%$)



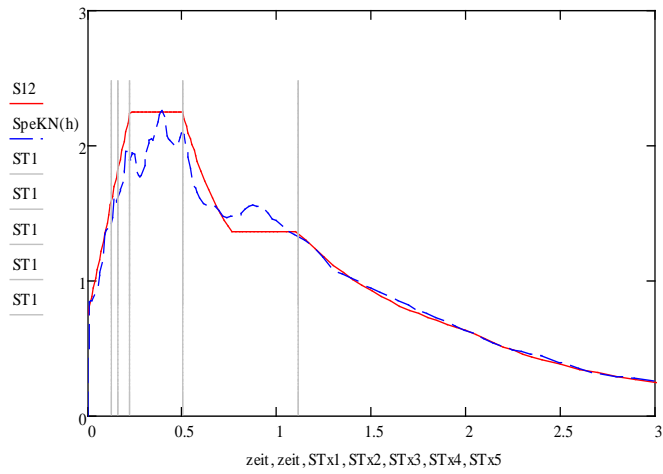
17.5m ($\xi_s = 5\%$)



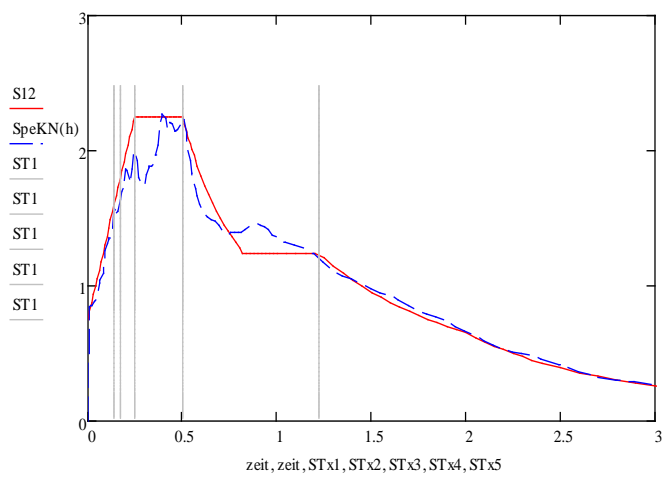
20m ($\xi_s = 5\%$)



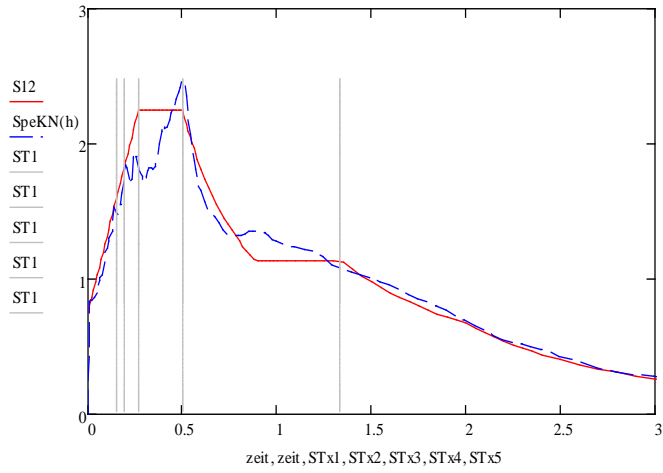
22.5m ($\xi_s = 5\%$)



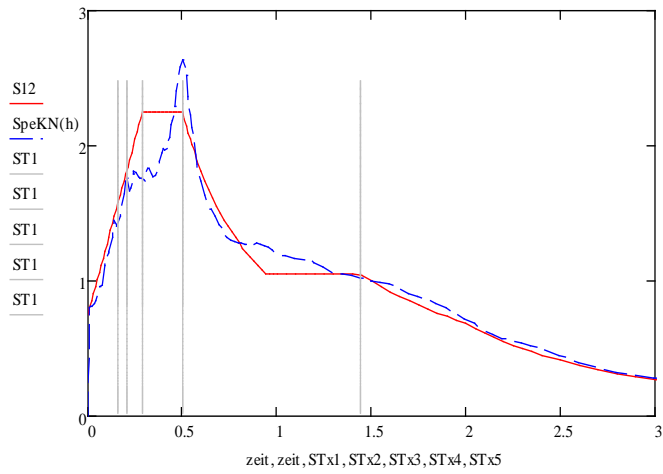
25m ($\xi_s = 5\%$)



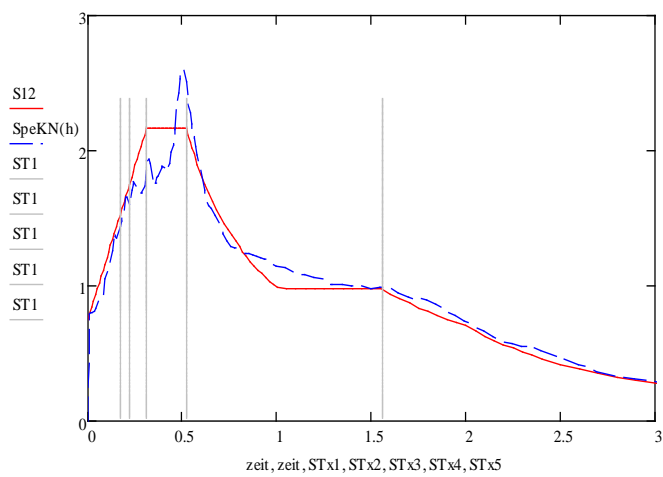
27.5m ($\xi_s = 5\%$)



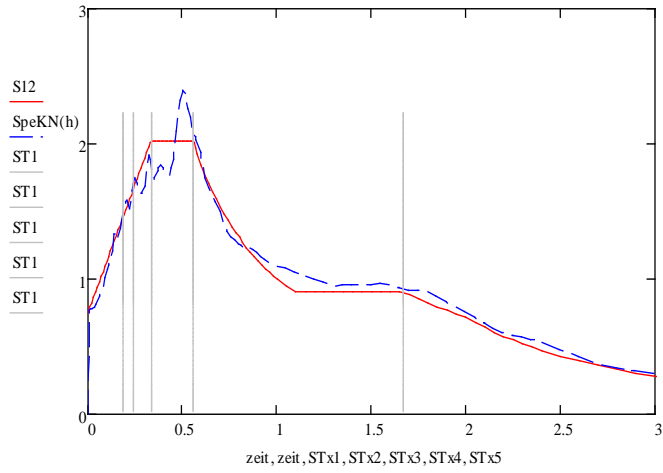
30m ($\xi_s = 5\%$)



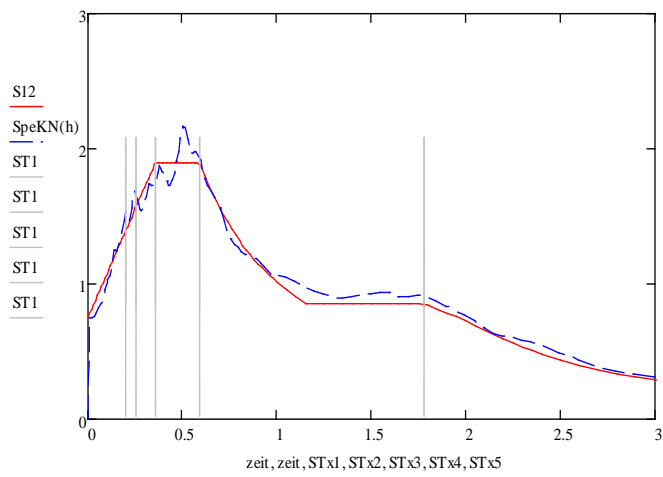
32.5m ($\xi_s = 5\%$)



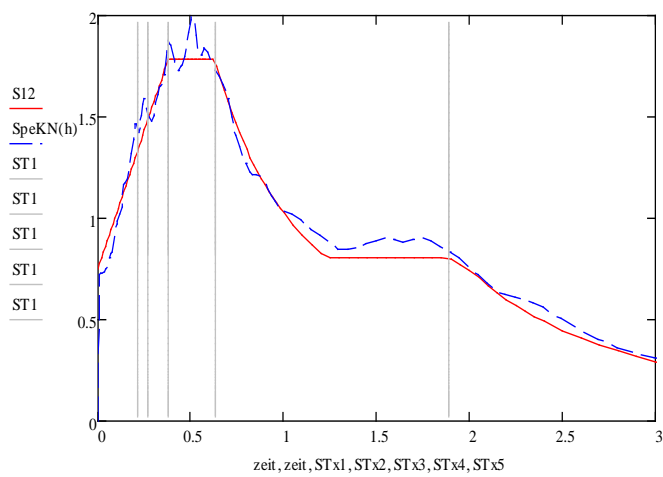
35m ($\xi_s = 5\%$)



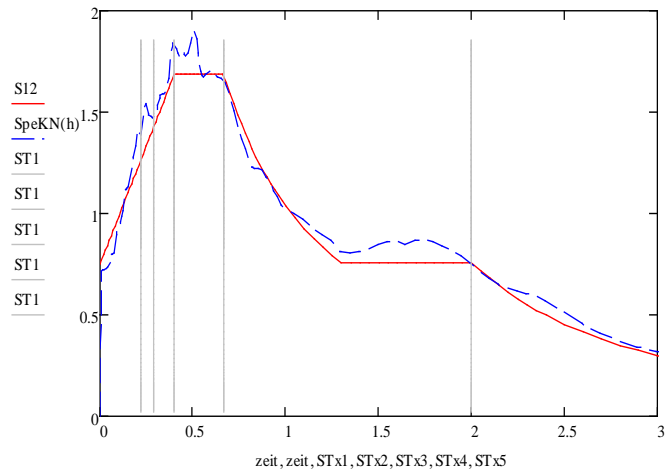
37.5m ($\xi_s = 5\%$)



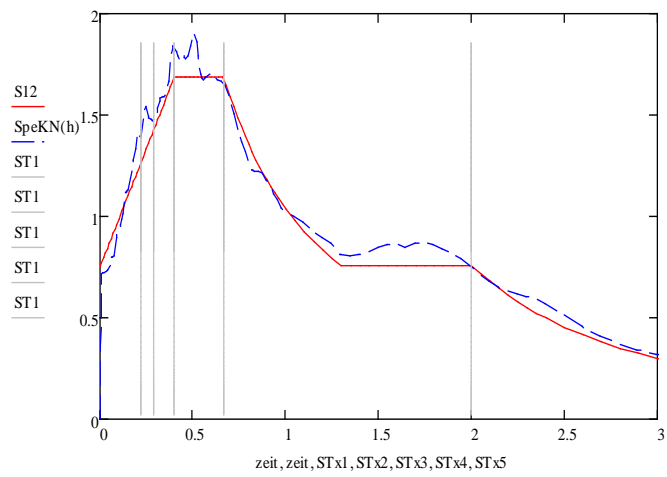
40m ($\xi_s = 5\%$)



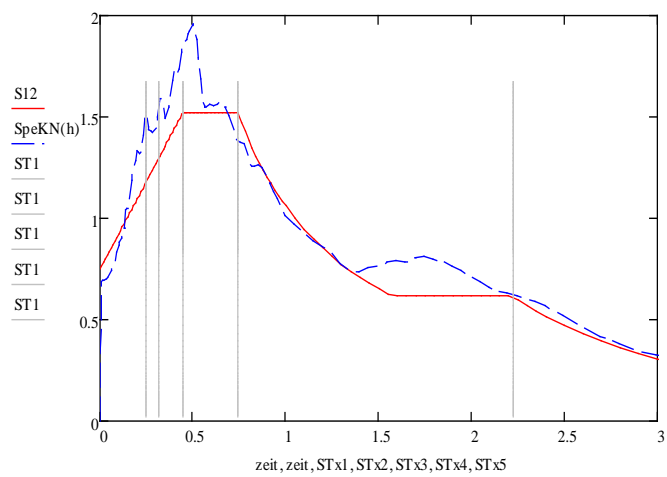
42.5m ($\xi_s = 5\%$)



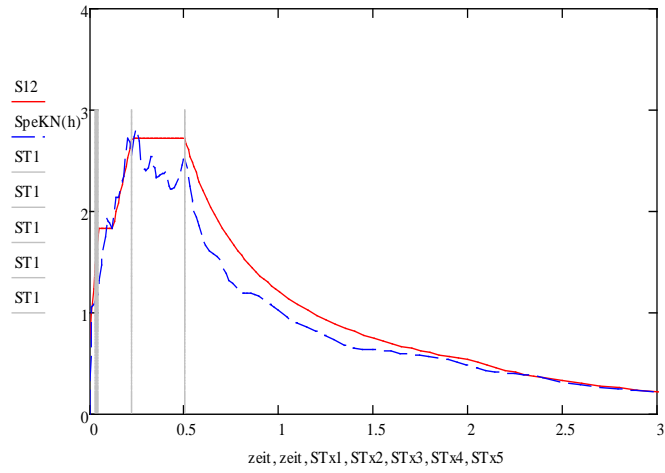
45m ($\xi_s = 5\%$)



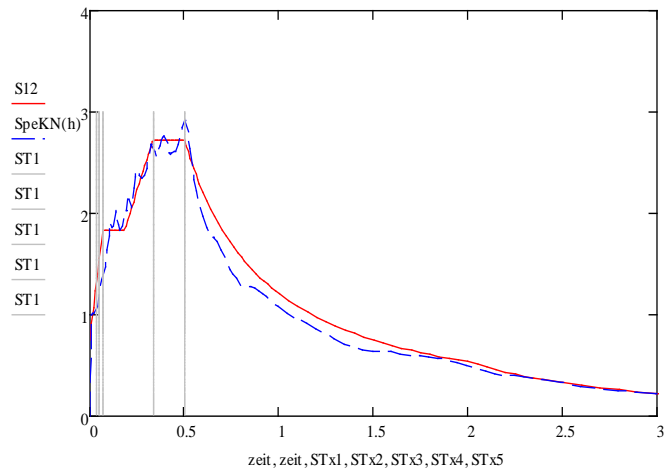
47.5m ($\xi_s = 5\%$)



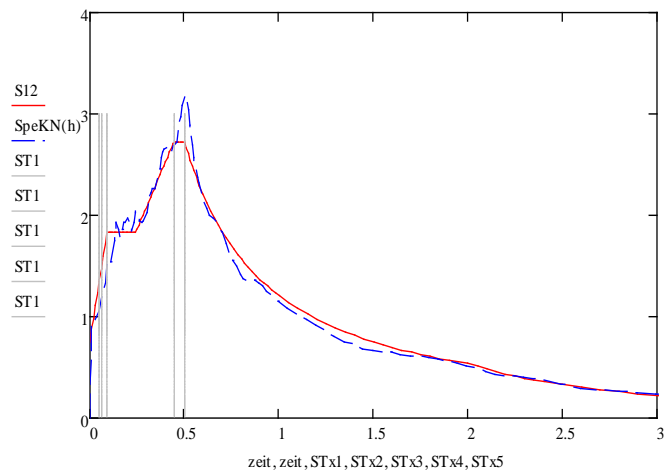
50m ($\xi_s = 5\%$)



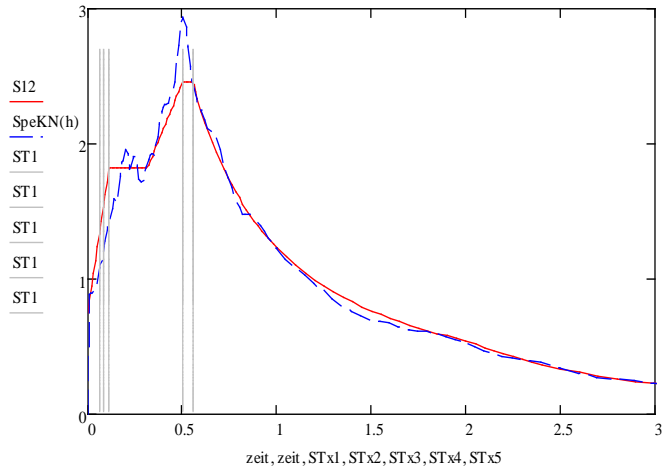
5m ($\xi_s = 10\%$)



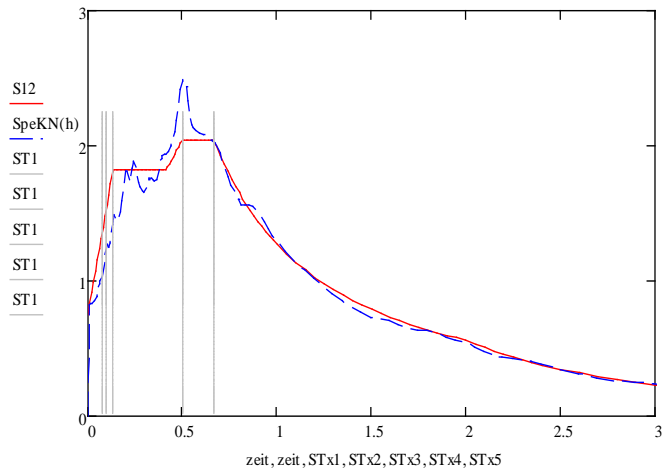
7.5m ($\xi_s = 10\%$)



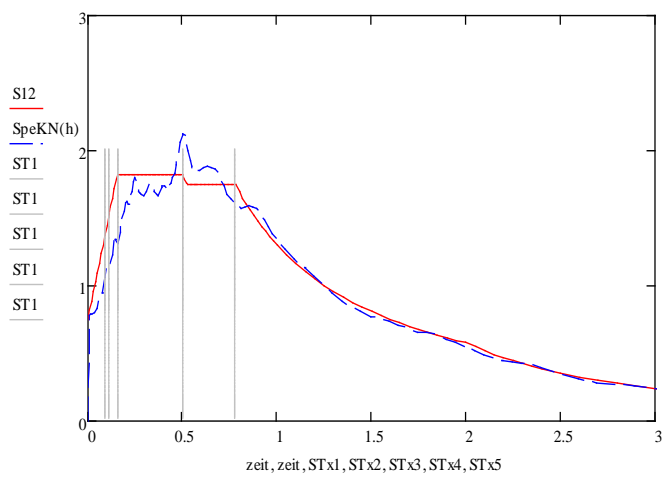
10m ($\xi_s = 10\%$)



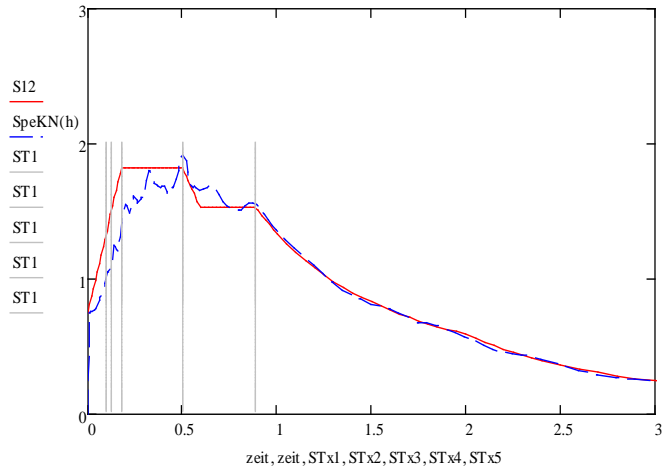
12.5m ($\xi_S= 10\%$)



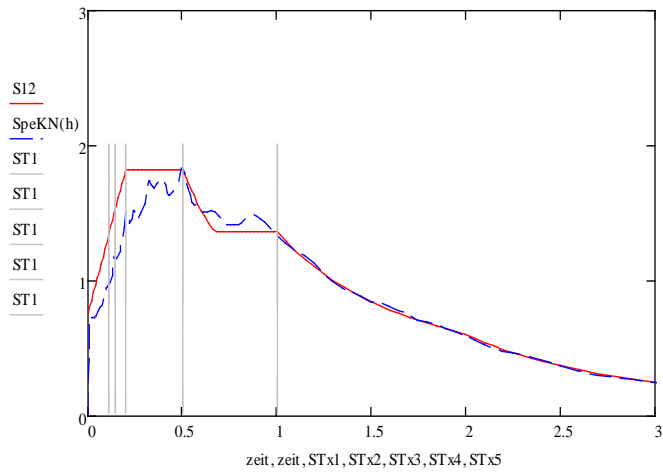
15m ($\xi_S= 10\%$)



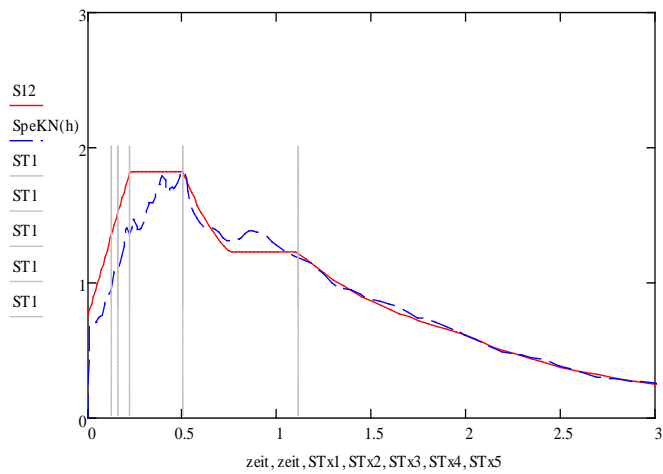
17.5m ($\xi_S= 10\%$)



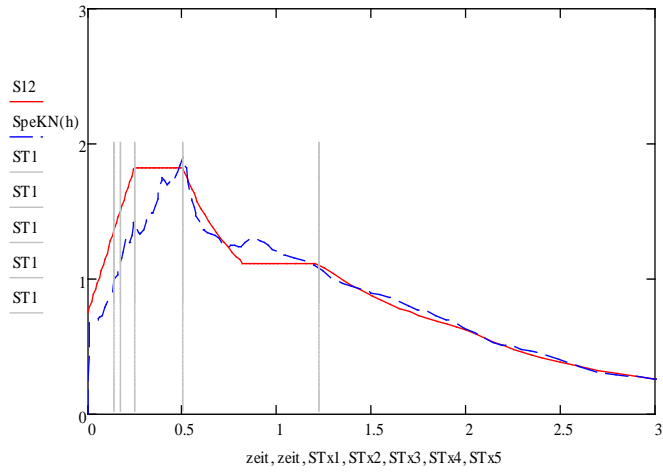
20m ($\xi_S = 10\%$)



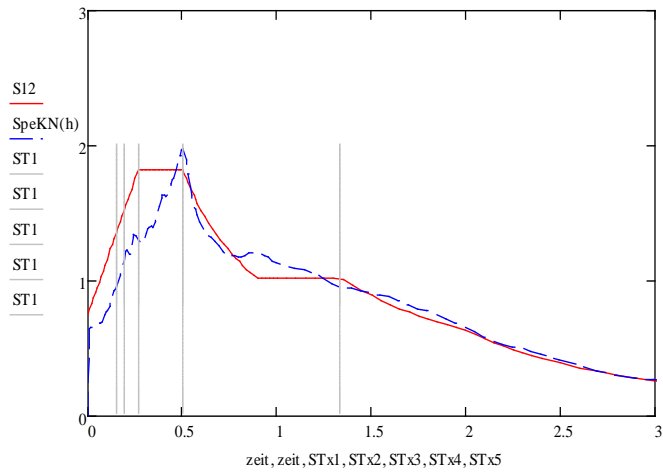
22.5m ($\xi_S = 10\%$)



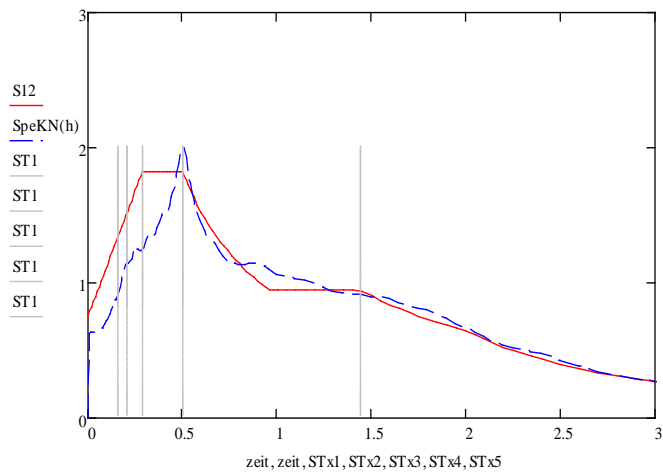
25m ($\xi_S = 10\%$)



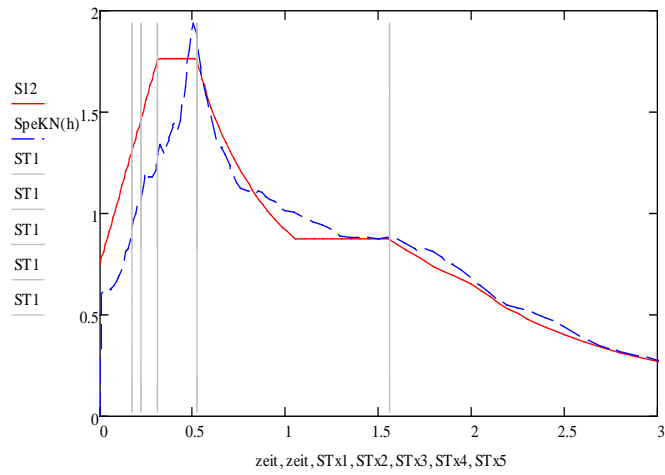
27.5m ($\xi_s = 10\%$)



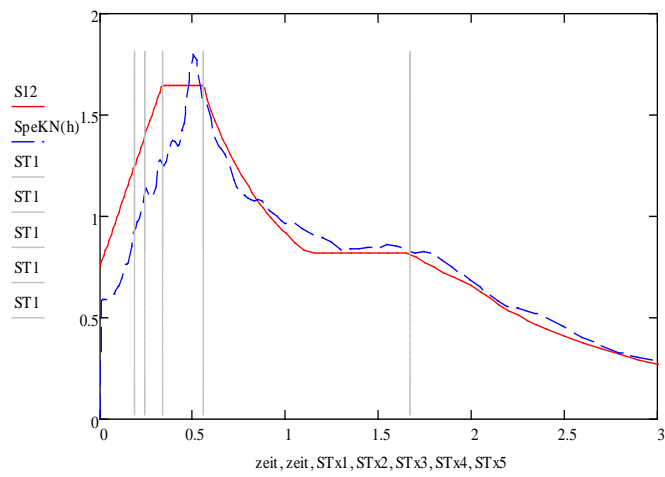
30m ($\xi_s = 10\%$)



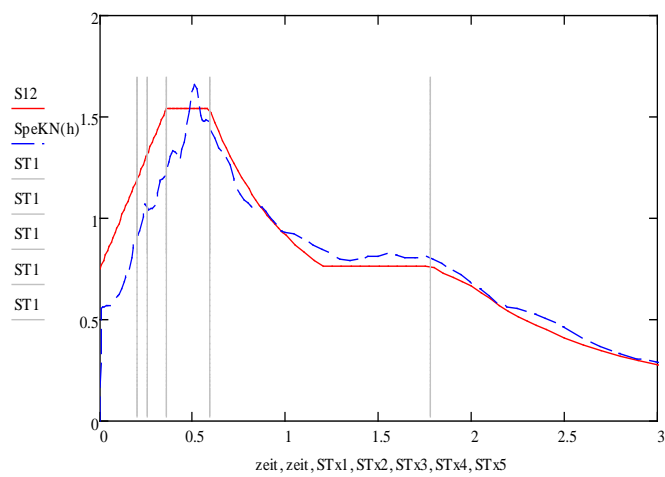
32.5m ($\xi_s = 10\%$)



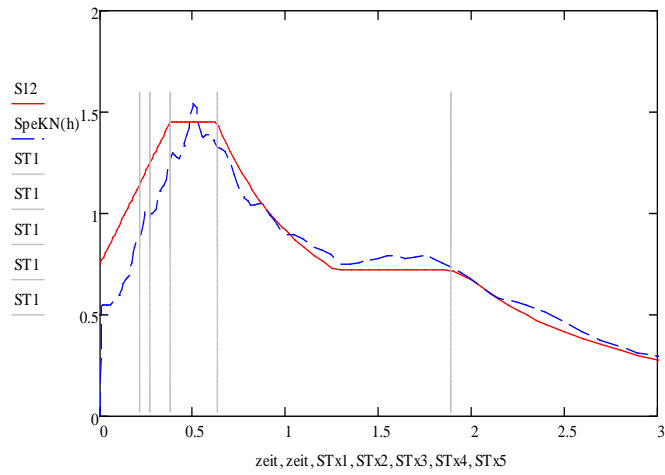
35m ($\xi_s = 10\%$)



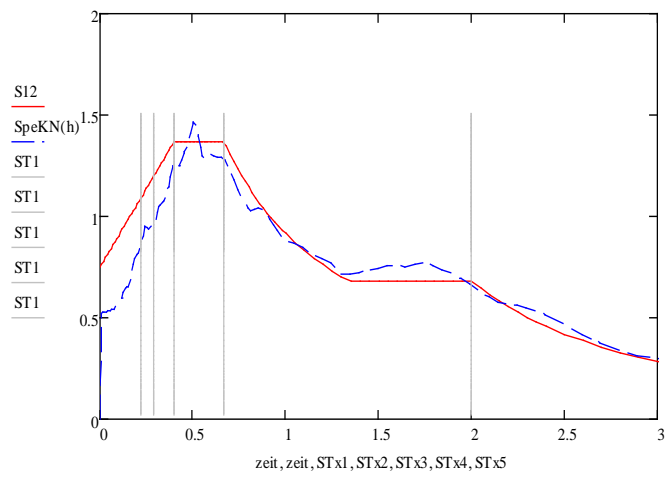
37.5m ($\xi_s = 10\%$)



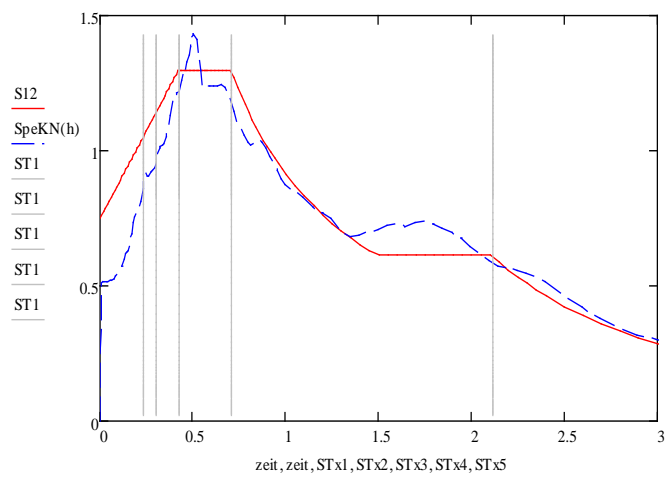
40m ($\xi_s = 10\%$)



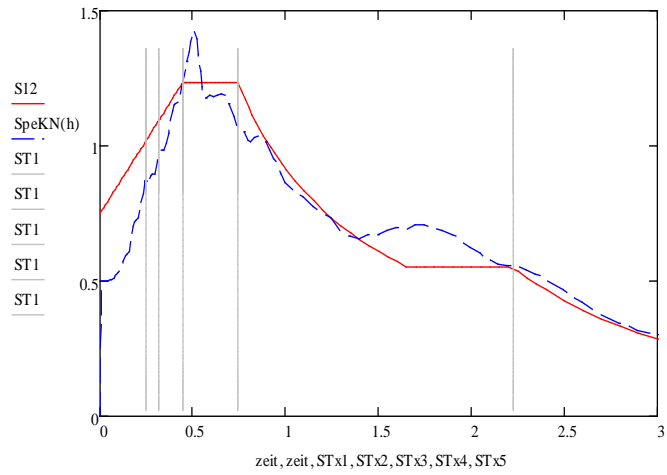
42.5m ($\xi_s = 10\%$)



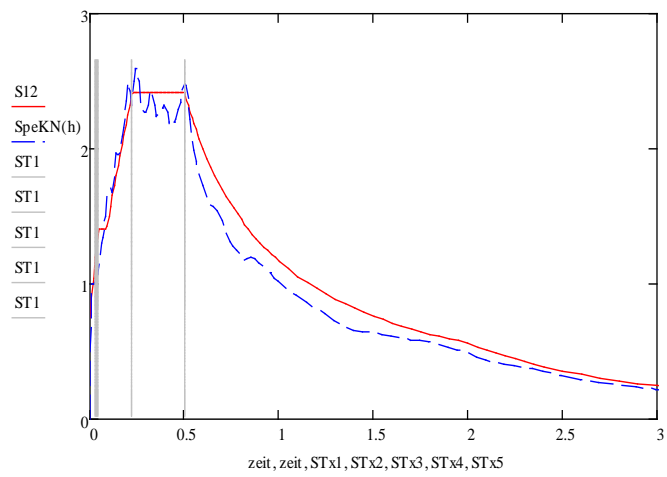
45m ($\xi_s = 10\%$)



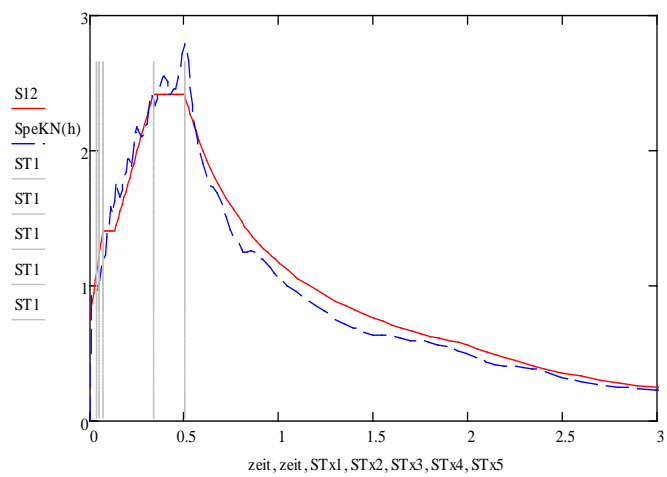
47.5m ($\xi_s = 10\%$)



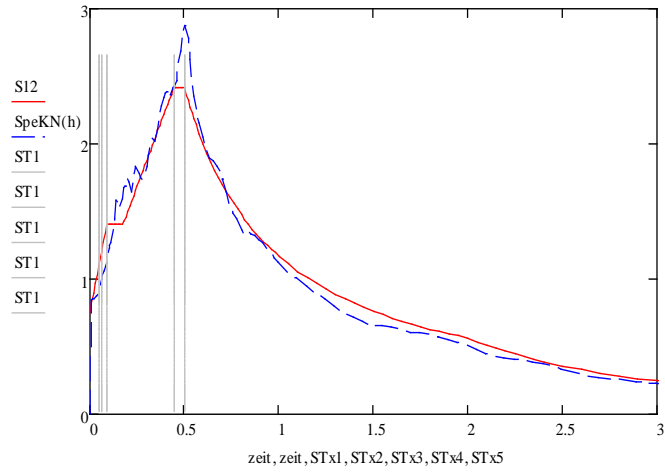
50m ($\xi_s = 10\%$)



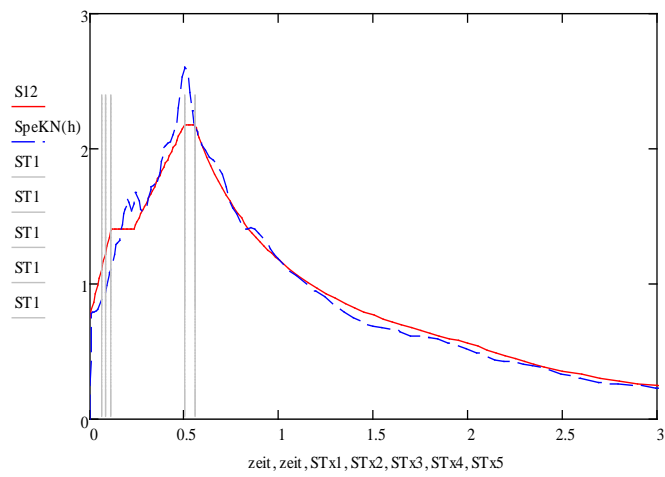
5m ($\xi_s = 15\%$)



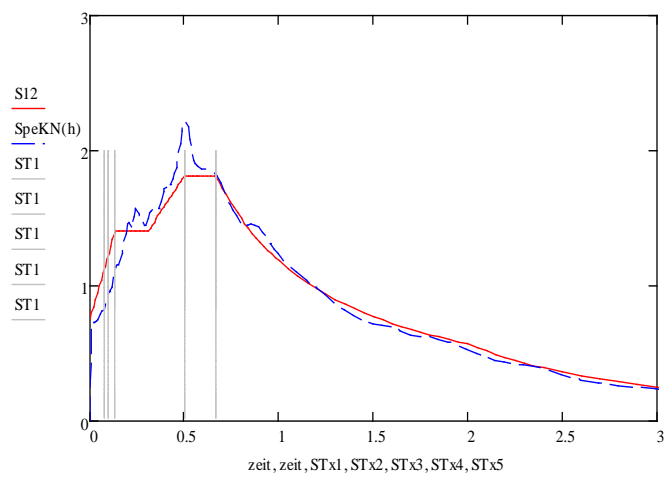
7.5m ($\xi_s = 15\%$)



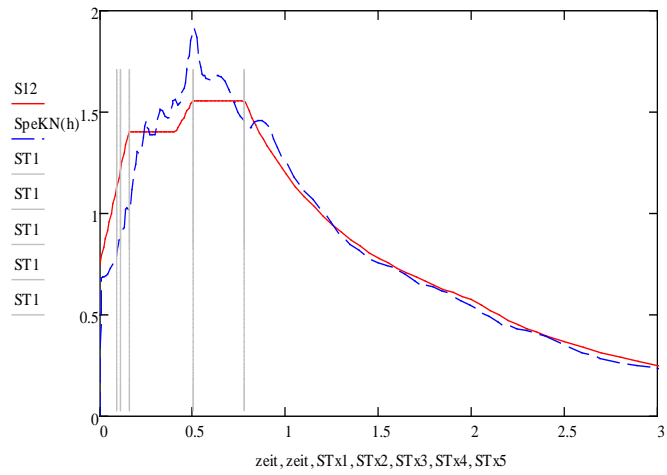
10m ($\xi_S=15\%$)



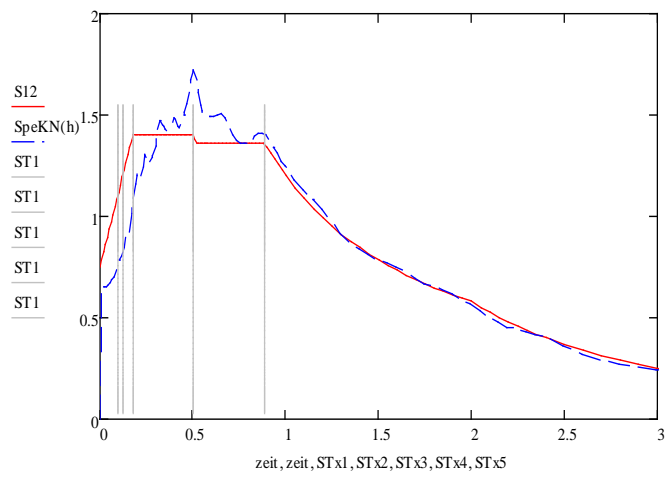
12.5m ($\xi_S=15\%$)



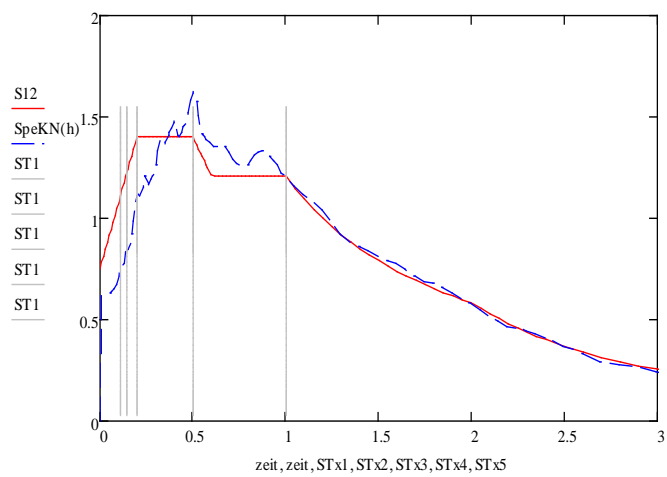
15m ($\xi_S=15\%$)



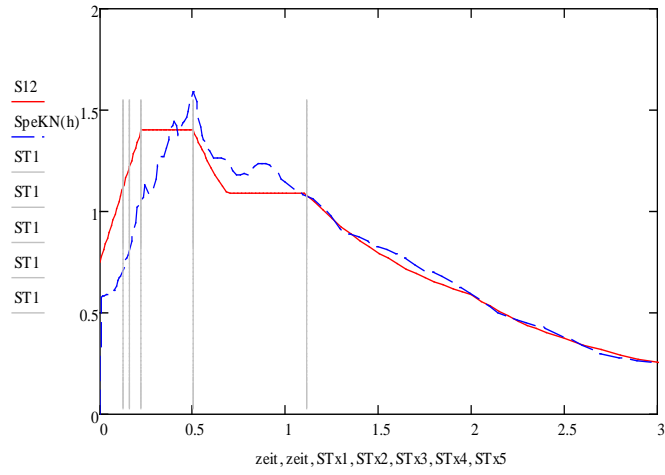
17.5m ($\xi_s = 15\%$)



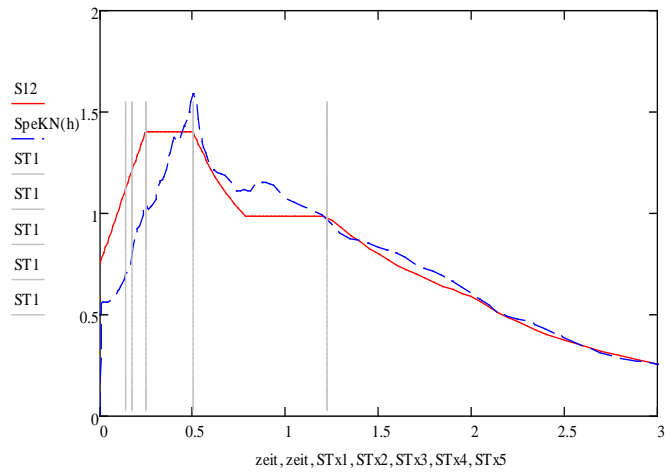
20m ($\xi_s = 15\%$)



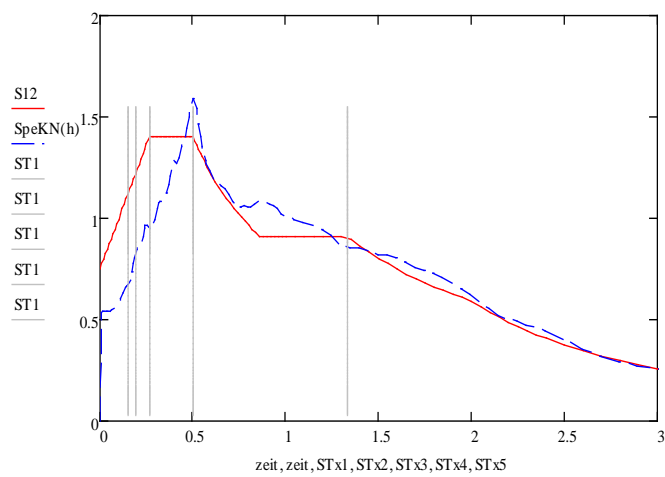
22.5m ($\xi_s = 15\%$)



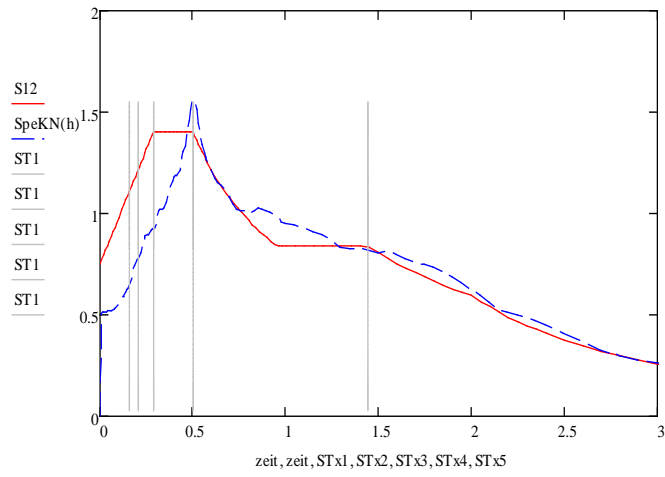
25m ($\xi_S = 15\%$)



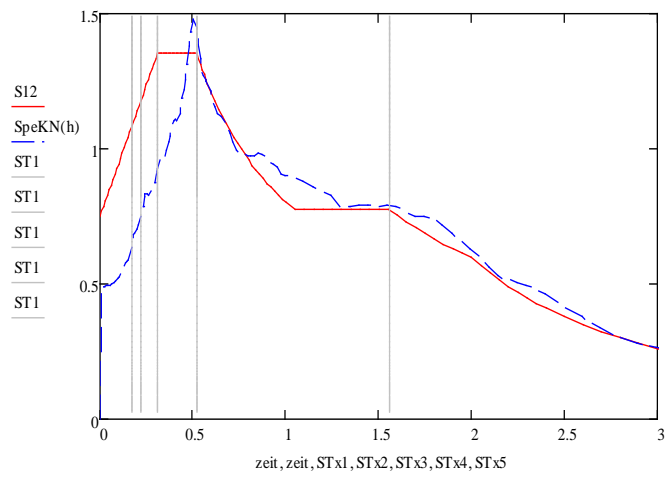
27.5m ($\xi_S = 15\%$)



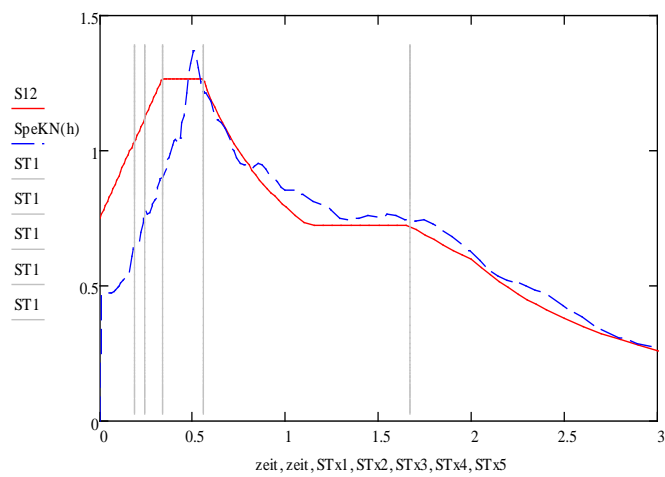
30m ($\xi_S = 15\%$)



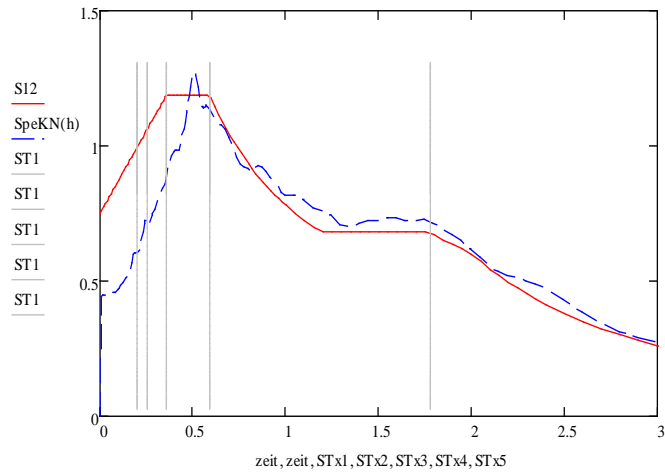
32.5m ($\xi_s = 15\%$)



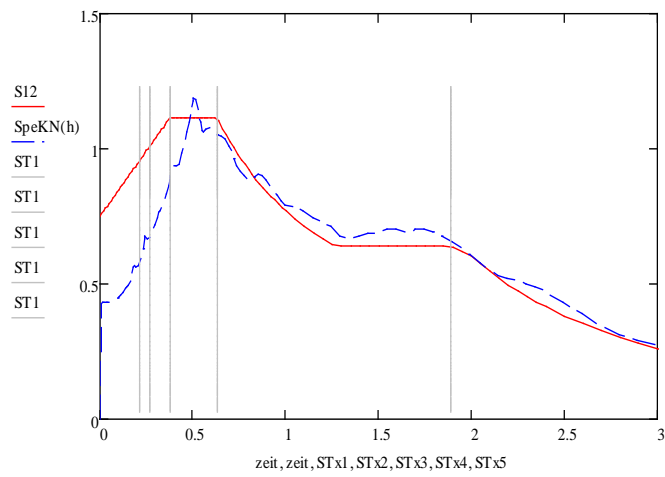
35m ($\xi_s = 15\%$)



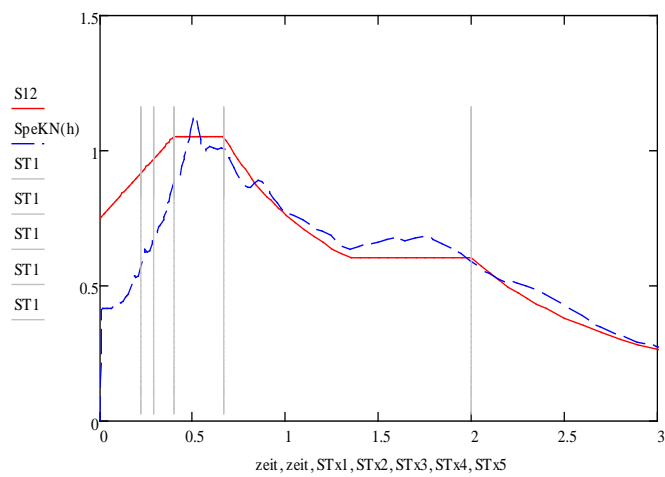
37.5m ($\xi_s = 15\%$)



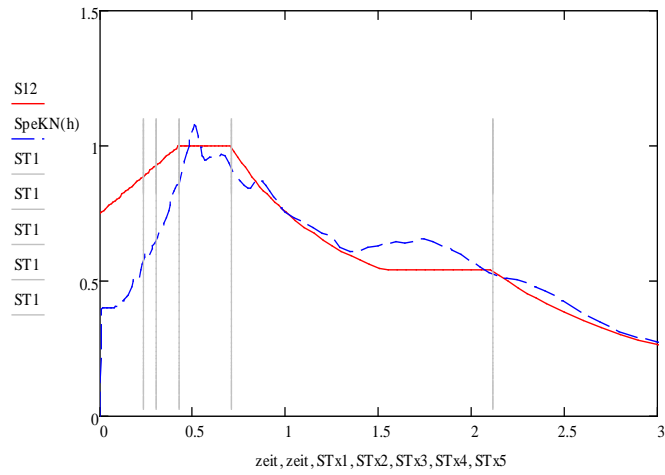
40m ($\xi_s = 15\%$)



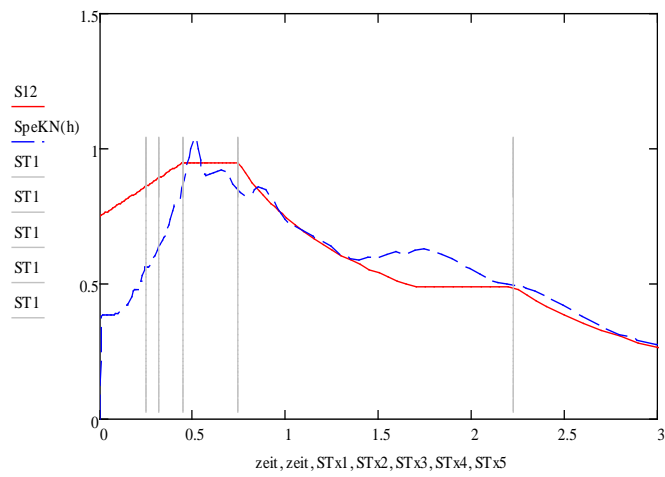
42.5m ($\xi_s = 15\%$)



45m ($\xi_s = 15\%$)

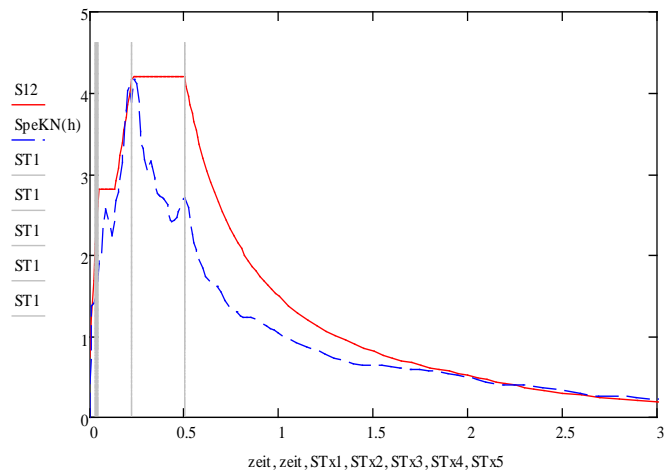


47.5m ($\xi_S=15\%$)

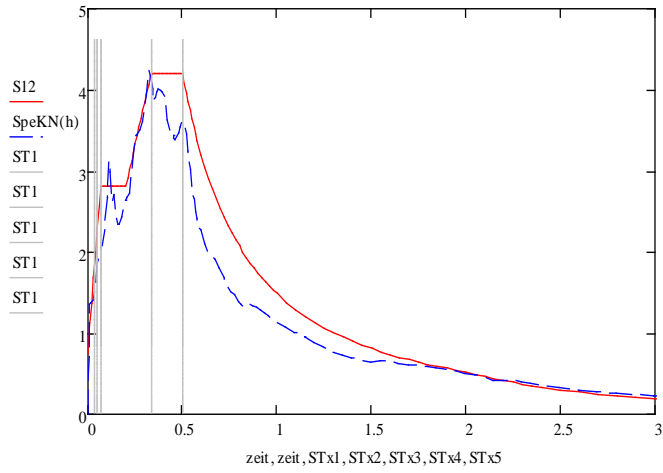


50m ($\xi_S=15\%$)

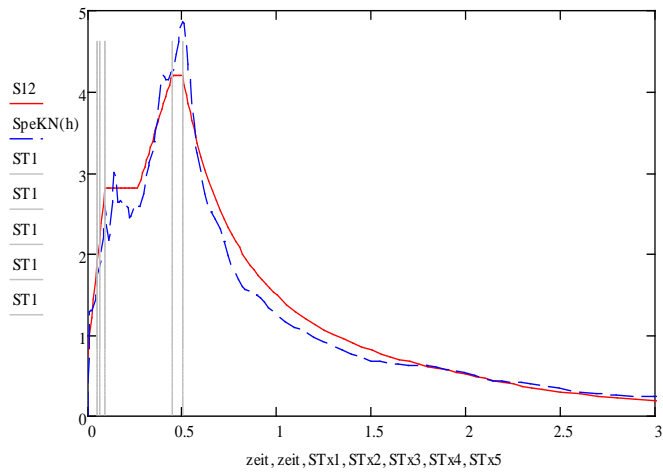
6.5.2 Bedrock shear wave velocity equal with 250 m/s



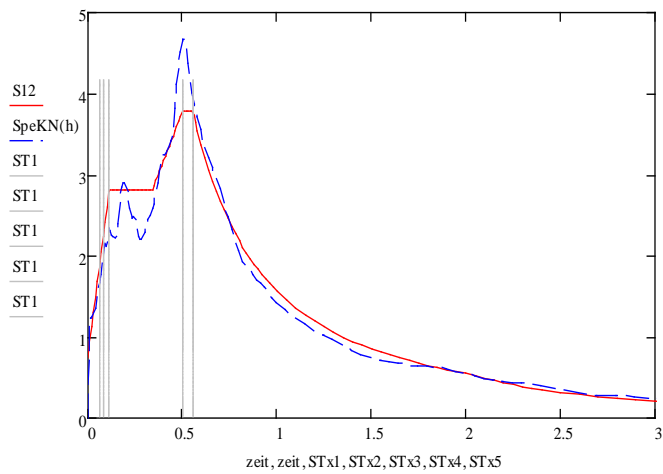
5m ($\xi_S=5\%$)



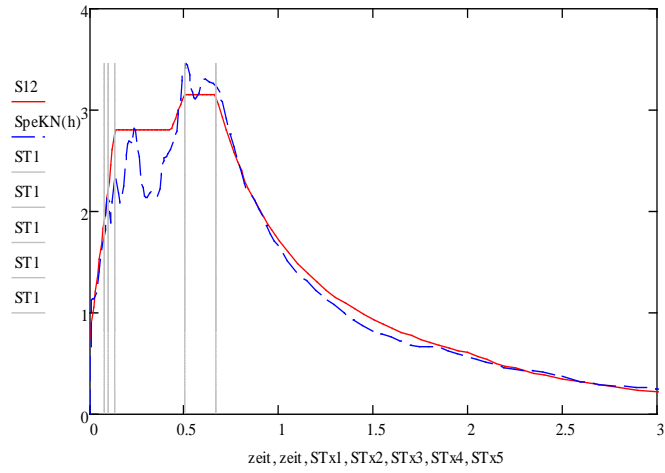
7.5m ($\xi_s= 5\%$)



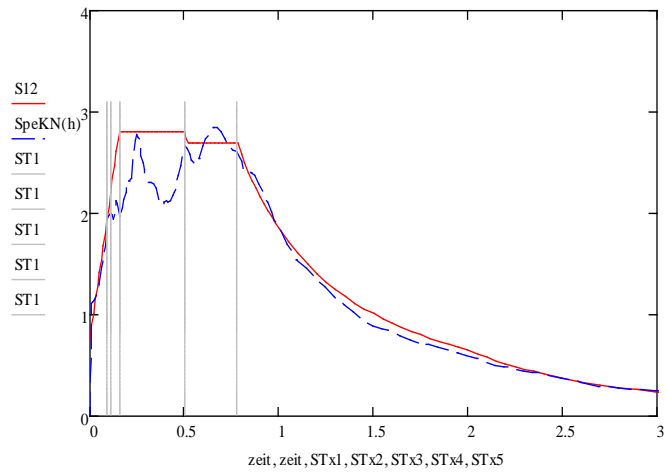
10m ($\xi_s= 5\%$)



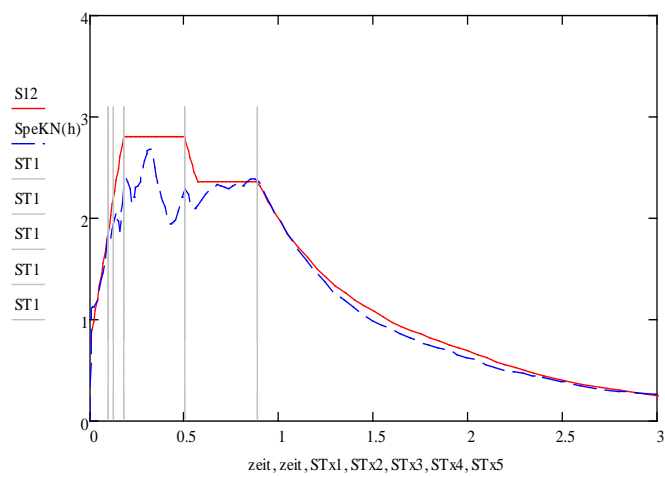
12.5m ($\xi_s= 5\%$)



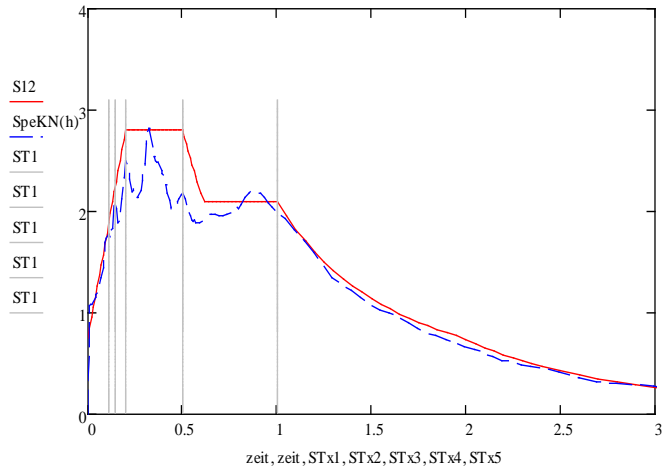
15m ($\xi_s = 5\%$)



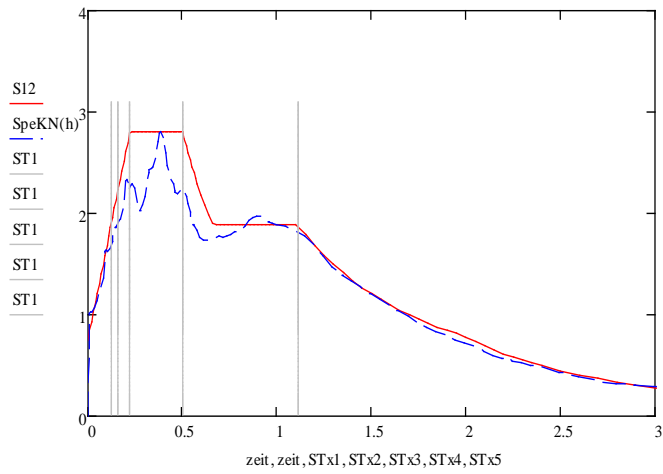
17.5m ($\xi_s = 5\%$)



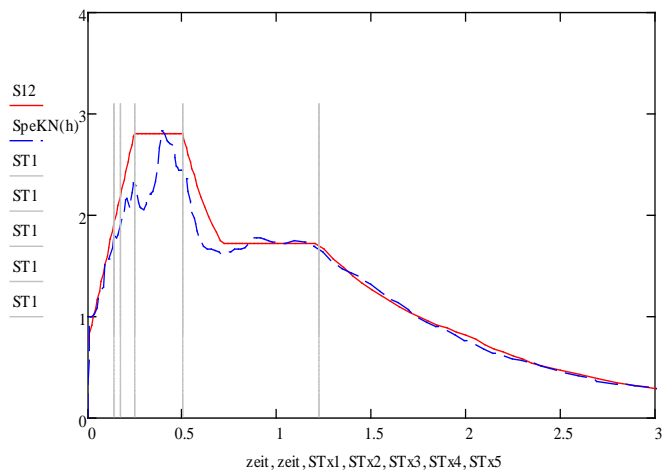
20m ($\xi_s = 5\%$)



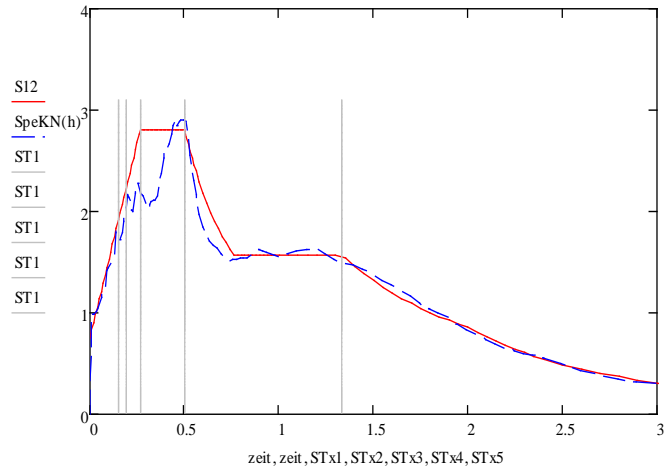
22.5m ($\xi_s = 5\%$)



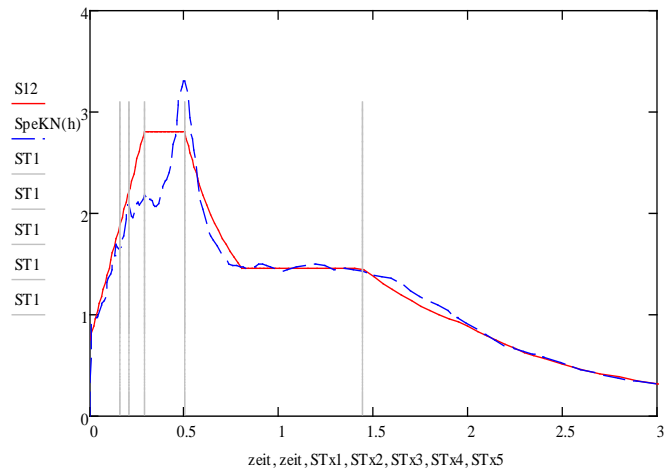
25m ($\xi_s = 5\%$)



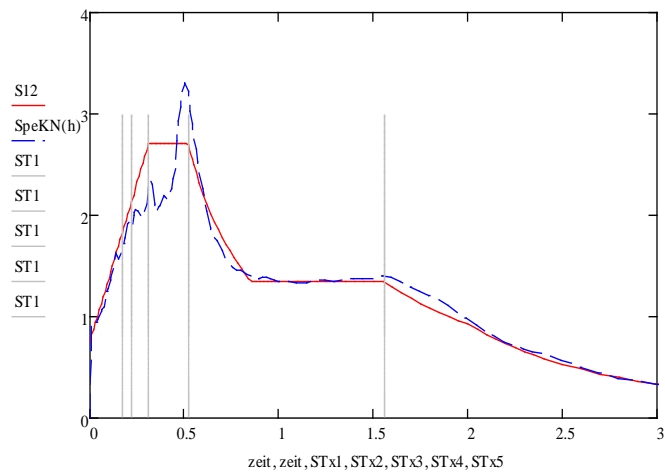
27.5m ($\xi_s = 5\%$)



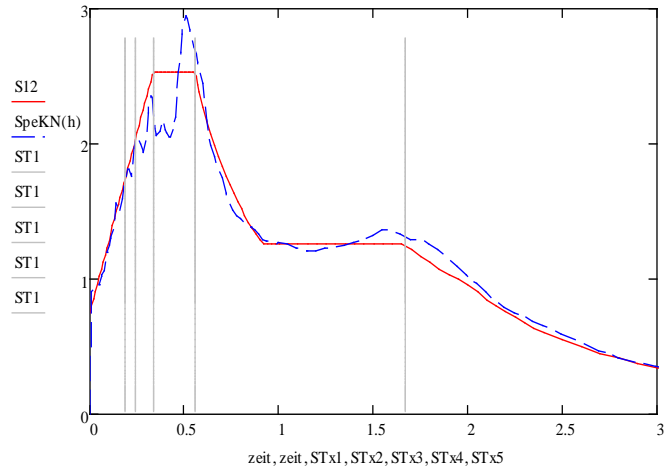
30m ($\xi_s = 5\%$)



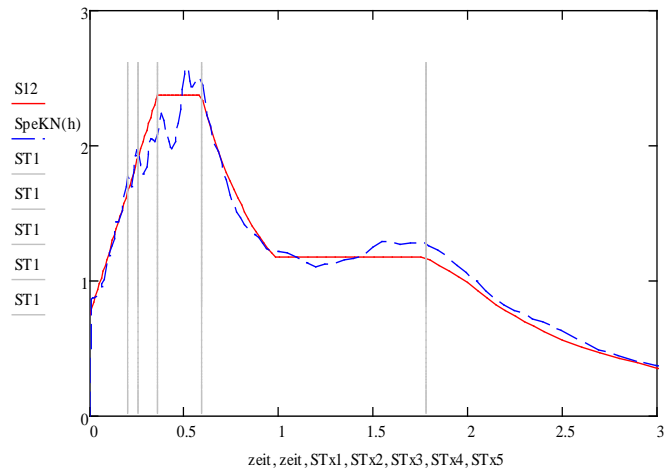
32.5m ($\xi_s = 5\%$)



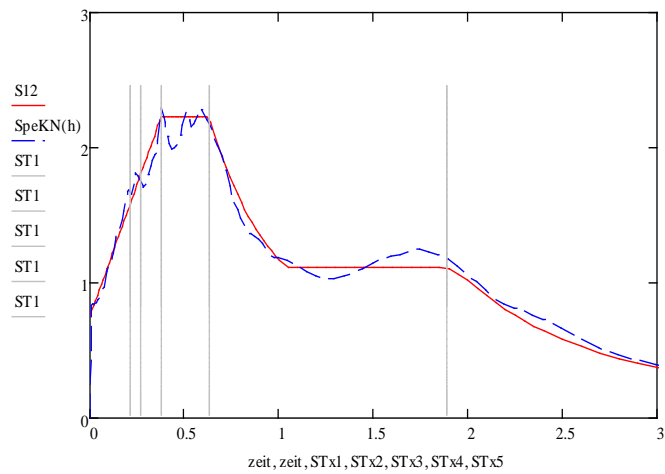
35m ($\xi_s = 5\%$)



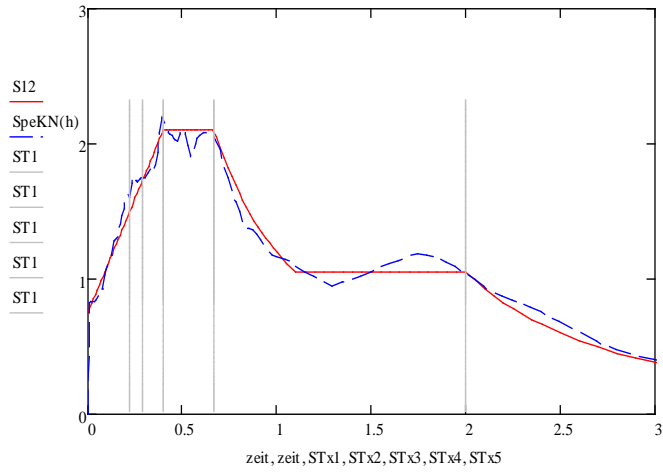
37.5m ($\xi_s = 5\%$)



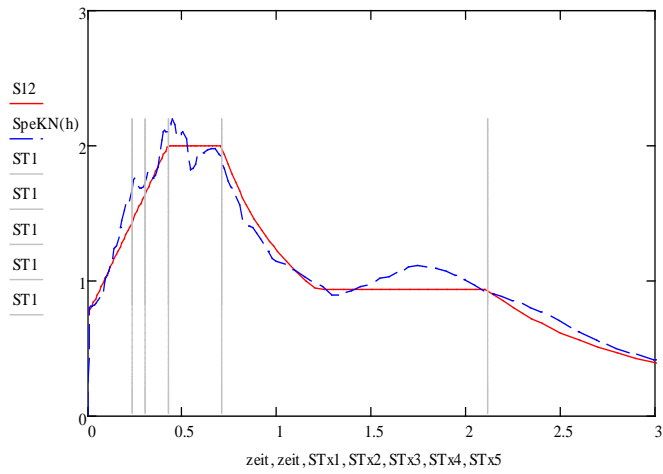
40m ($\xi_s = 5\%$)



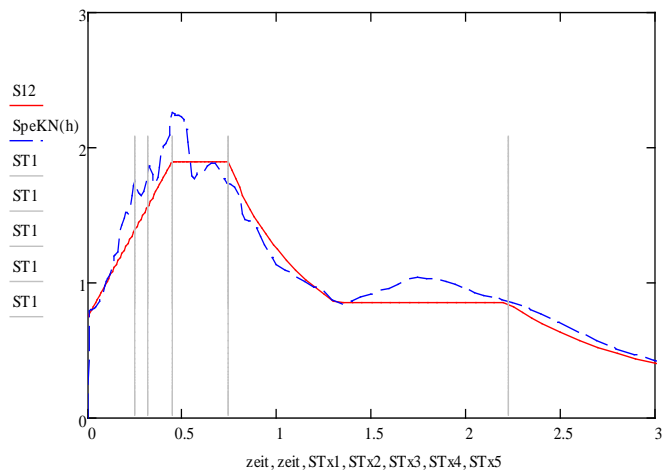
42.5m ($\xi_s = 5\%$)



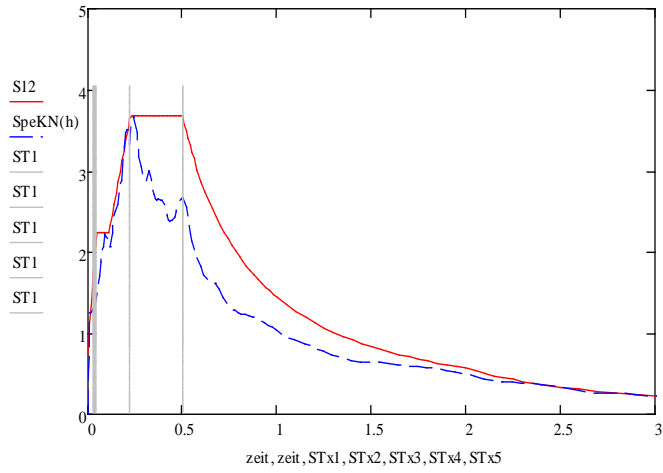
45m ($\xi_s = 5\%$)



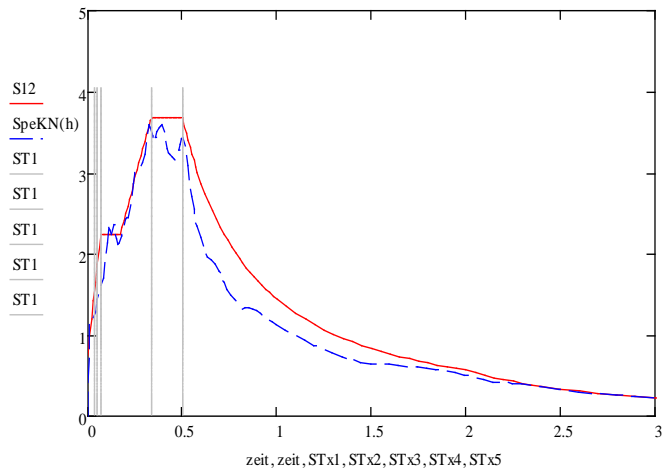
47.5m ($\xi_s = 5\%$)



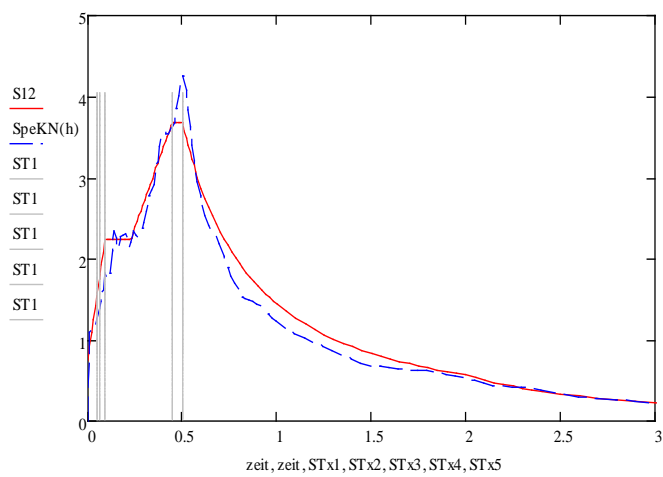
50m ($\xi_s = 5\%$)



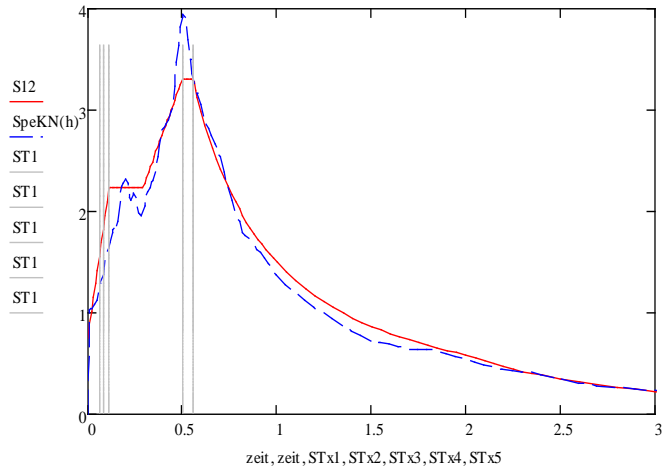
5m ($\xi_s = 10\%$)



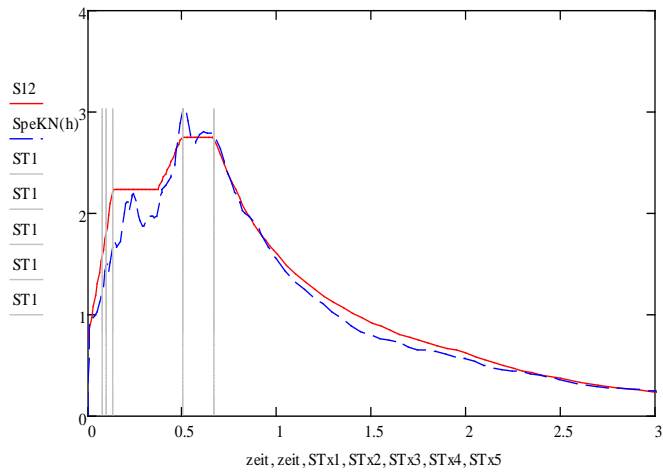
7.5m ($\xi_s = 10\%$)



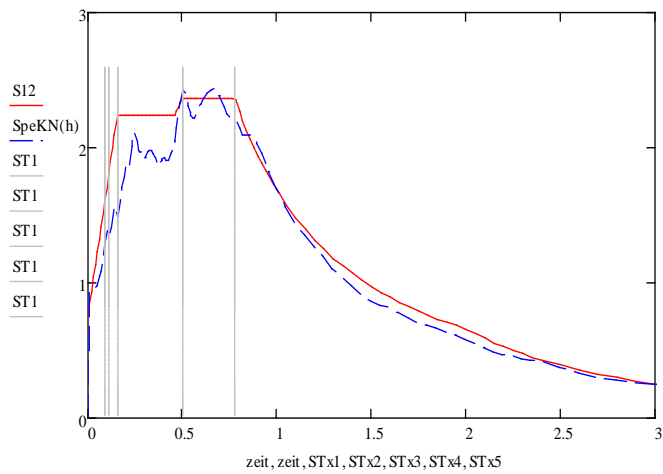
10m ($\xi_s = 10\%$)



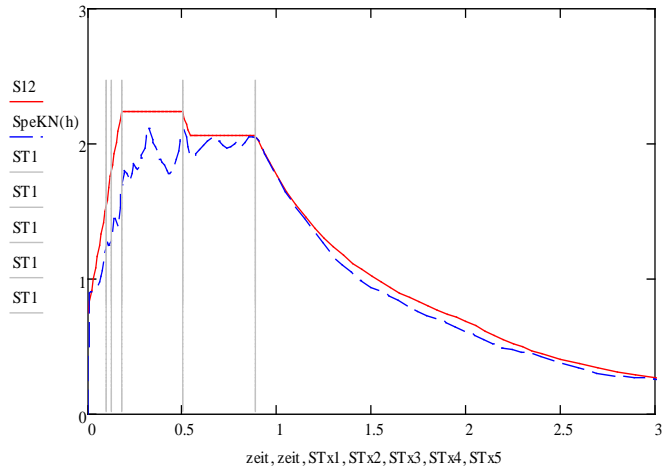
12.5m ($\xi_S= 10\%$)



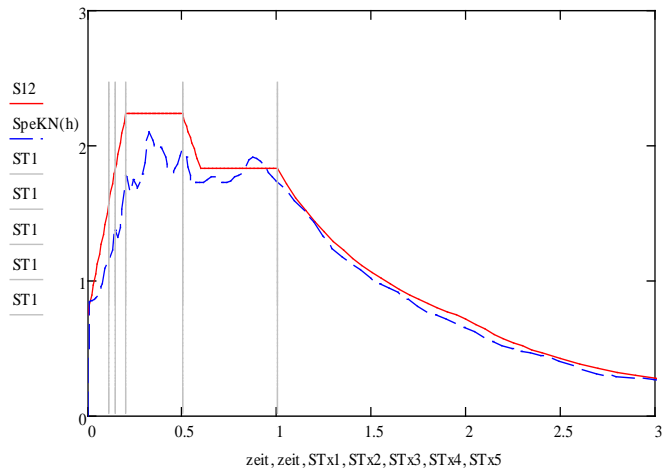
15m ($\xi_S= 10\%$)



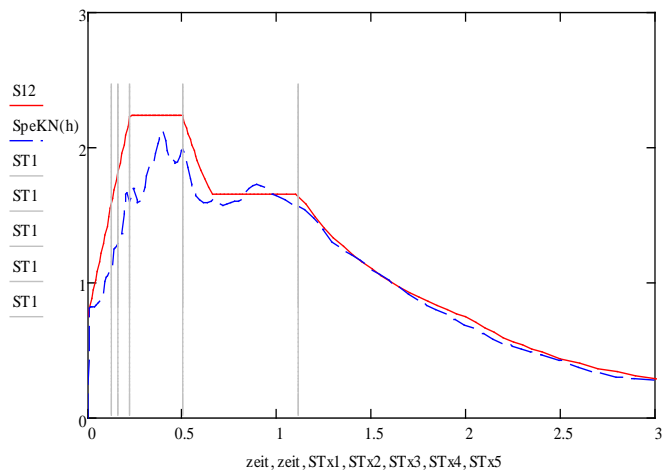
17.5m ($\xi_S= 10\%$)



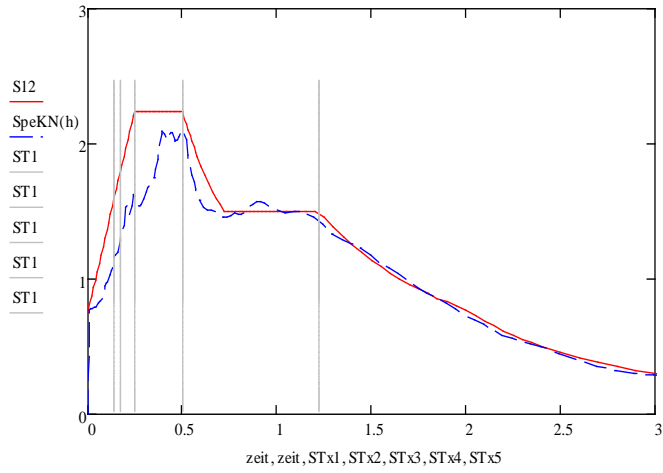
20m ($\xi_S = 10\%$)



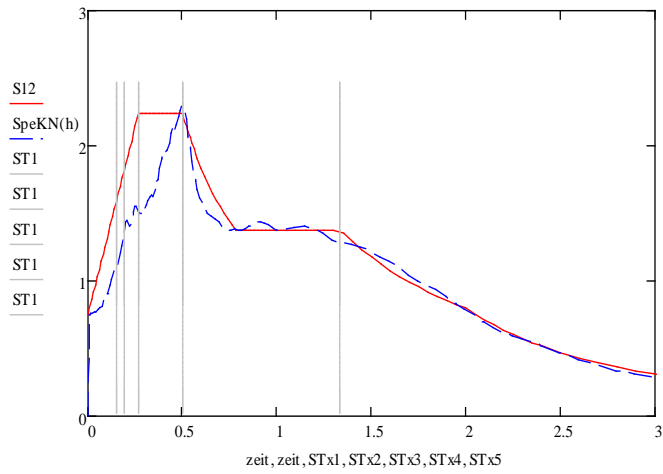
22.5m ($\xi_S = 10\%$)



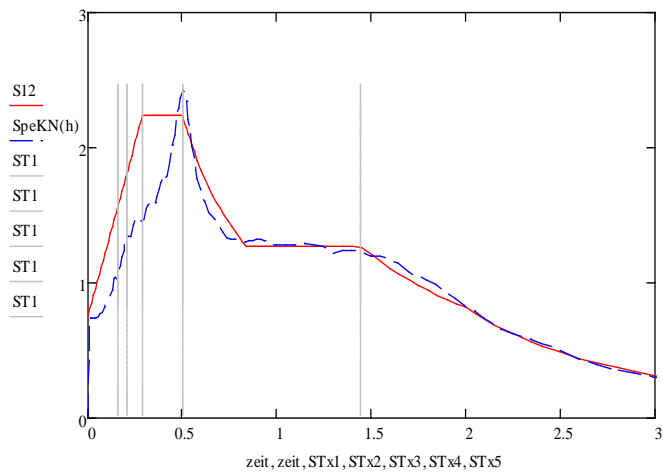
25m ($\xi_S = 10\%$)



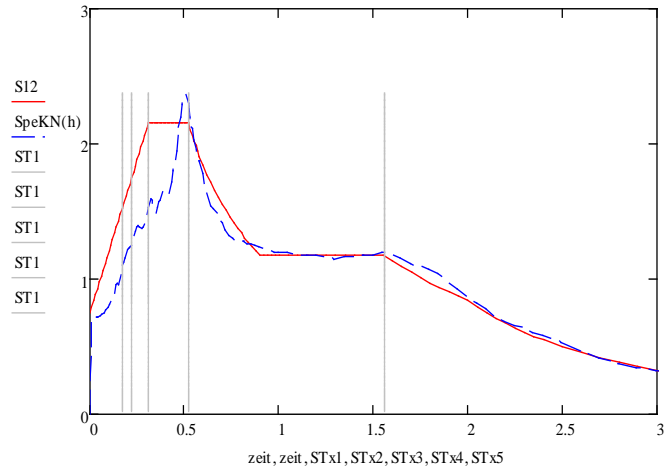
27.5m ($\xi_S=10\%$)



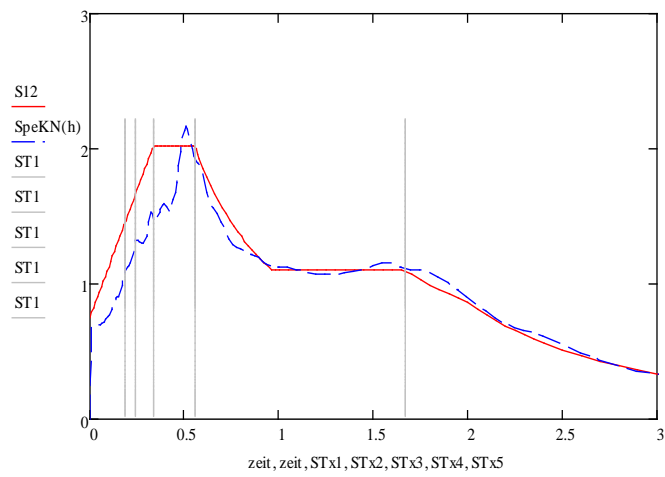
30m ($\xi_S=10\%$)



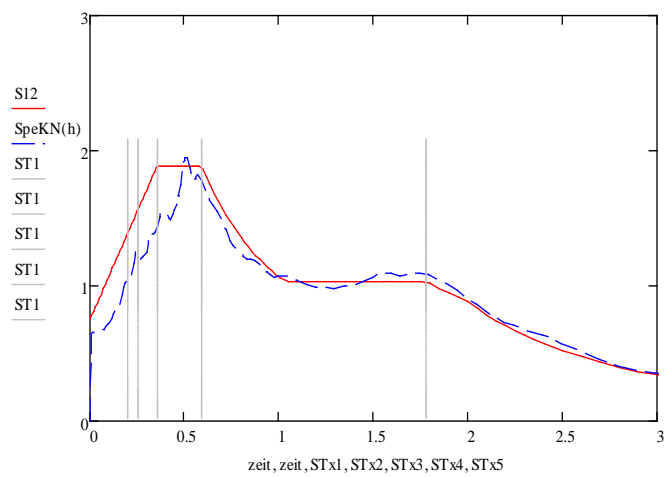
32.5m ($\xi_S=10\%$)



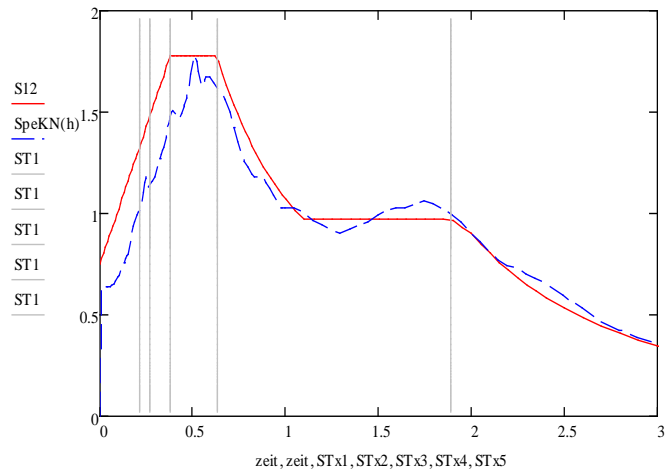
35m ($\xi_S = 10\%$)



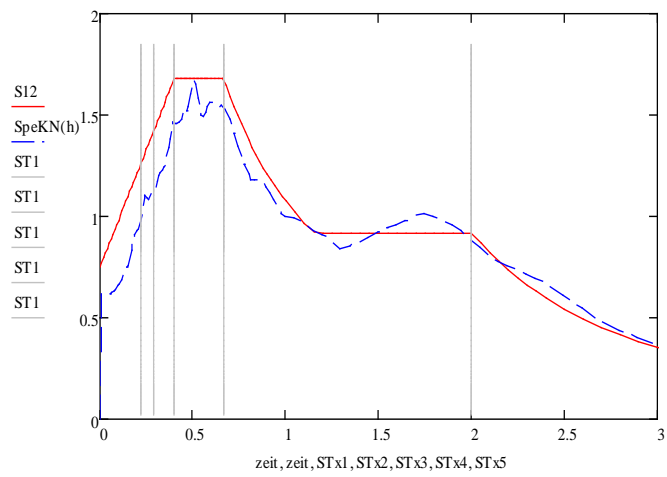
37.5m ($\xi_S = 10\%$)



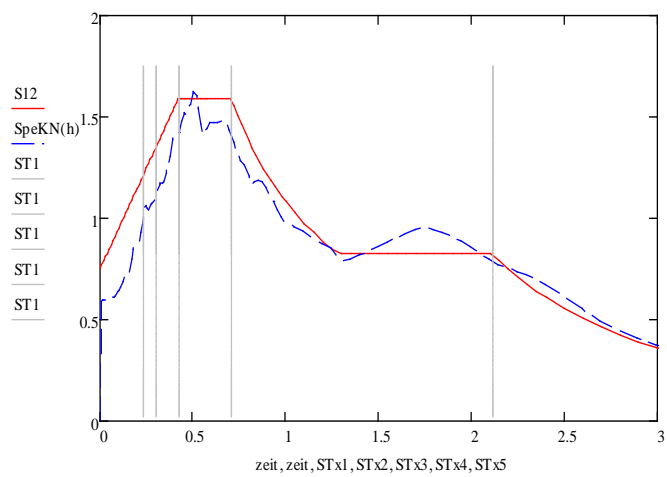
40m ($\xi_S = 10\%$)



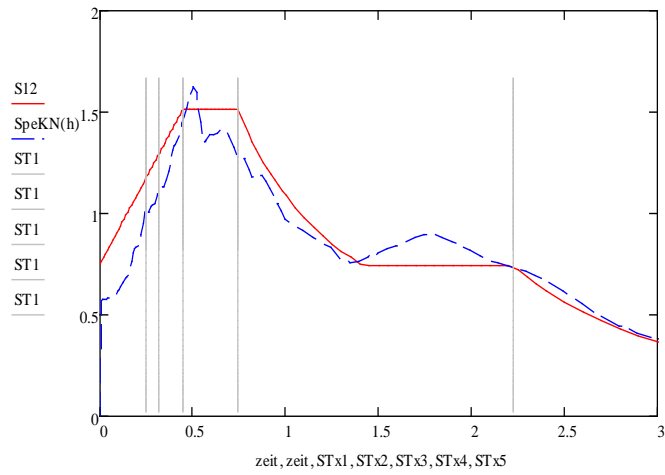
42.5m ($\xi_s = 10\%$)



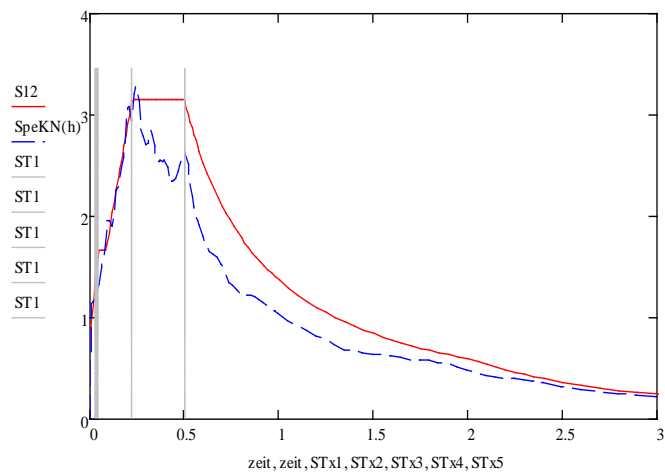
45m ($\xi_s = 10\%$)



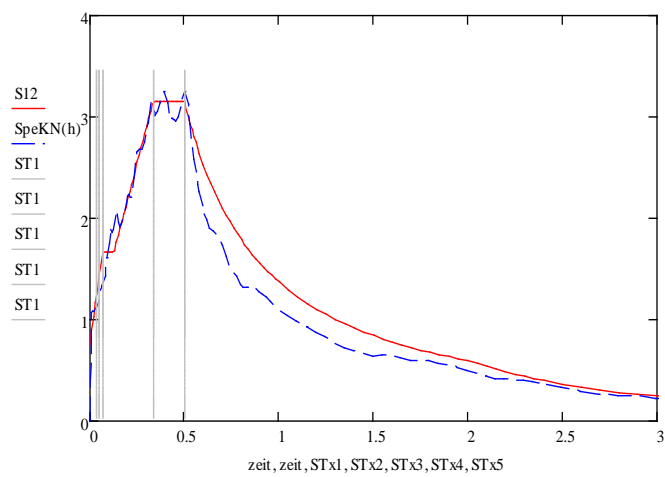
47.5m ($\xi_s = 10\%$)



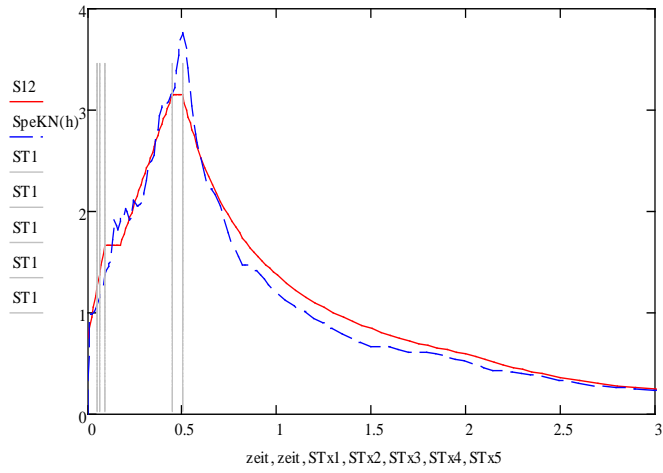
50m ($\xi_s = 10\%$)



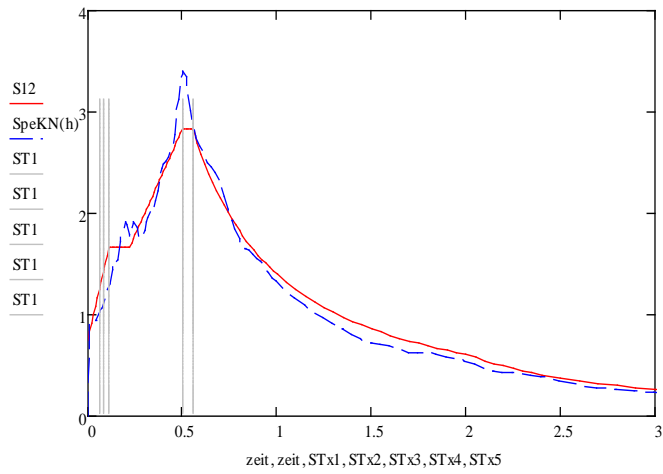
5m ($\xi_s = 15\%$)



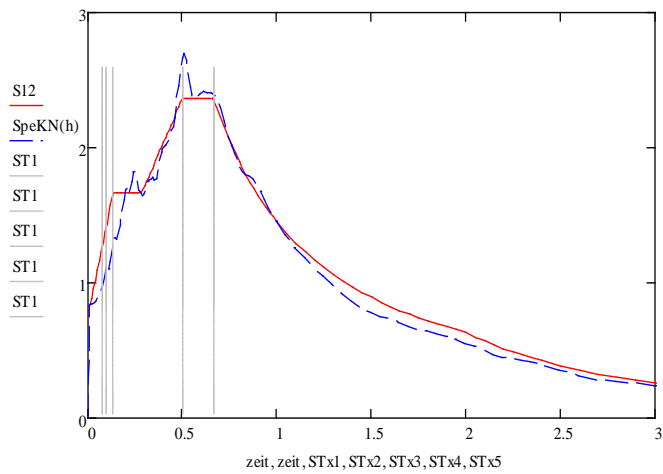
7.5m ($\xi_s = 15\%$)



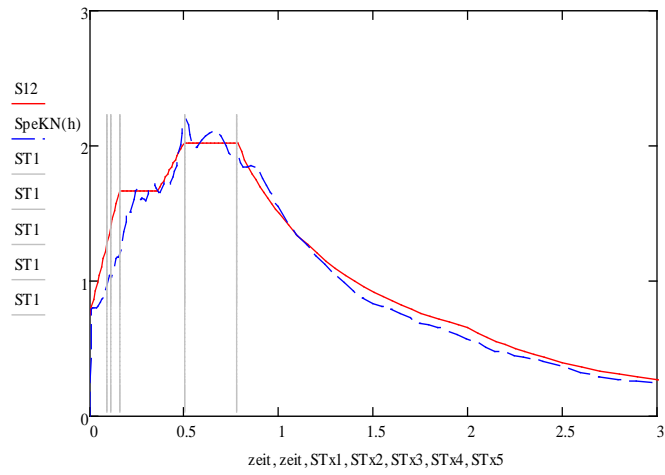
10m ($\xi_S=15\%$)



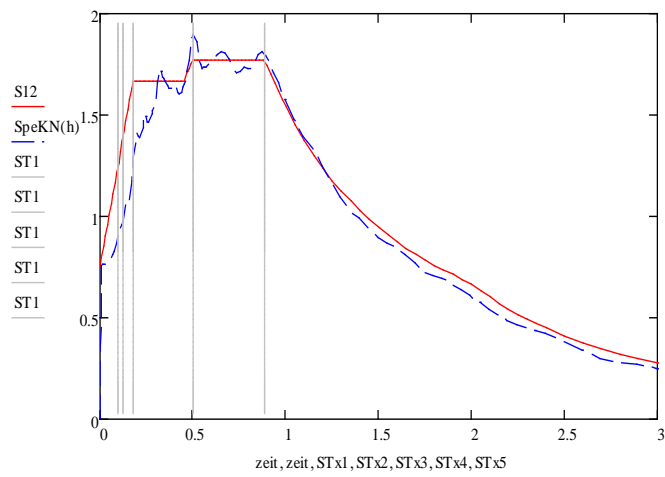
12.5m ($\xi_S=15\%$)



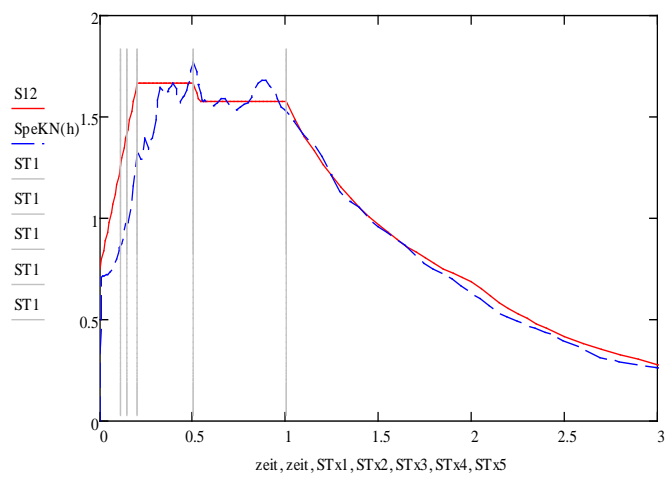
15m ($\xi_S=15\%$)



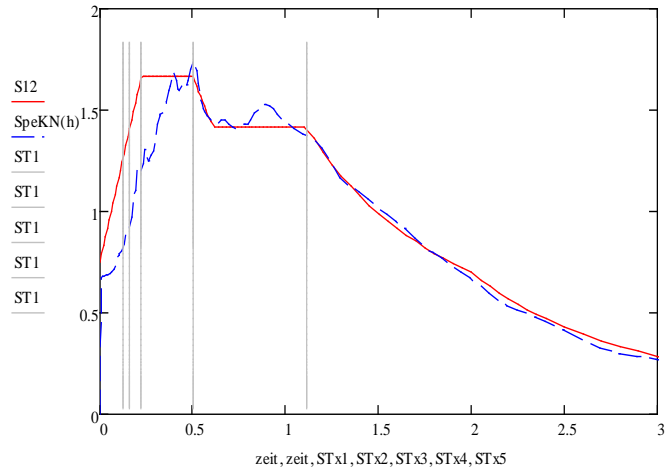
17.5m ($\xi_s = 15\%$)



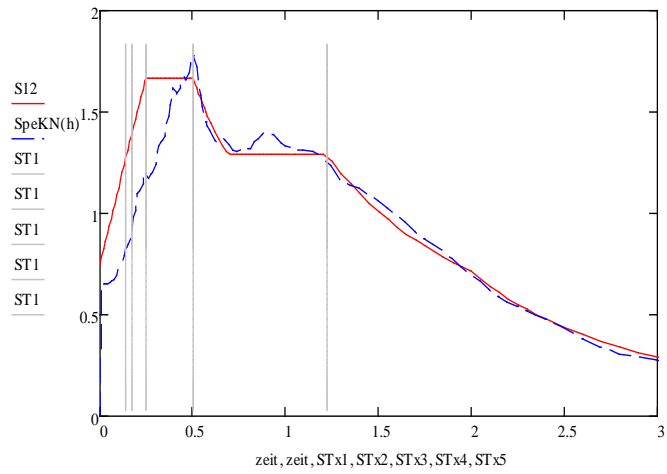
20m ($\xi_s = 15\%$)



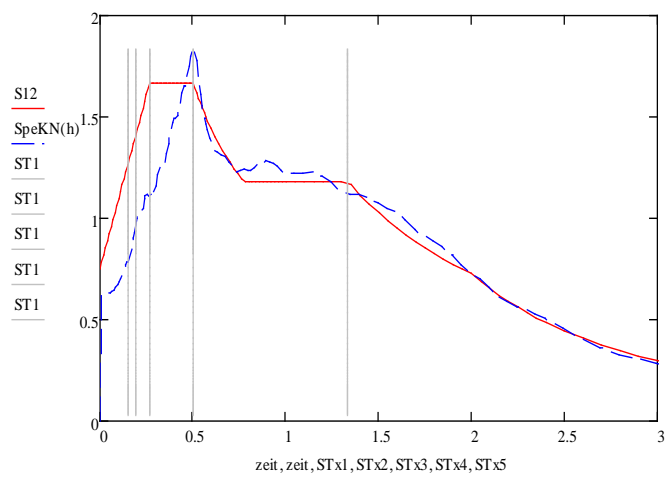
22.5m ($\xi_s = 15\%$)



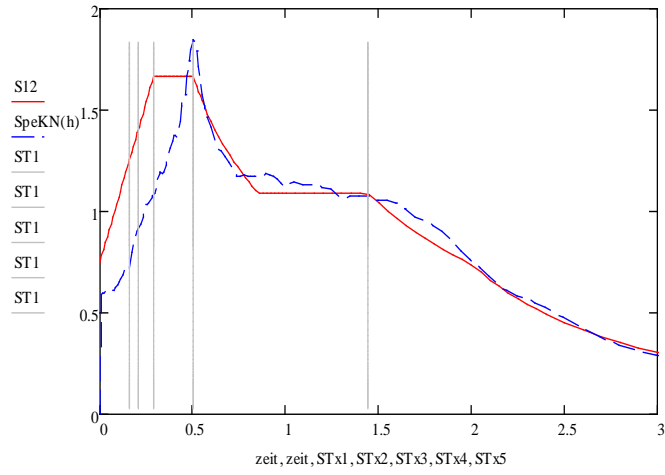
25m ($\xi_S = 15\%$)



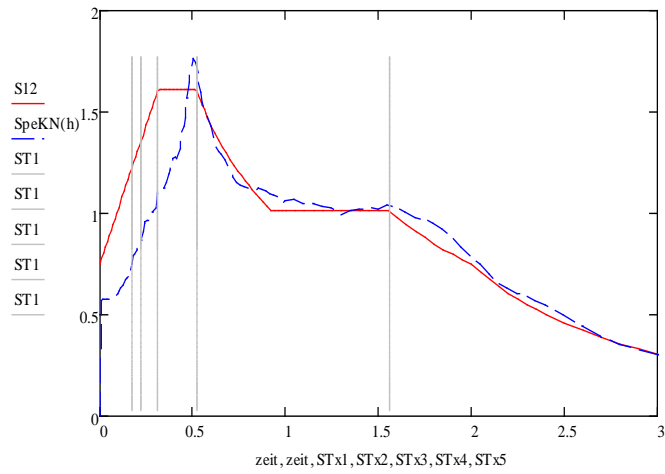
27.5m ($\xi_S = 15\%$)



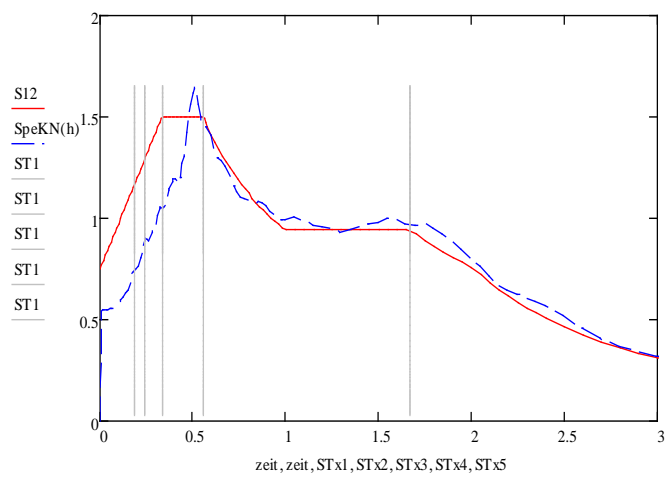
30m ($\xi_S = 15\%$)



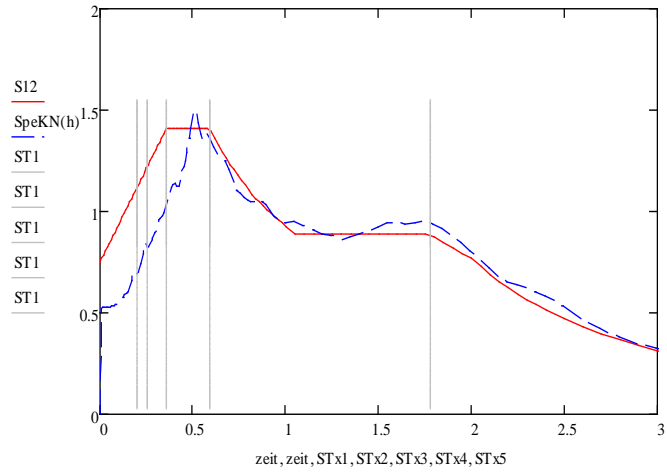
32.5m ($\xi_s = 15\%$)



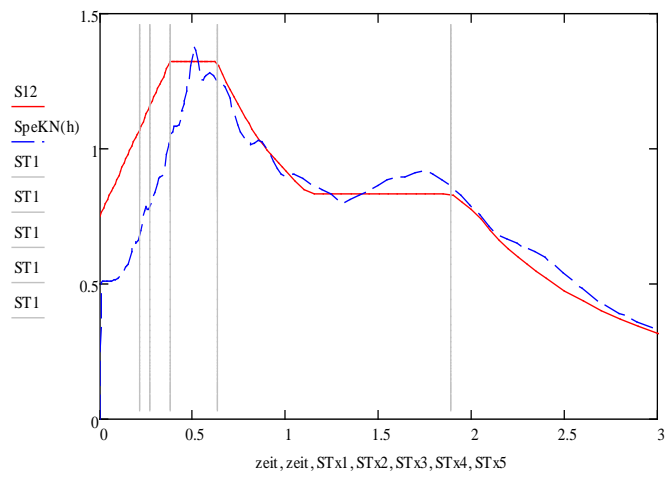
35m ($\xi_s = 15\%$)



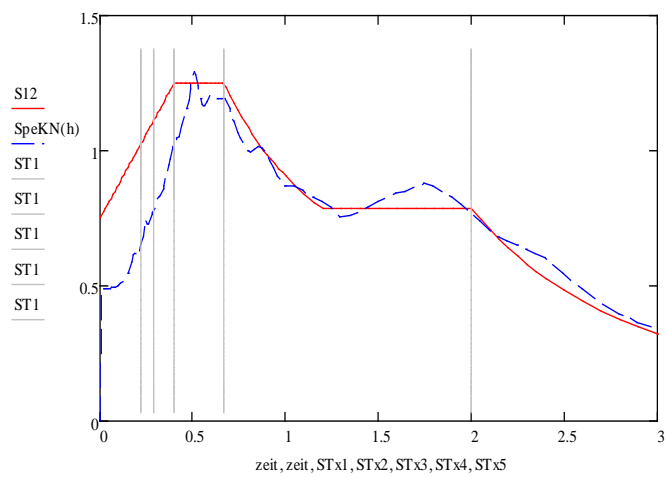
37.5m ($\xi_s = 15\%$)



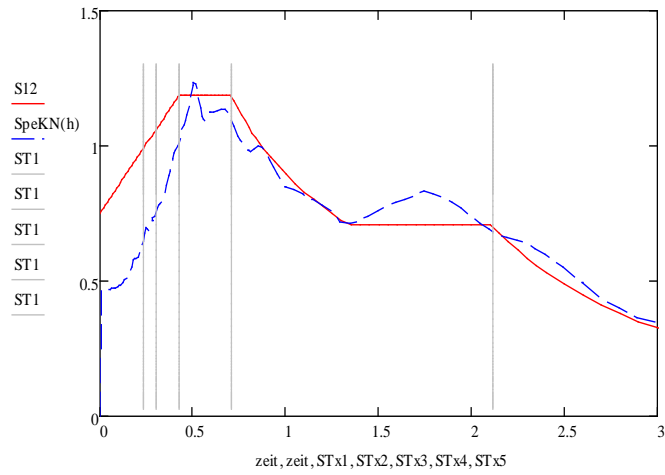
40m ($\xi_S = 15\%$)



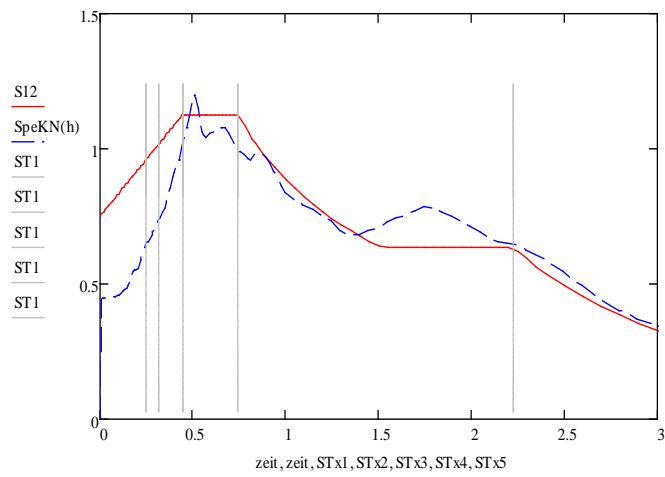
42.5m ($\xi_S = 15\%$)



45m ($\xi_S = 15\%$)

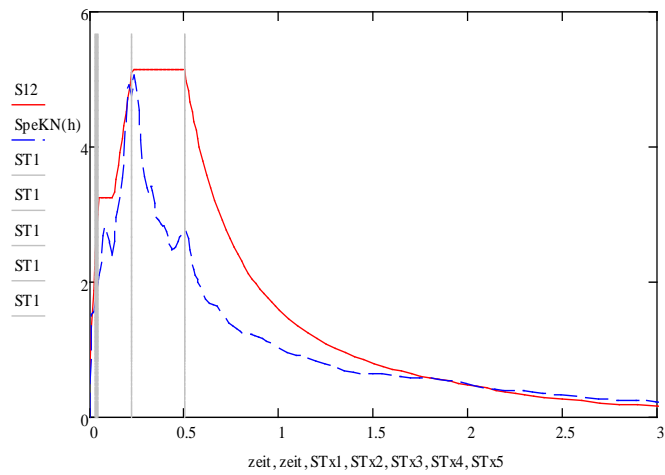


47.5m ($\xi_S = 15\%$)

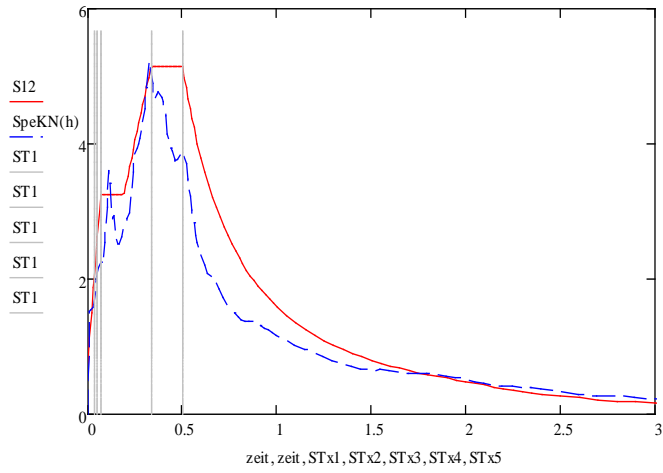


50m ($\xi_S = 15\%$)

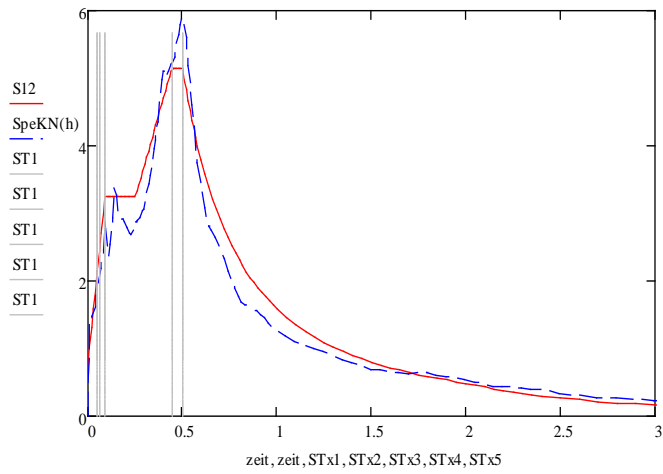
6.5.3 Bedrock shear wave velocity equal with 350 m/s



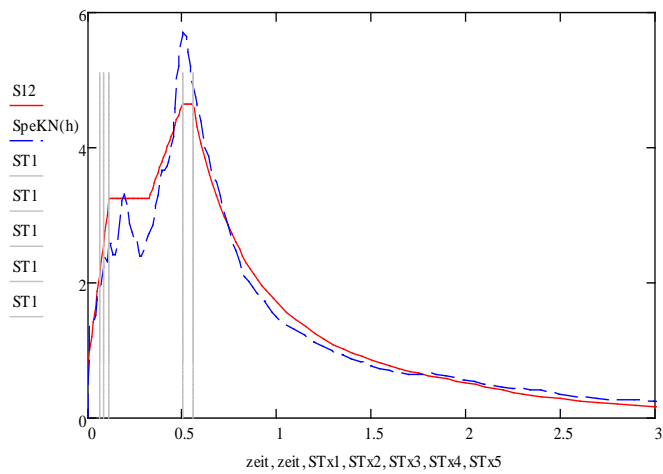
5m ($\xi_S = 5\%$)



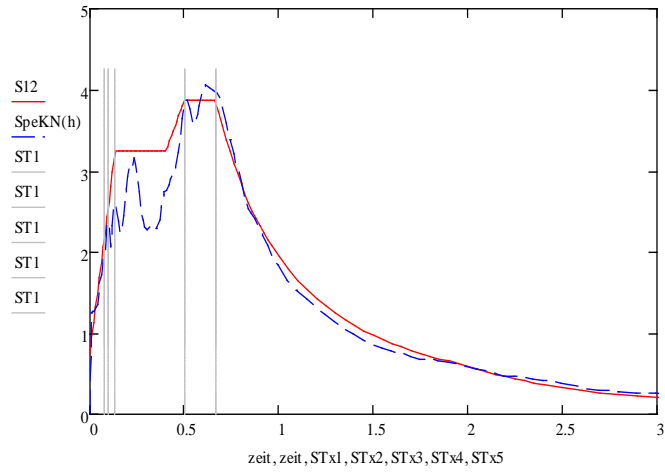
7.5m ($\xi_s= 5\%$)



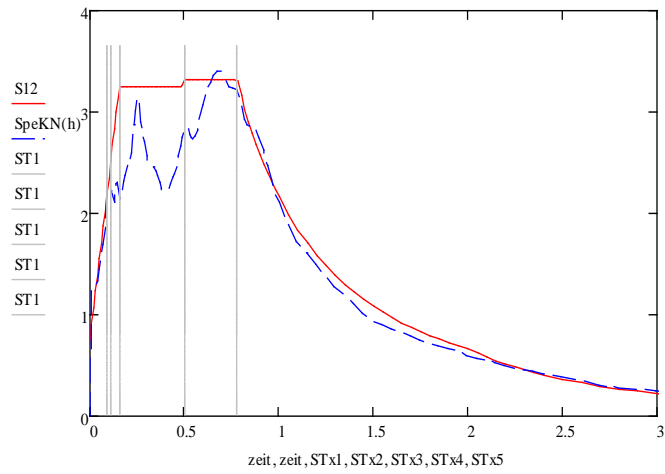
10m ($\xi_s= 5\%$)



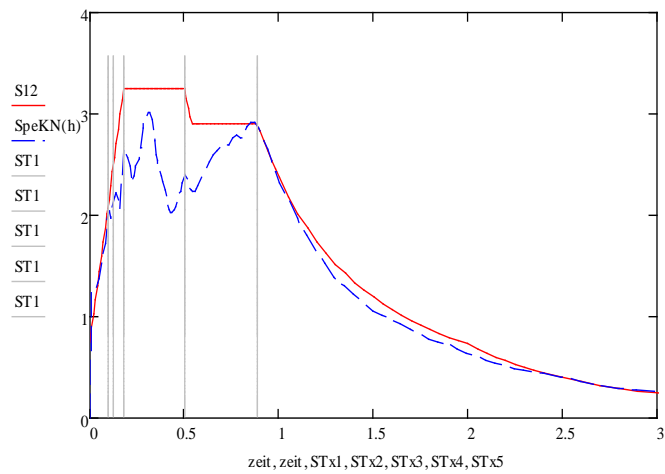
12.5m ($\xi_s= 5\%$)



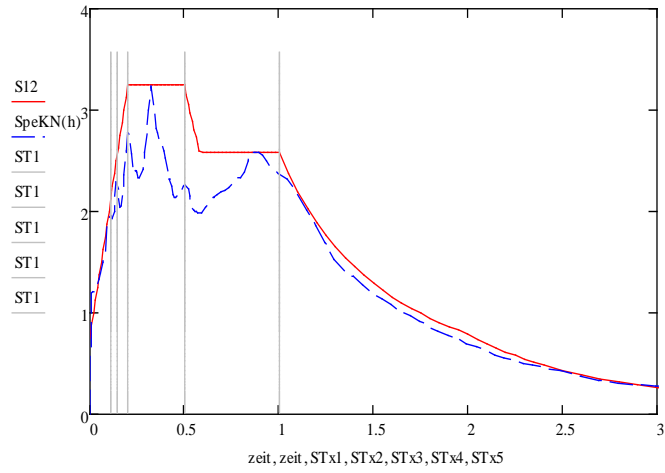
15m ($\xi_s = 5\%$)



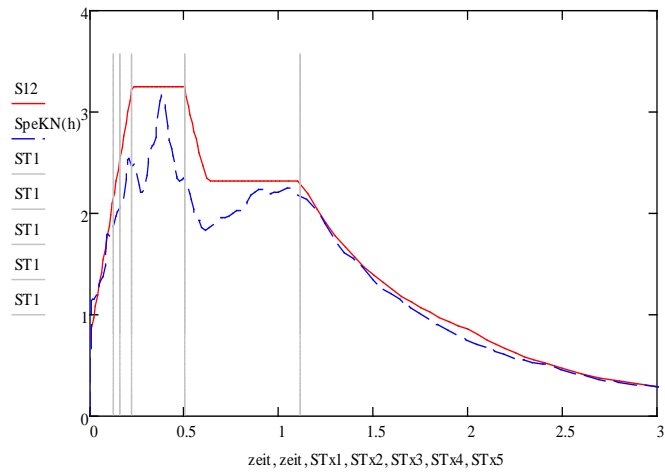
17.5m ($\xi_s = 5\%$)



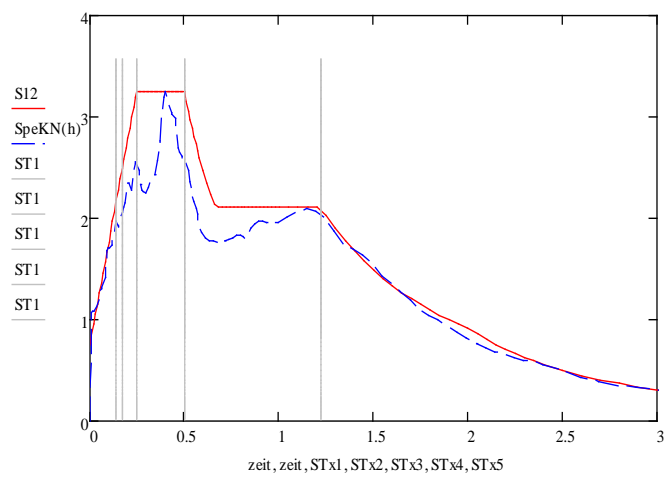
20m ($\xi_s = 5\%$)



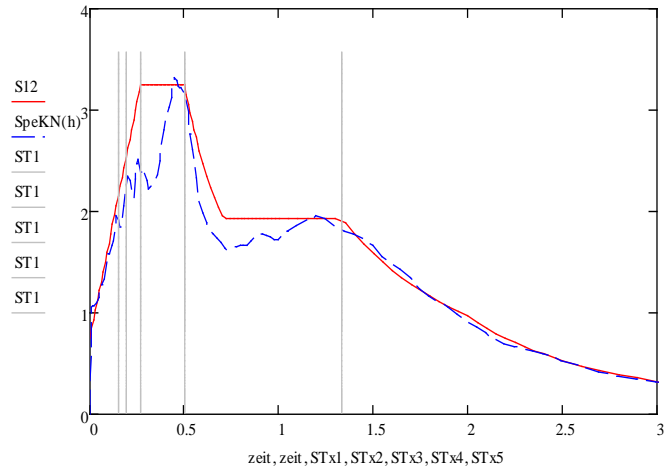
22.5m ($\xi_s = 5\%$)



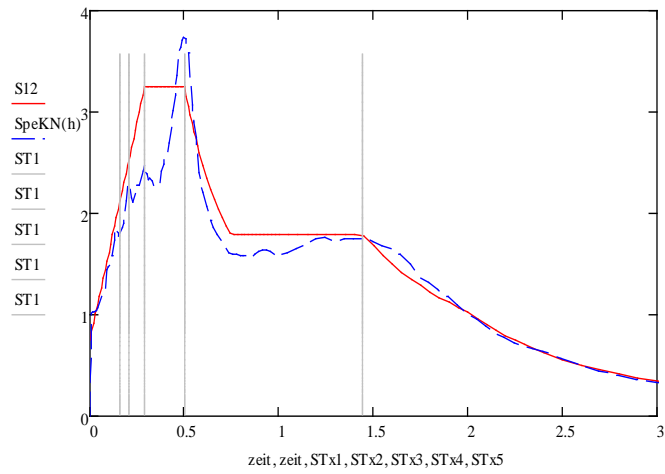
25m ($\xi_s = 5\%$)



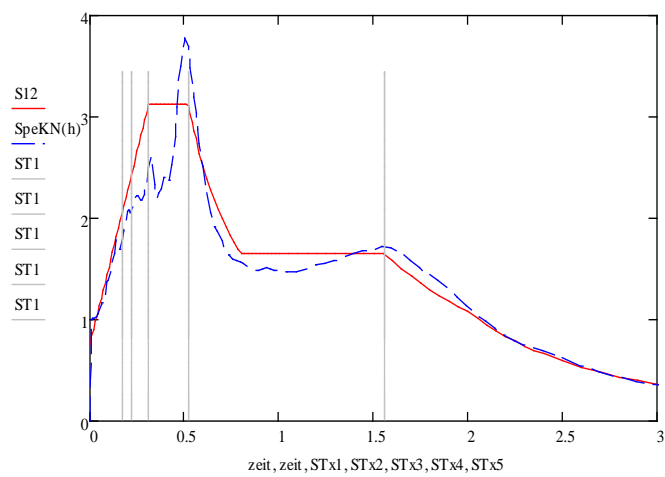
27.5m ($\xi_s = 5\%$)



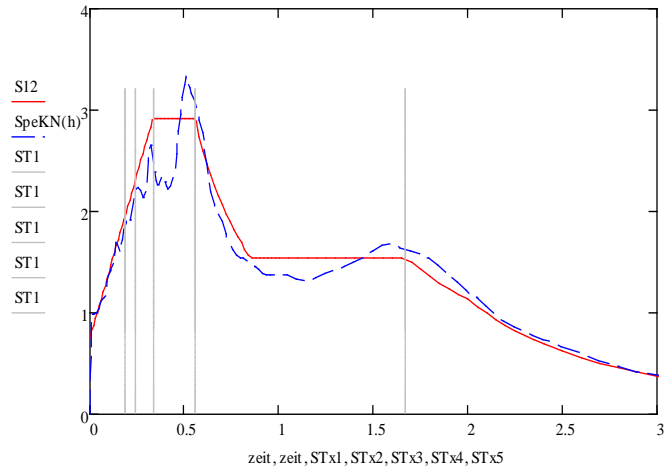
30m ($\xi_s = 5\%$)



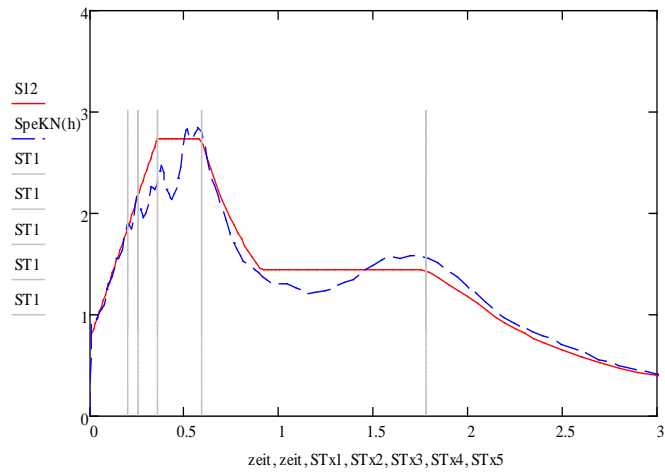
32.5m ($\xi_s = 5\%$)



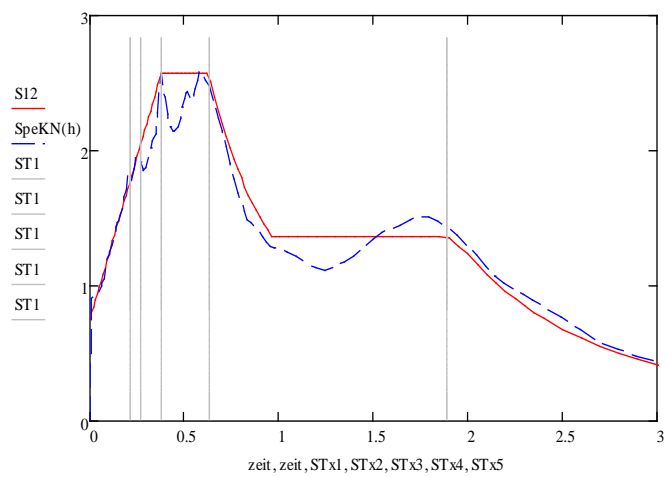
35m ($\xi_s = 5\%$)



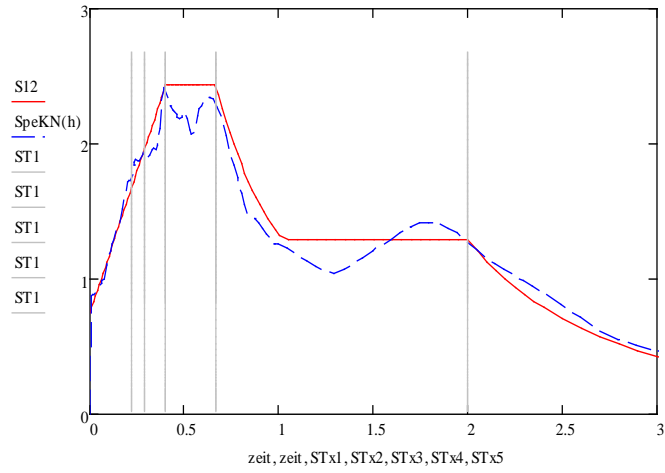
37.5m ($\xi_s = 5\%$)



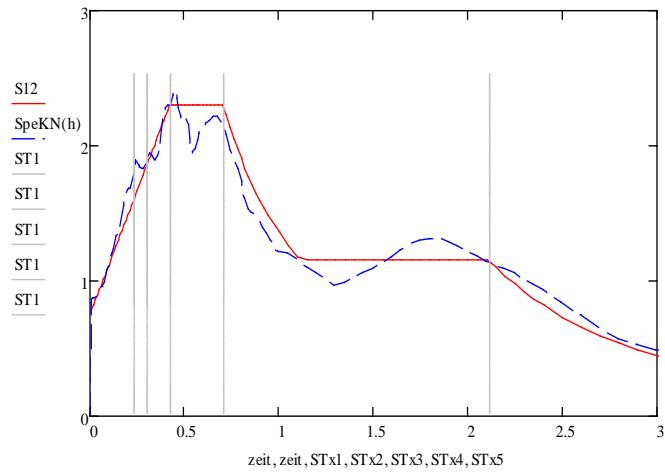
40m ($\xi_s = 5\%$)



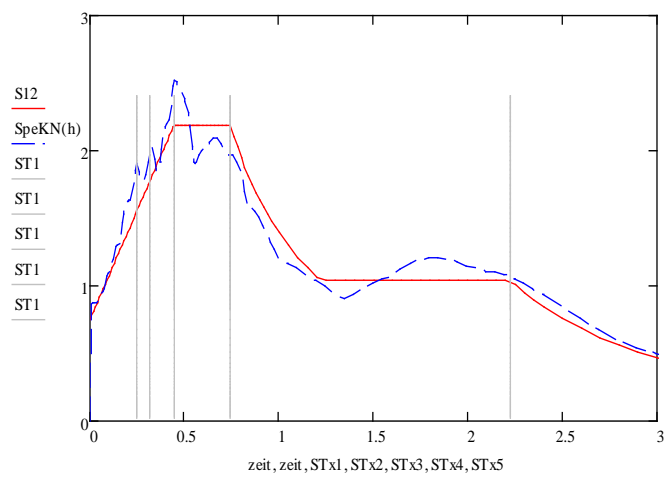
42.5m ($\xi_s = 5\%$)



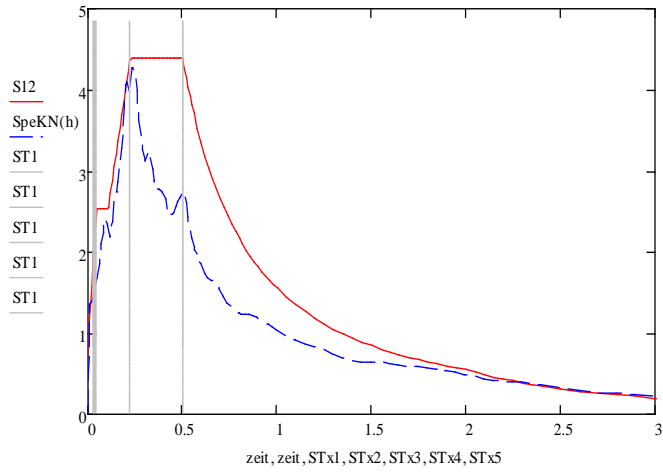
45m ($\xi_s = 5\%$)



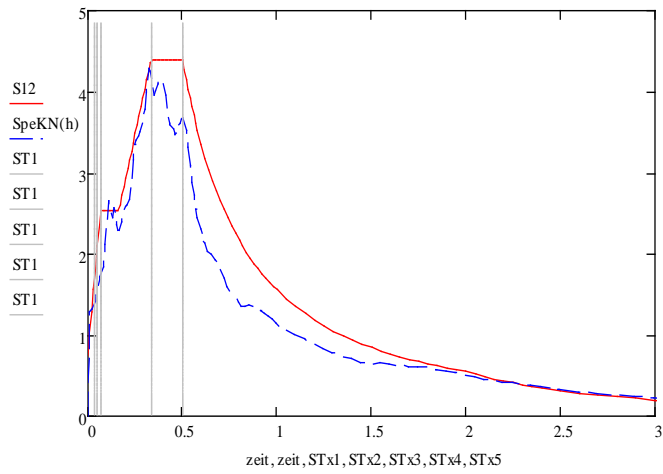
47.5m ($\xi_s = 5\%$)



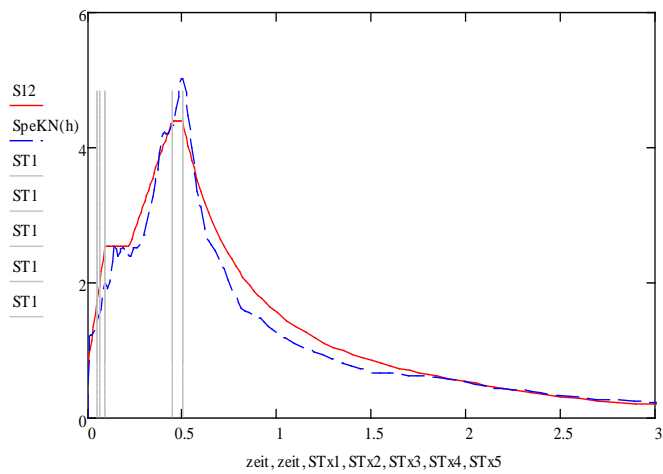
50m ($\xi_s = 5\%$)



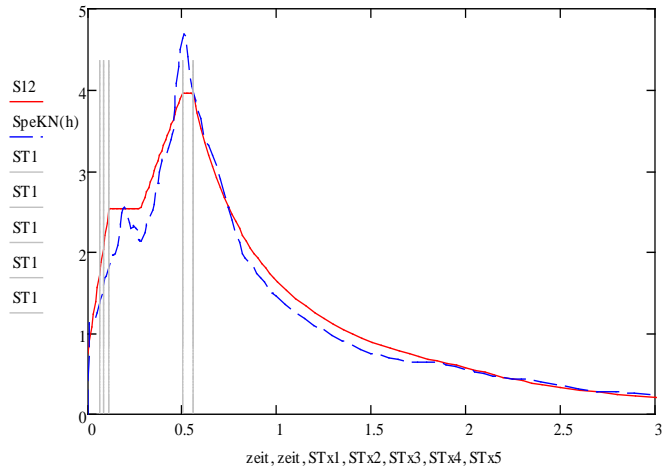
5m ($\xi_s = 10\%$)



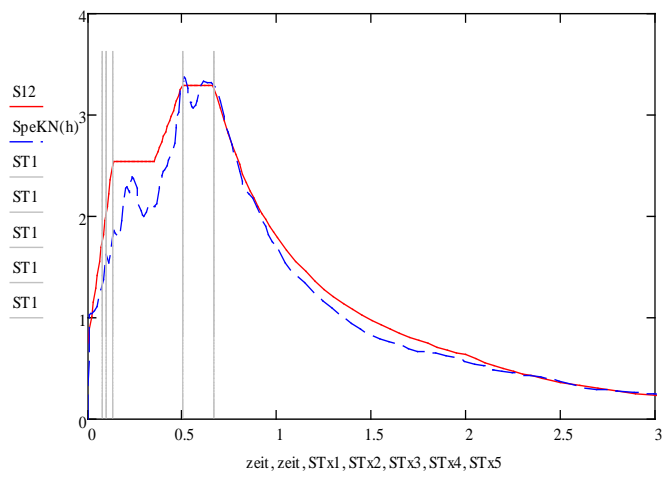
7.5m ($\xi_s = 10\%$)



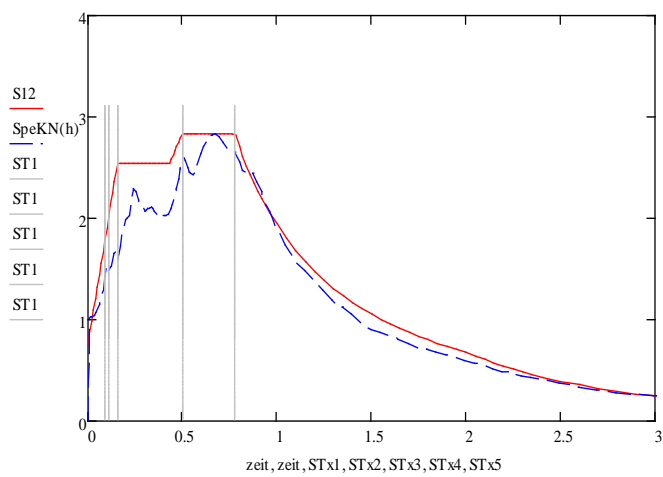
10m ($\xi_s = 10\%$)



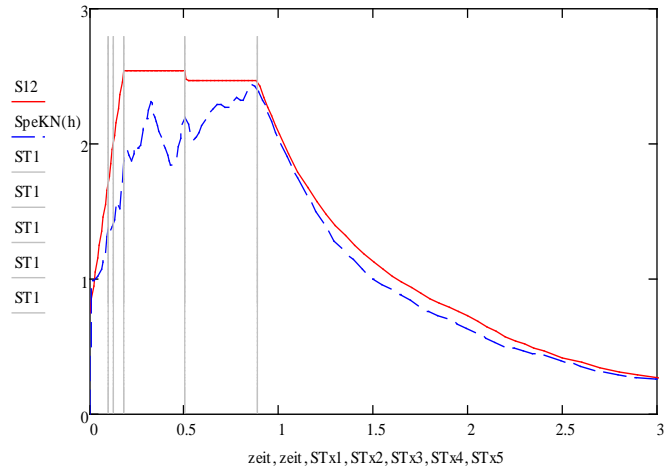
12.5m ($\xi_S= 10\%$)



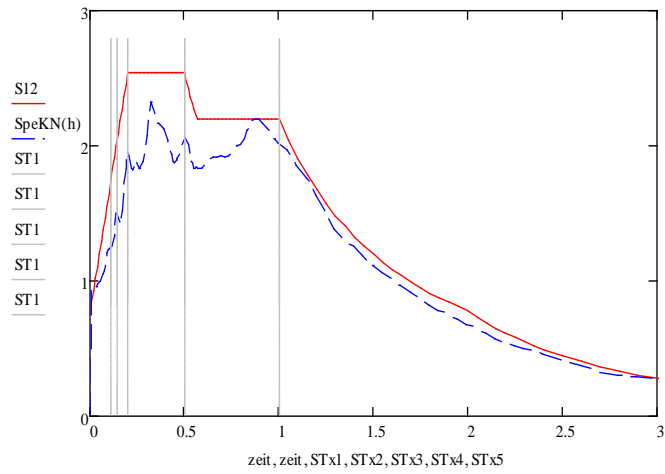
15m ($\xi_S= 10\%$)



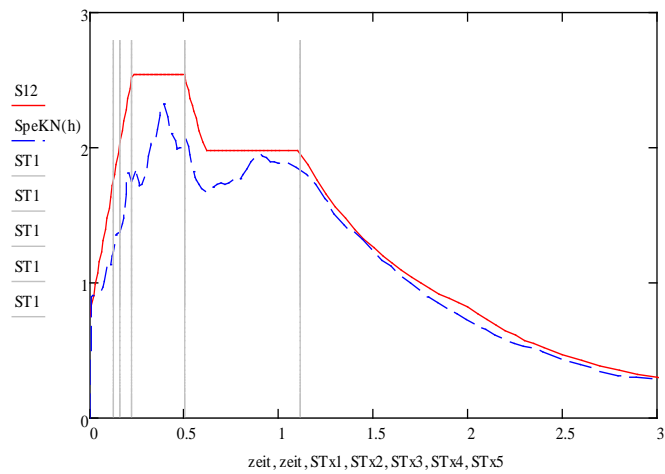
17.5m ($\xi_S= 10\%$)



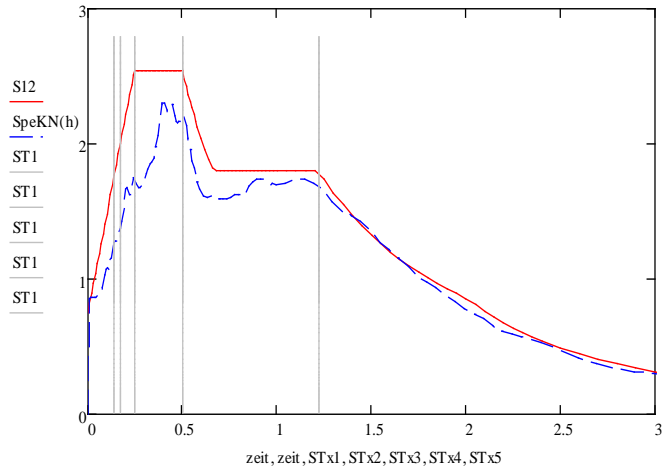
20m ($\xi_S = 10\%$)



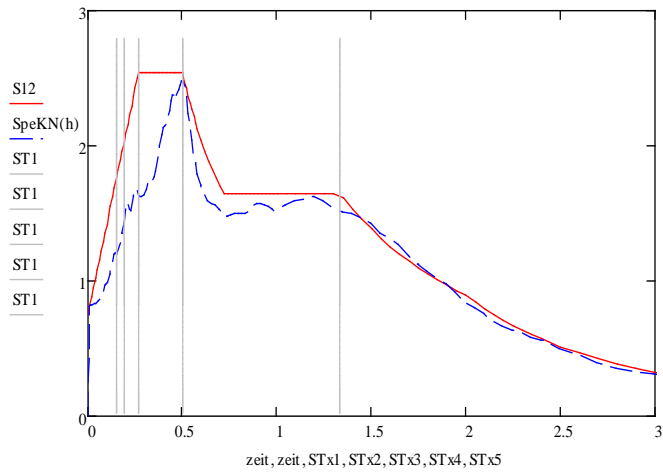
22.5m ($\xi_S = 10\%$)



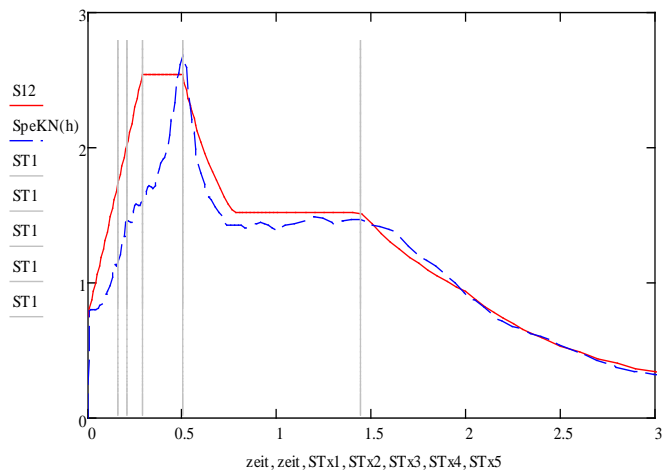
25m ($\xi_S = 10\%$)



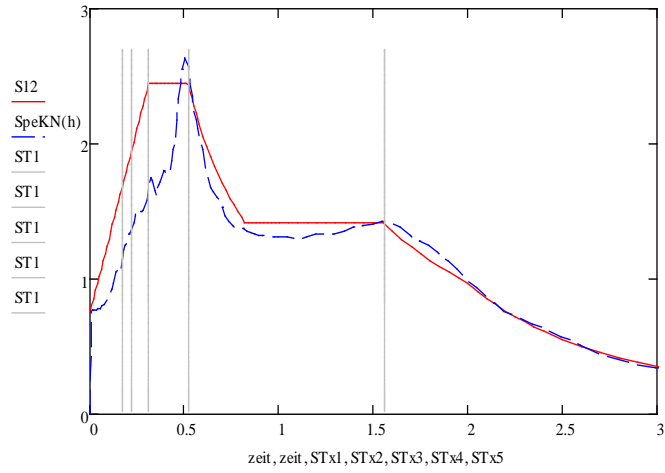
27.5m ($\xi_s= 10\%$)



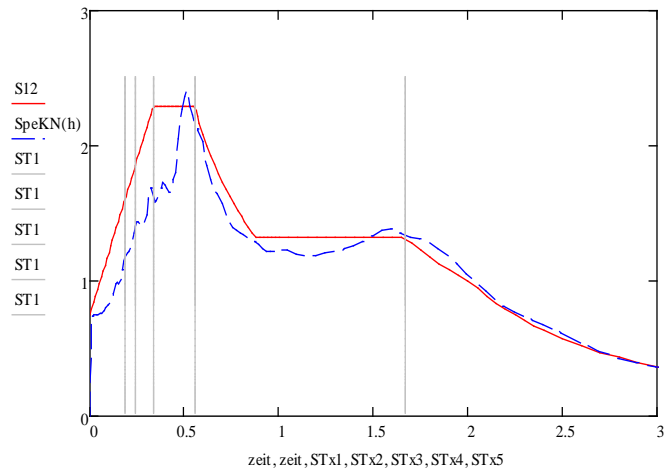
30m ($\xi_s= 10\%$)



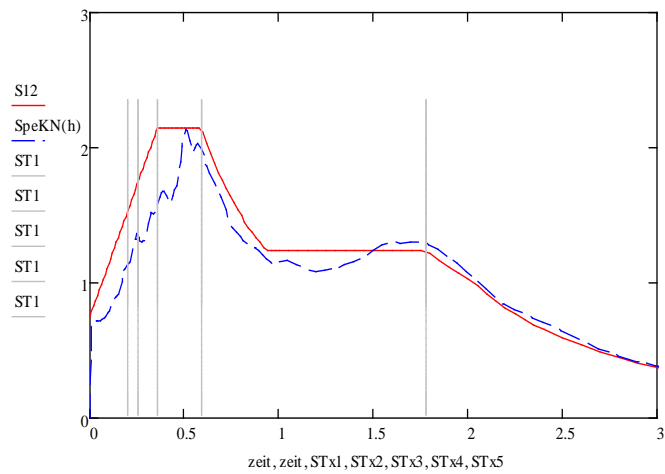
32.5m ($\xi_s= 10\%$)



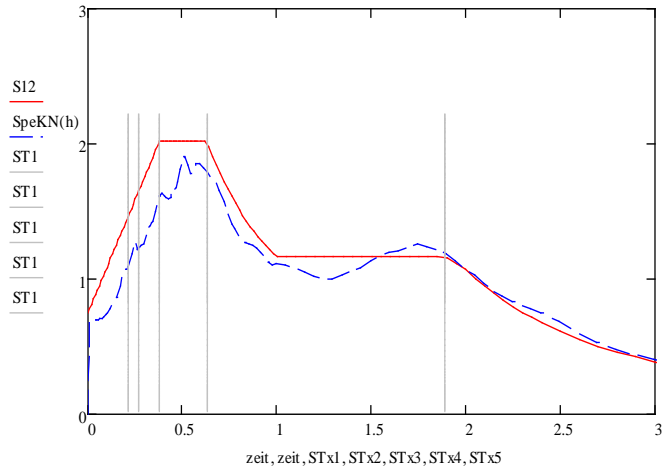
35m ($\xi_s = 10\%$)



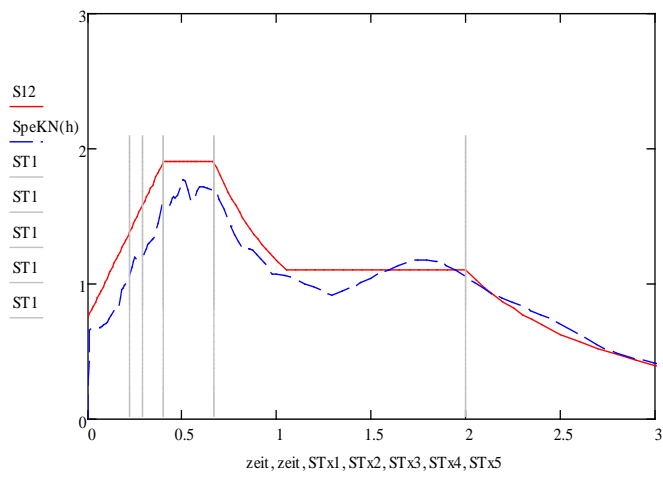
37.5m ($\xi_s = 10\%$)



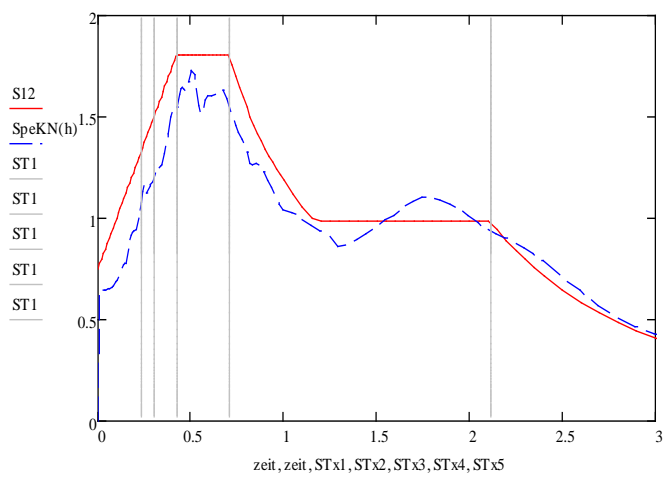
40m ($\xi_s = 10\%$)



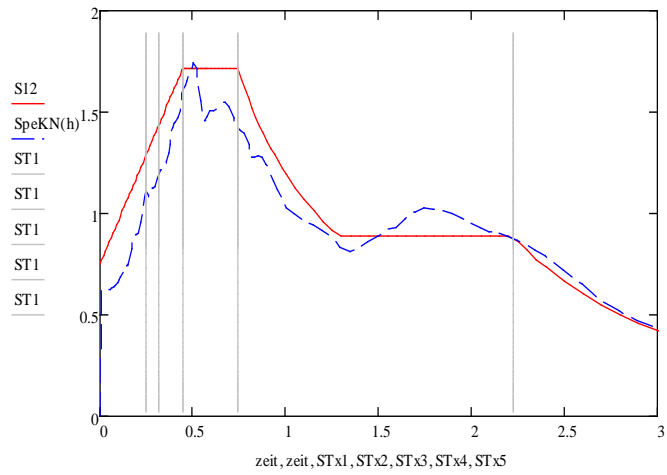
42.5m ($\xi_S = 10\%$)



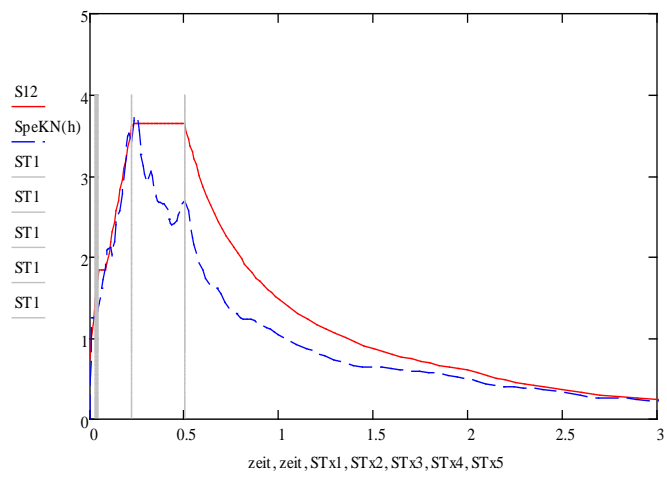
45m ($\xi_S = 10\%$)



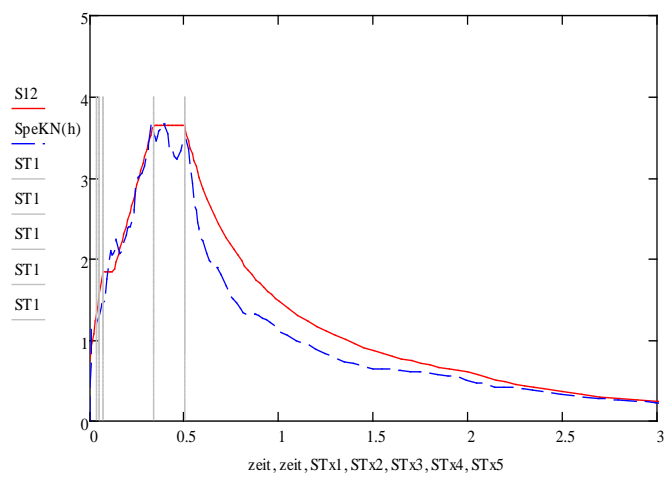
47.5m ($\xi_S = 10\%$)



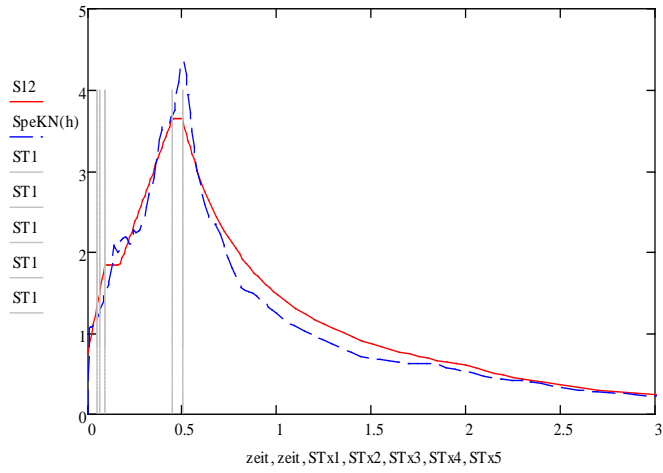
50m ($\xi_s = 10\%$)



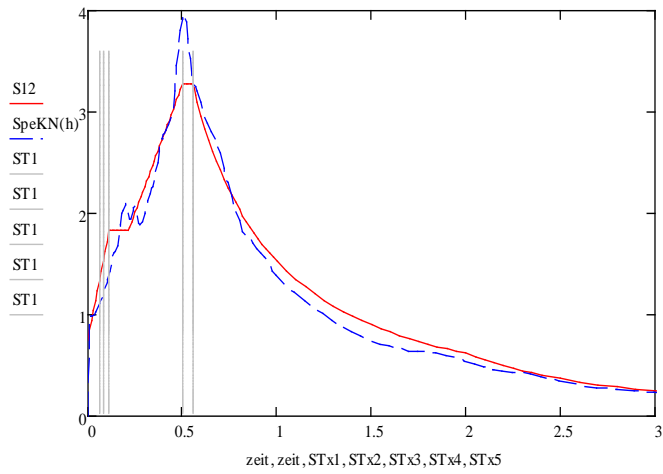
5m ($\xi_s = 15\%$)



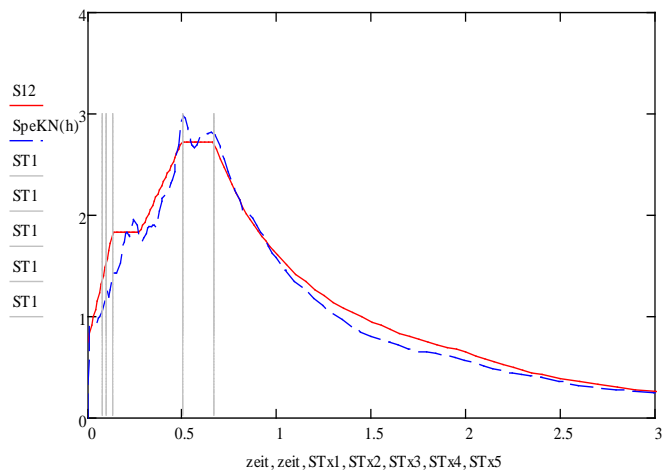
7.5m ($\xi_s = 15\%$)



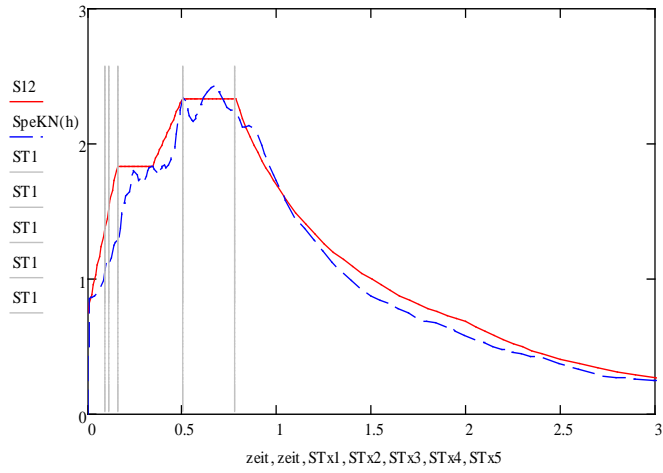
10m ($\xi_S = 15\%$)



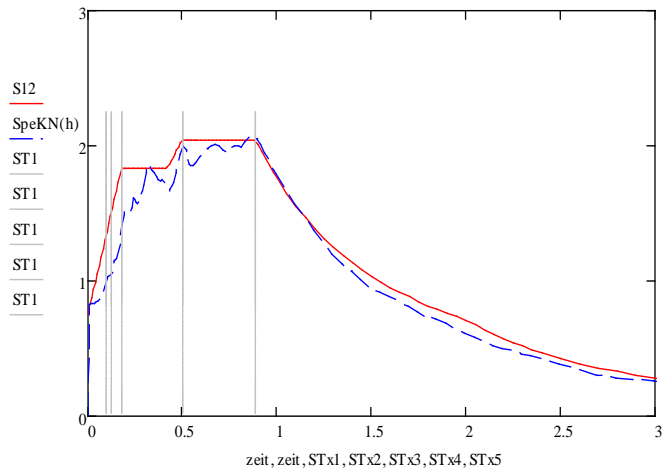
12.5m ($\xi_S = 15\%$)



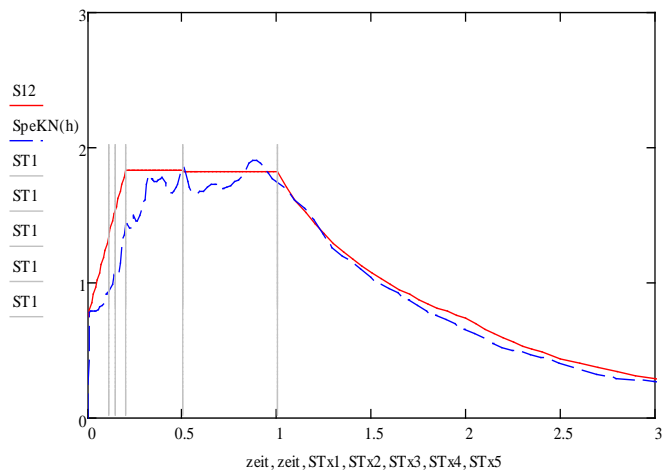
15m ($\xi_S = 15\%$)



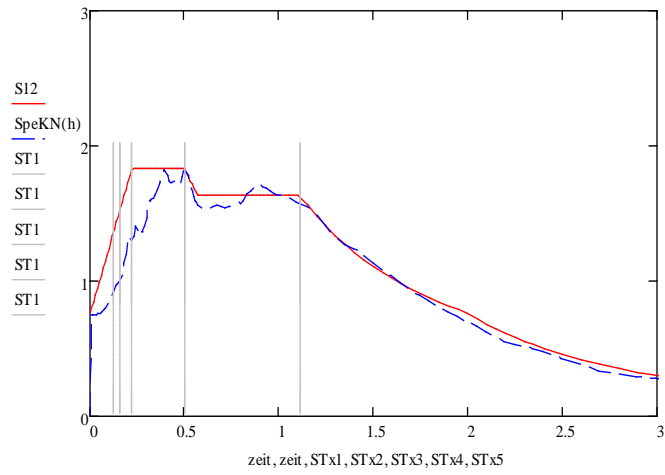
17.5m ($\xi_S=15\%$)



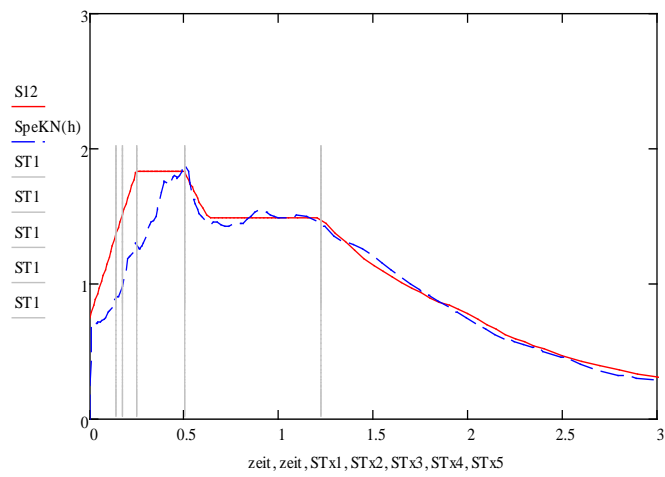
20m ($\xi_S=15\%$)



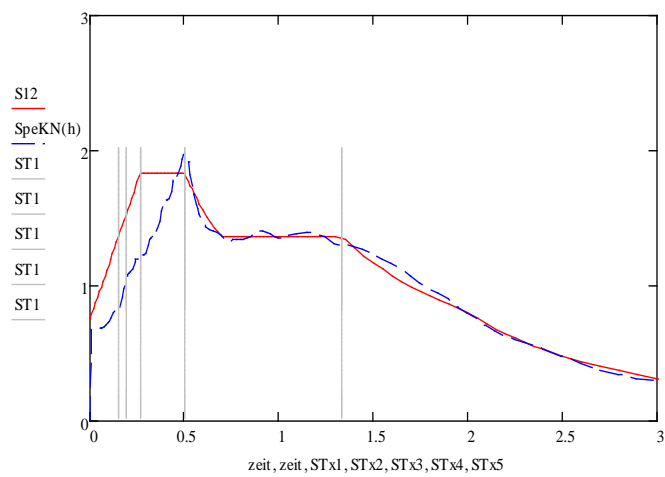
22.5m ($\xi_S=15\%$)



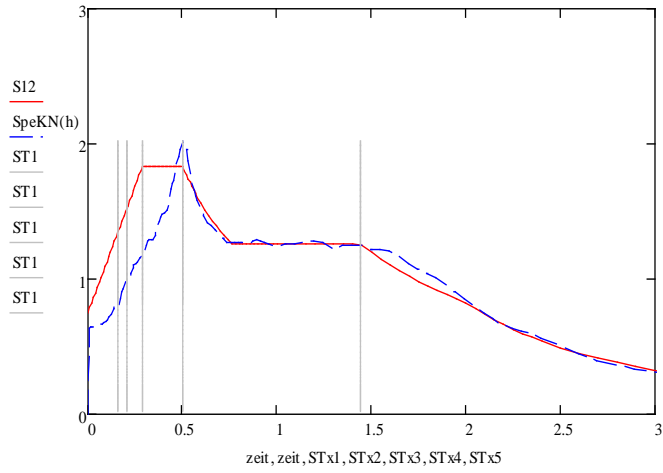
25m ($\xi_S = 15\%$)



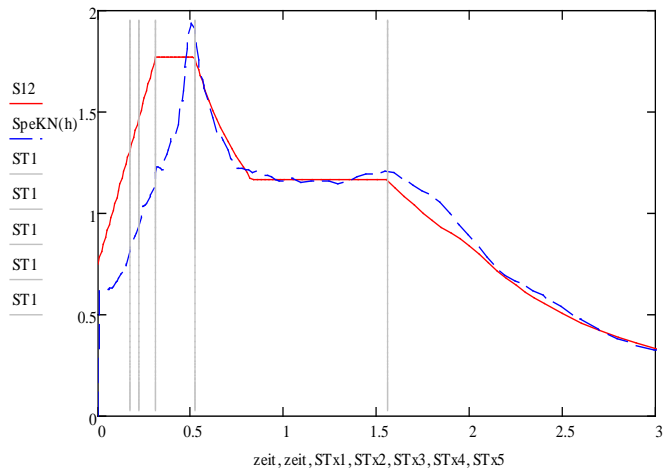
27.5m ($\xi_S = 15\%$)



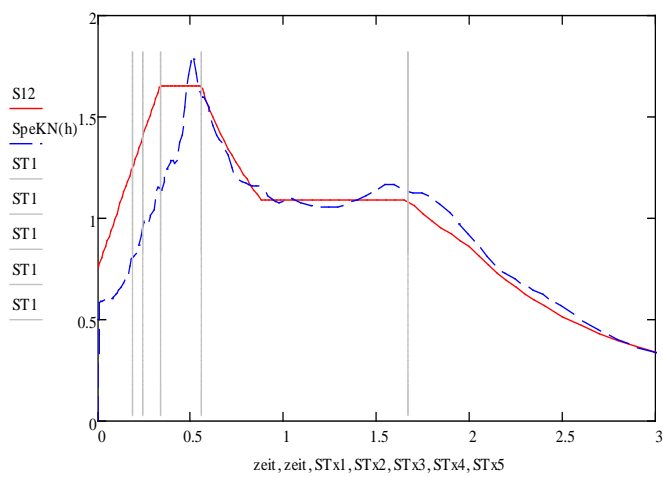
30m ($\xi_S = 15\%$)



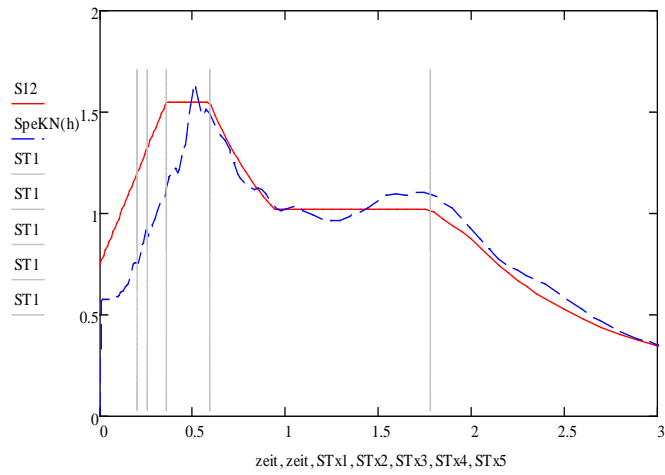
32.5m ($\xi_s = 15\%$)



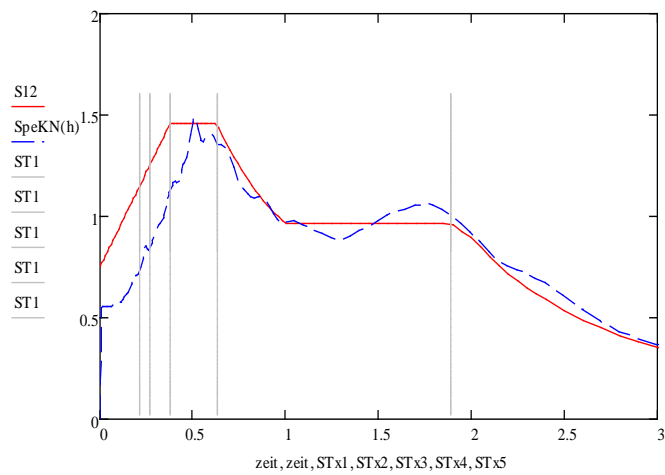
35m ($\xi_s = 15\%$)



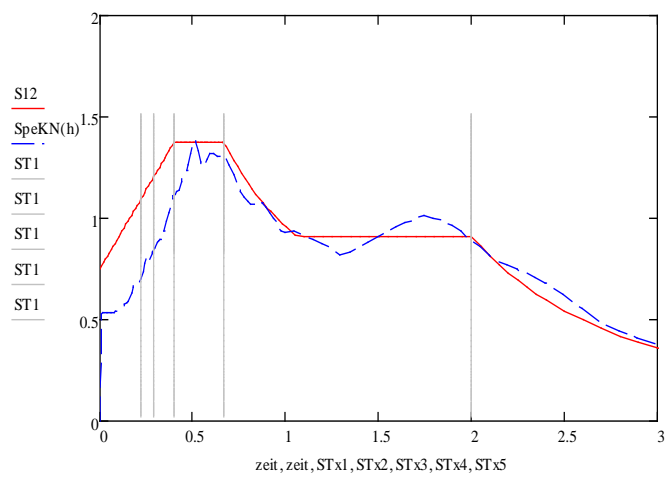
37.5m ($\xi_s = 15\%$)



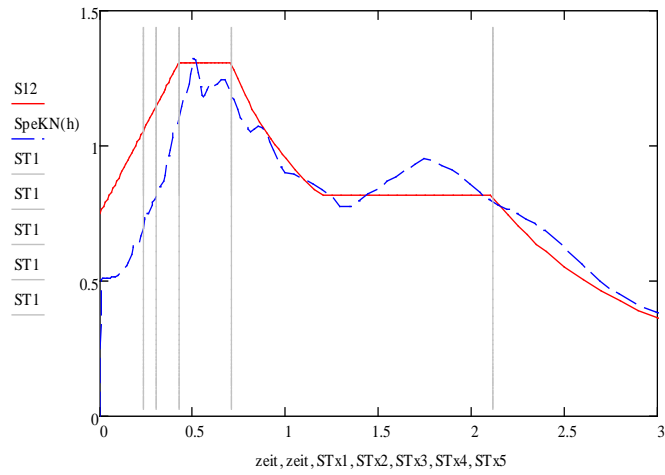
40m ($\xi_S = 15\%$)



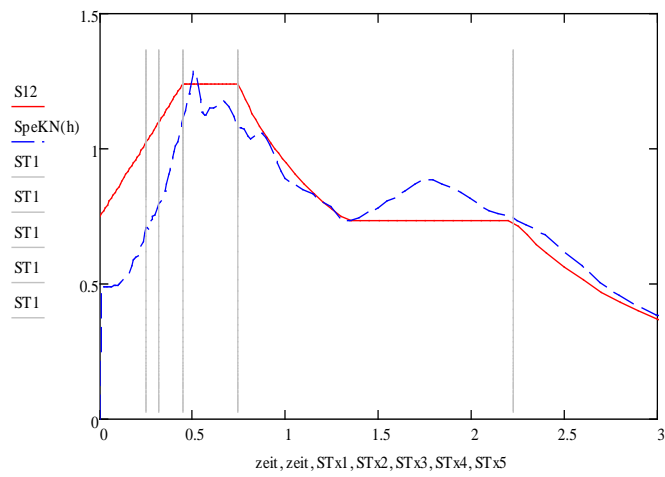
42.5m ($\xi_S = 15\%$)



45m ($\xi_S = 15\%$)

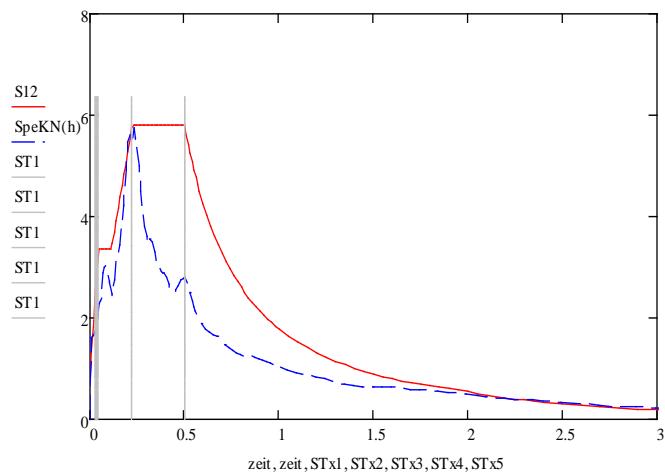


47.5m ($\xi_s = 15\%$)

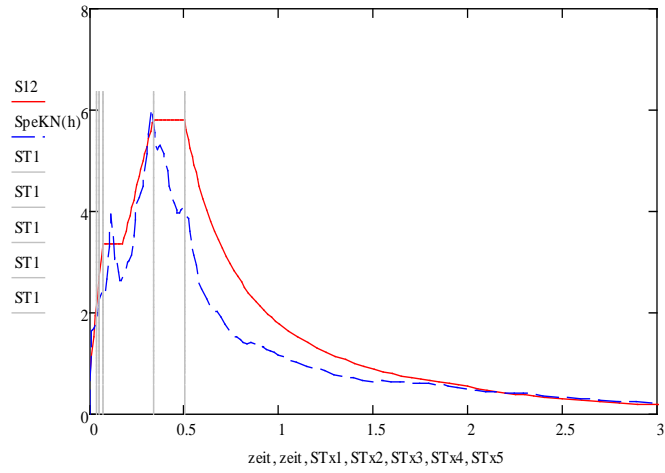


50m ($\xi_s = 15\%$)

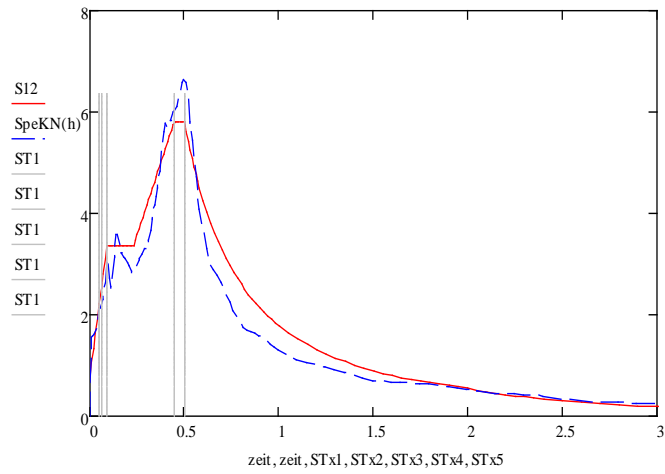
6.5.4 Bedrock shear wave velocity equal with 450 m/s



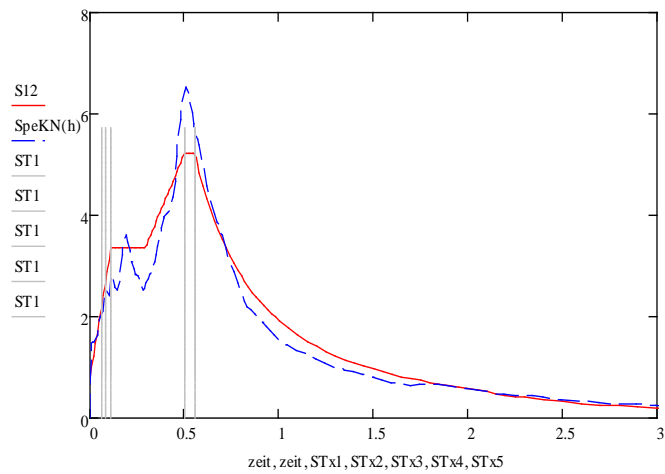
5m ($\xi_s = 5\%$)



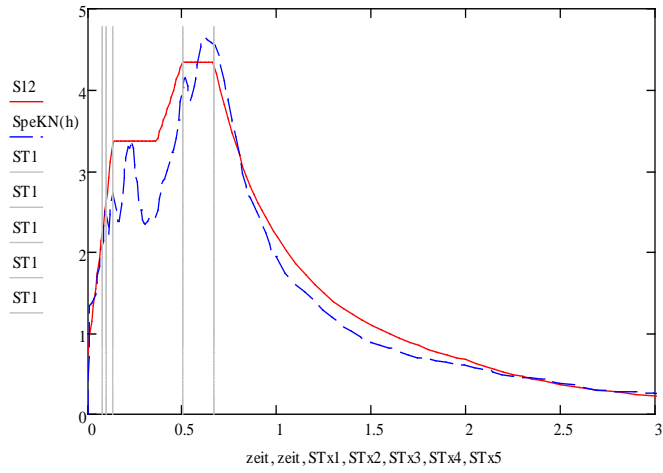
7.5m ($\xi_s = 5\%$)



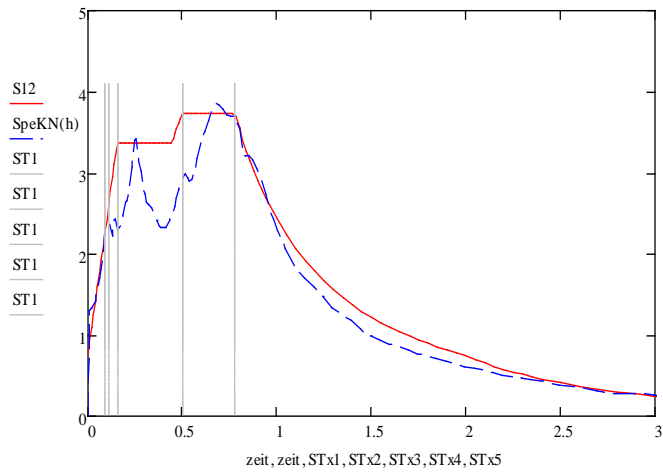
10m ($\xi_s = 5\%$)



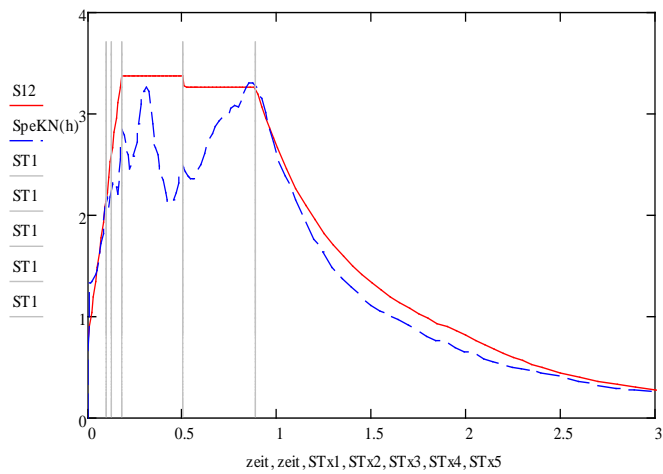
12.5m ($\xi_s = 5\%$)



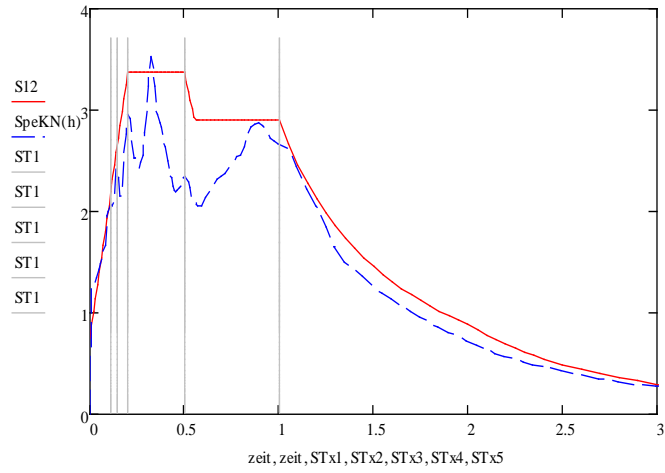
15m ($\xi_s = 5\%$)



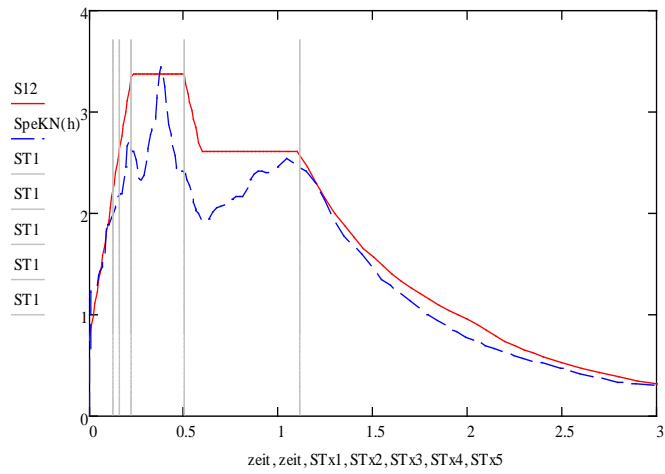
17.5m ($\xi_s = 5\%$)



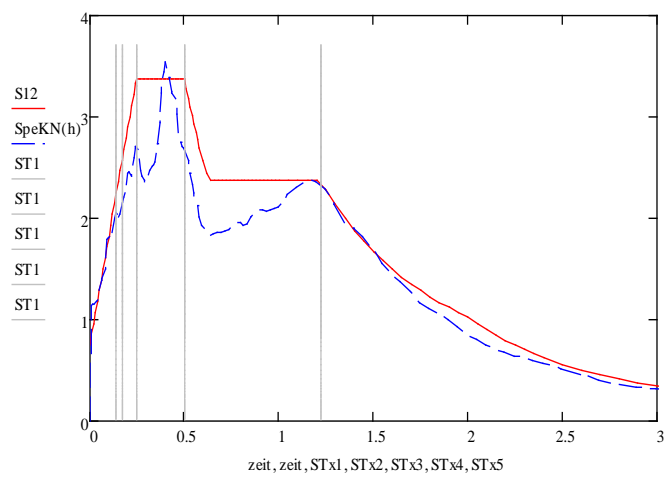
20m ($\xi_s = 5\%$)



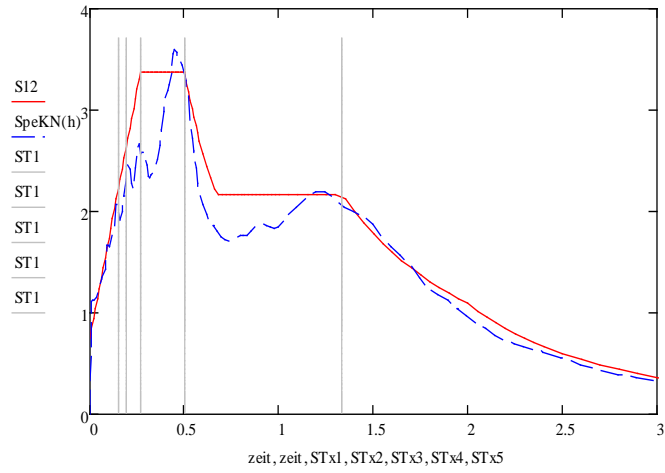
22.5m ($\xi_s = 5\%$)



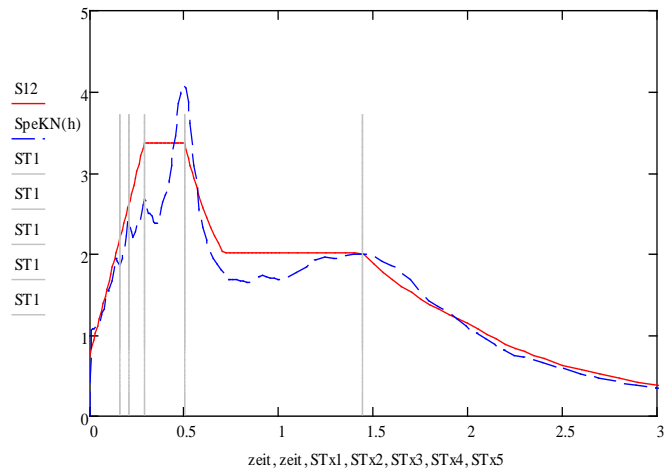
25m ($\xi_s = 5\%$)



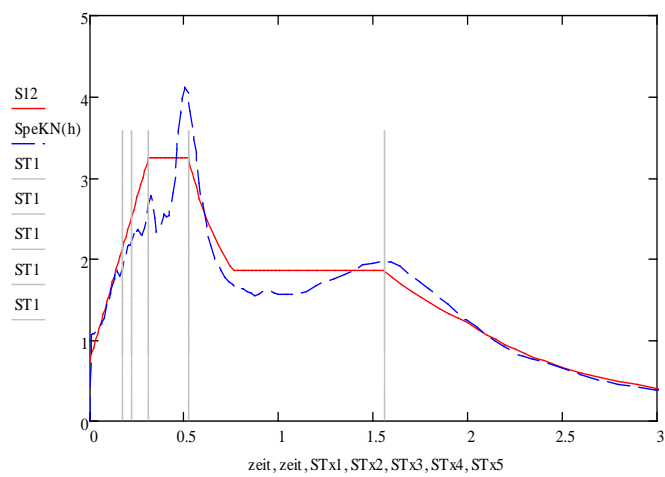
27.5m ($\xi_s = 5\%$)



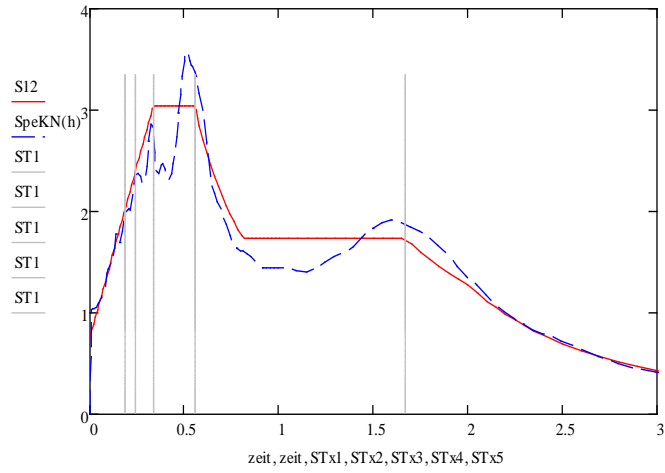
30m ($\xi_s = 5\%$)



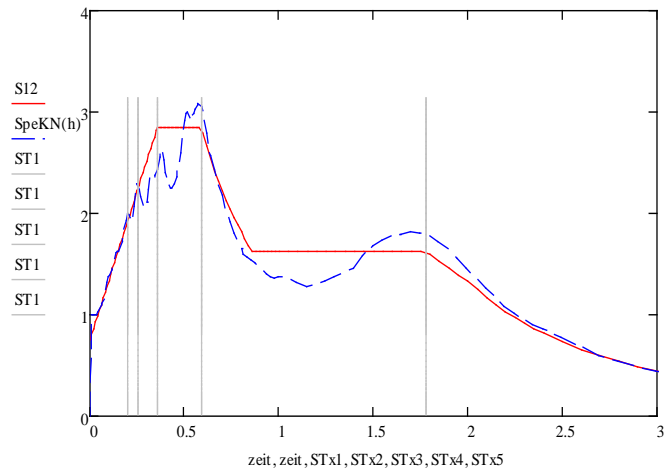
32.5m ($\xi_s = 5\%$)



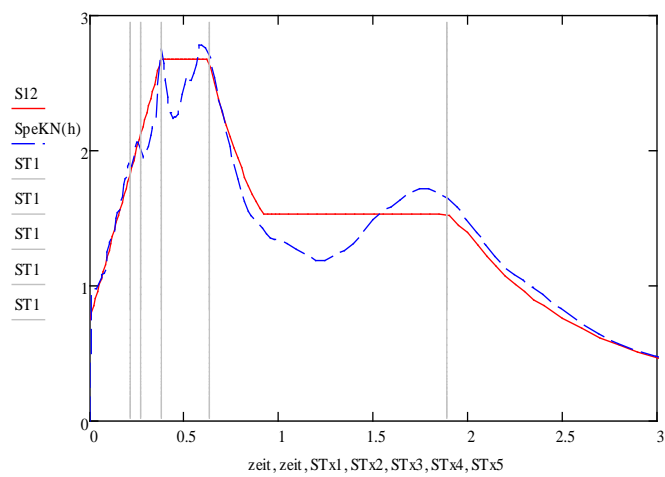
35m ($\xi_s = 5\%$)



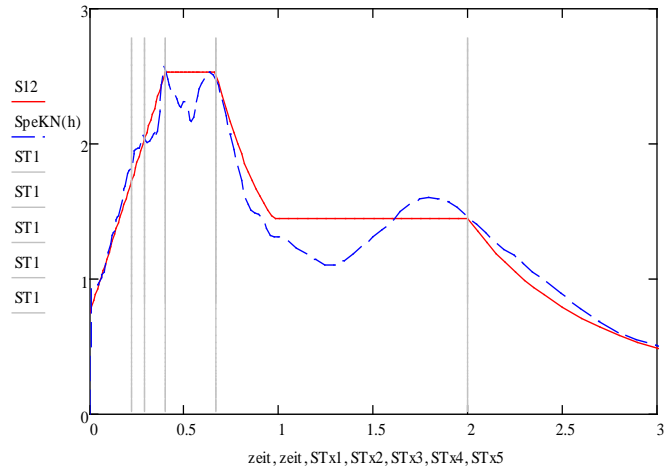
37.5m ($\xi_s = 5\%$)



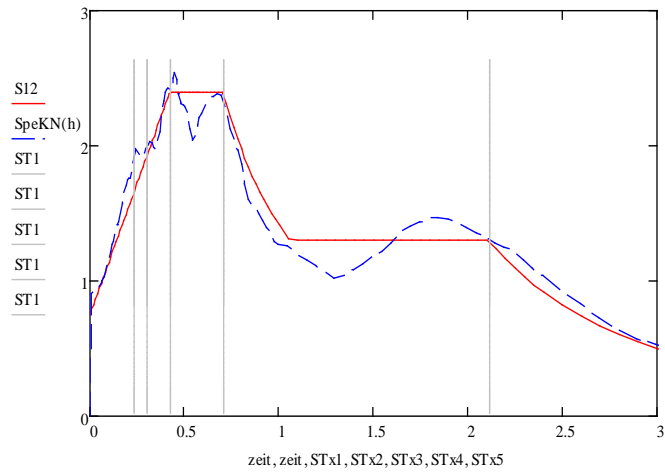
40m ($\xi_s = 5\%$)



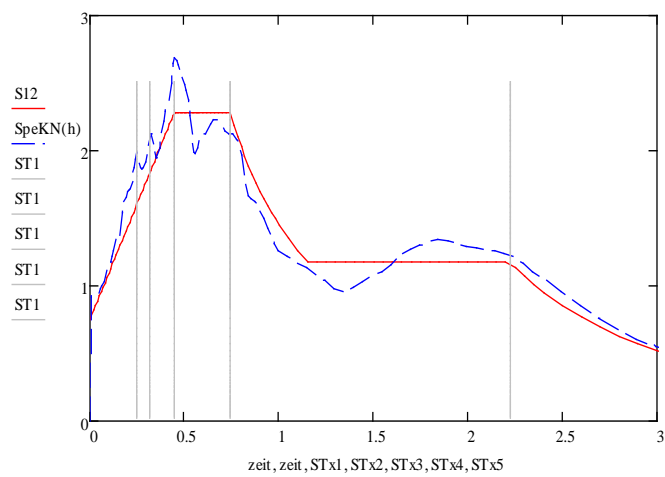
42.5m ($\xi_s = 5\%$)



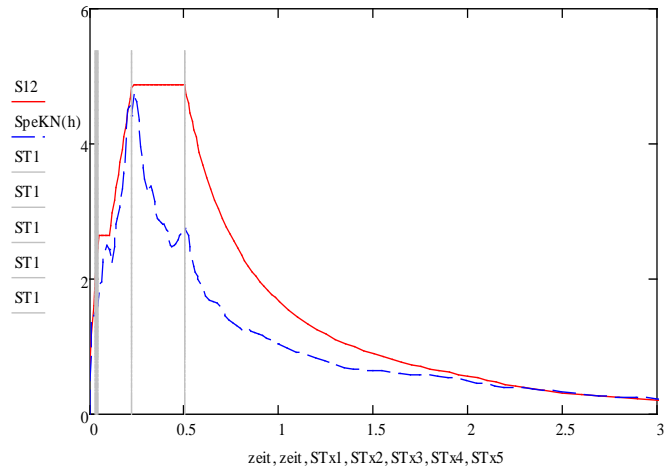
45m ($\xi_s = 5\%$)



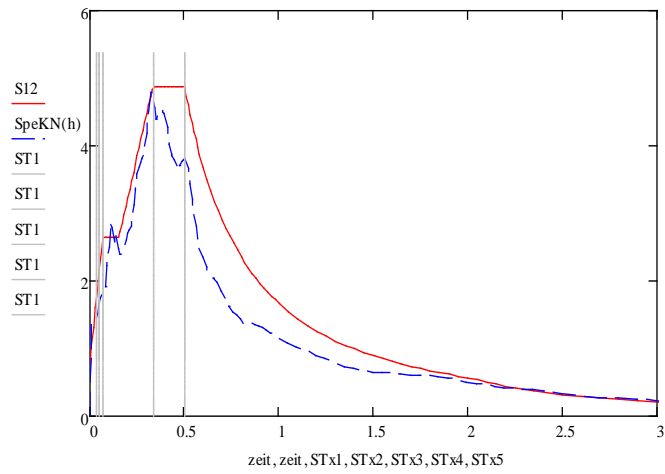
47.5m ($\xi_s = 5\%$)



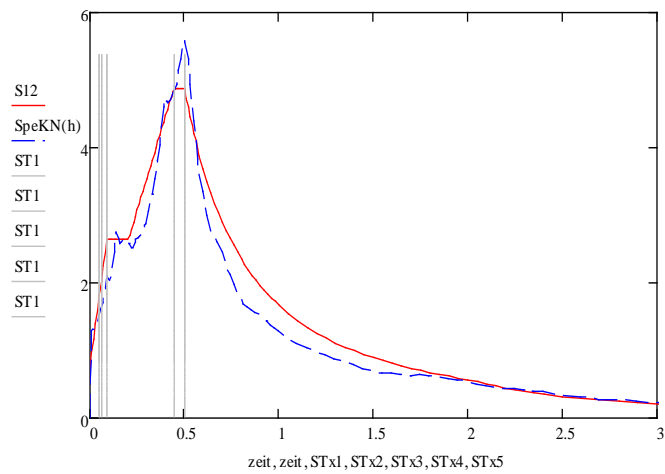
50m ($\xi_s = 5\%$)



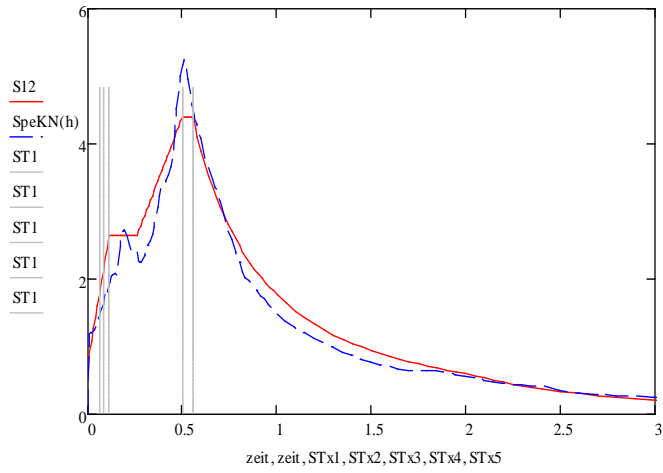
5m ($\xi_S = 10\%$)



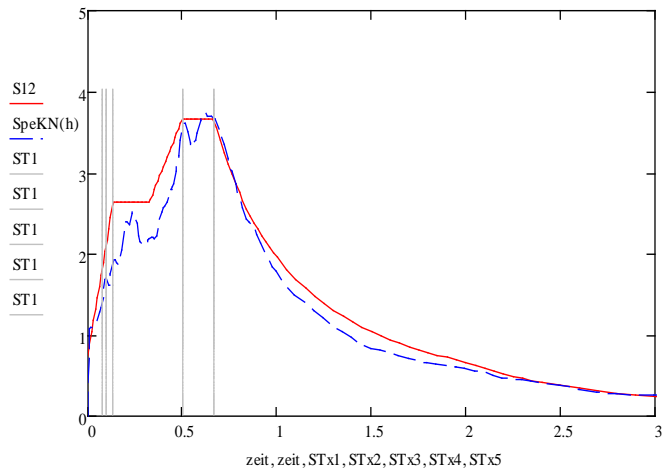
7.5m ($\xi_S = 10\%$)



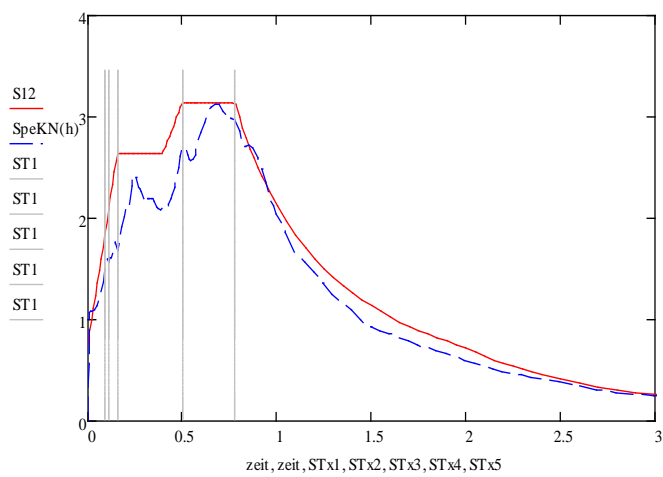
10m ($\xi_S = 10\%$)



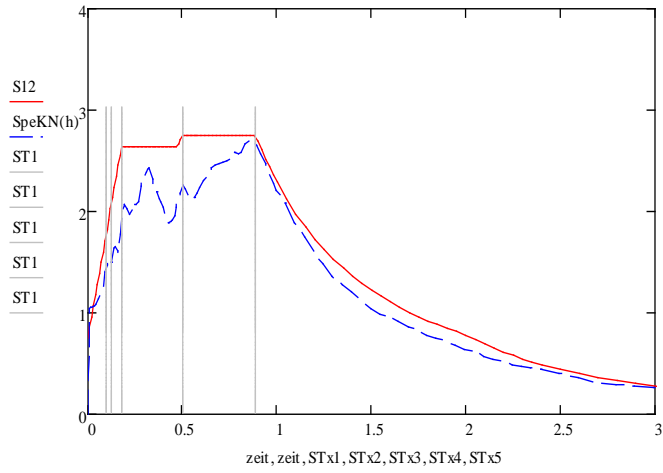
12.5m ($\xi_S = 10\%$)



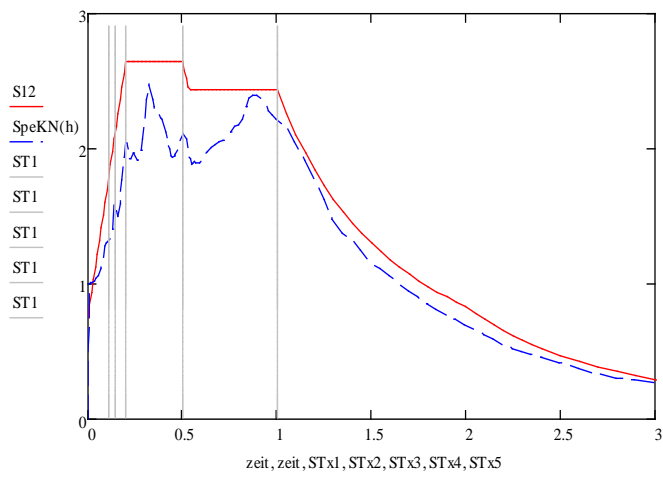
15m ($\xi_S = 10\%$)



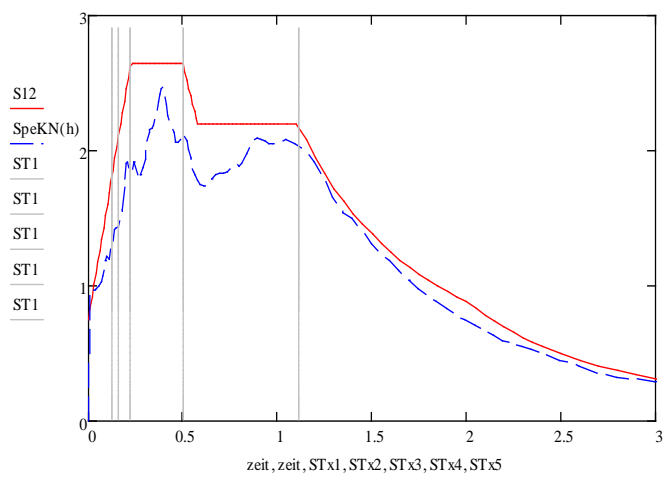
17.5m ($\xi_S = 10\%$)



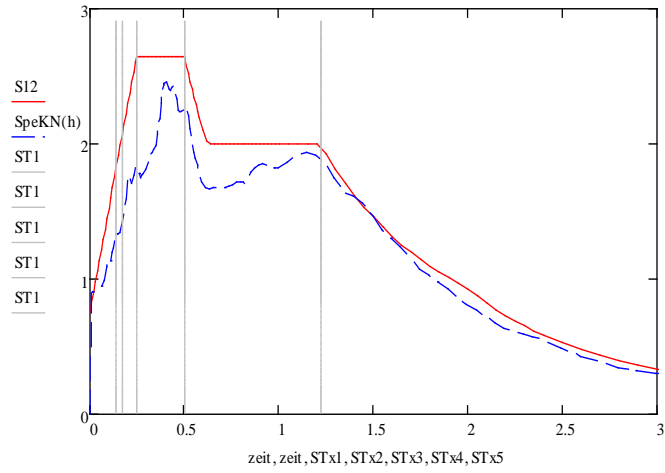
20m ($\xi_S = 10\%$)



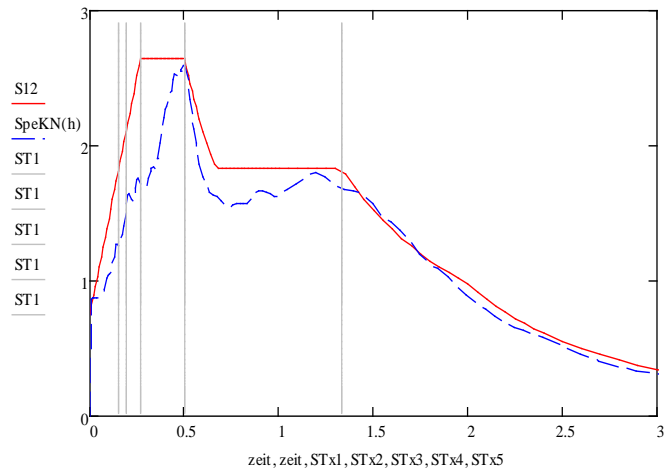
22.5m ($\xi_S = 10\%$)



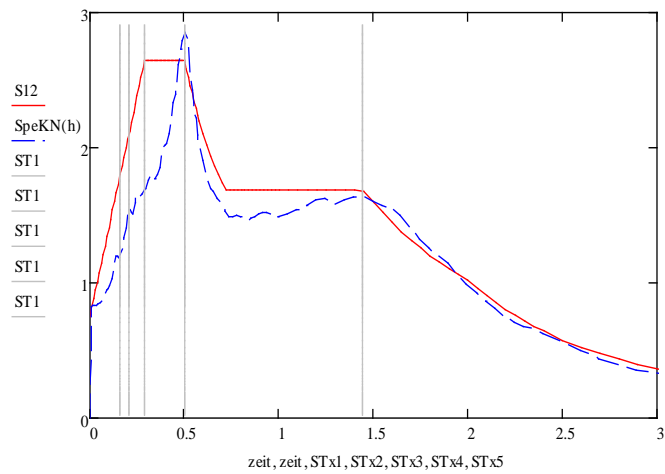
25m ($\xi_S = 10\%$)



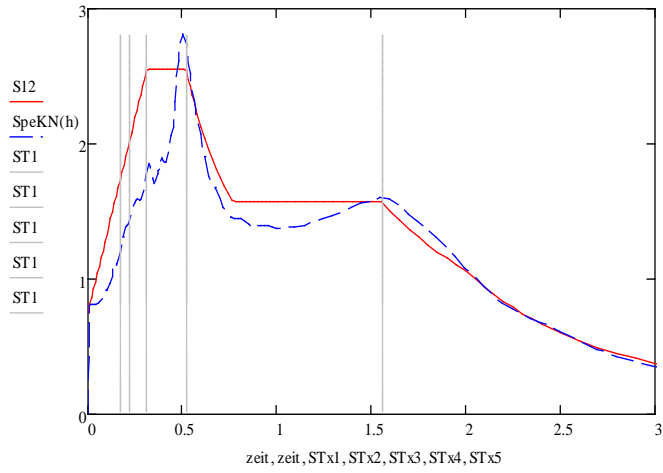
27.5m ($\xi_s = 10\%$)



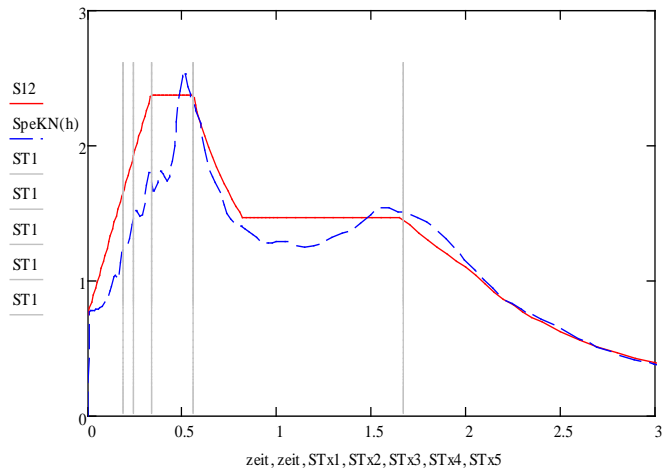
30m ($\xi_s = 10\%$)



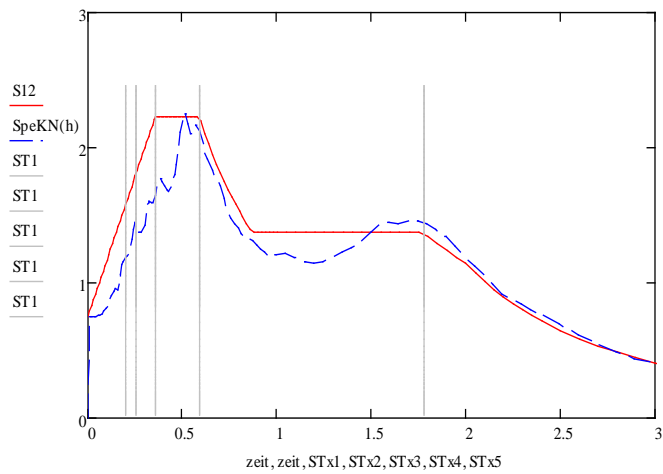
32.5m ($\xi_s = 10\%$)



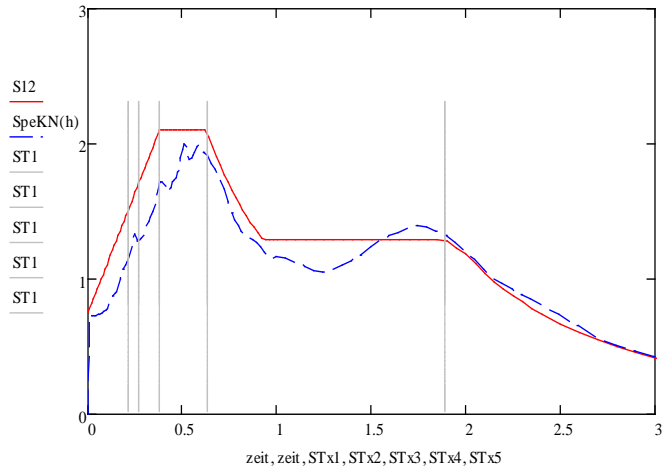
35m ($\xi_s=10\%$)



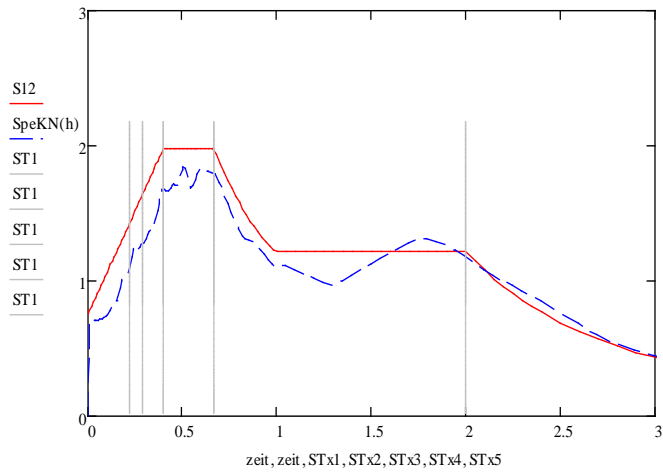
37.5m ($\xi_s=10\%$)



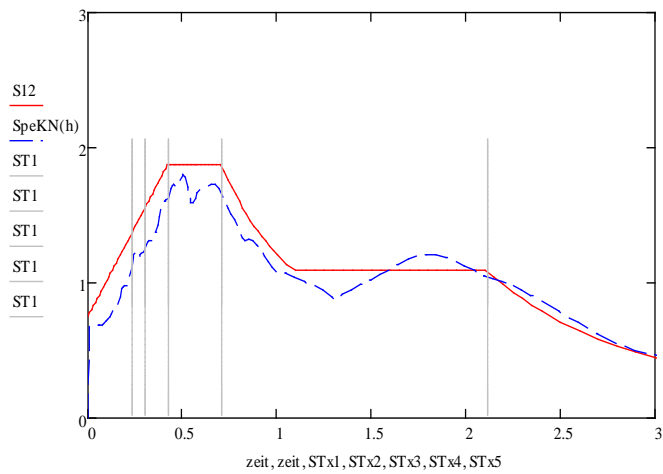
40m ($\xi_s=10\%$)



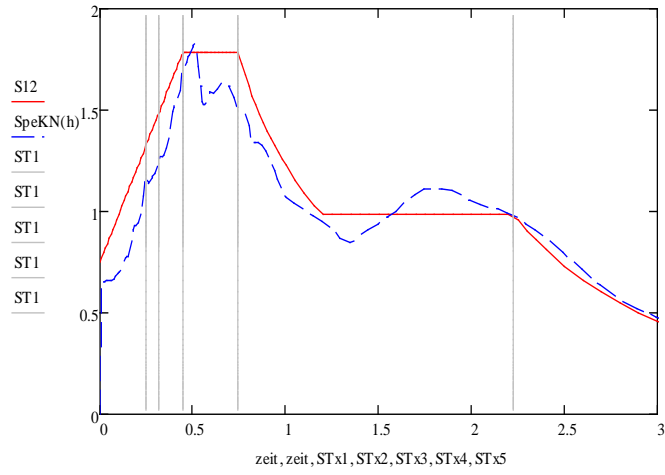
42.5m ($\xi_s = 10\%$)



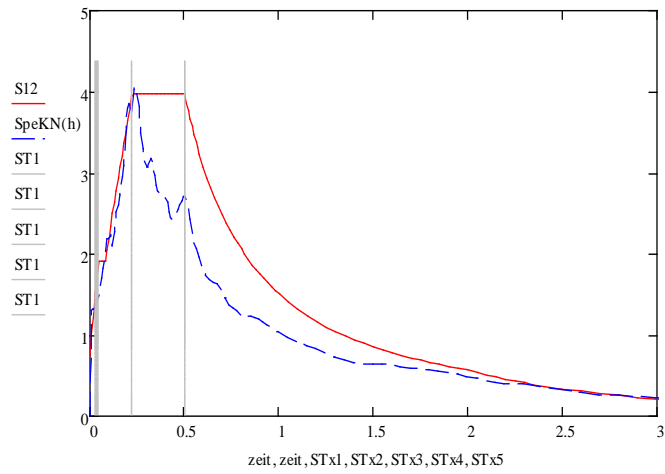
45m ($\xi_s = 10\%$)



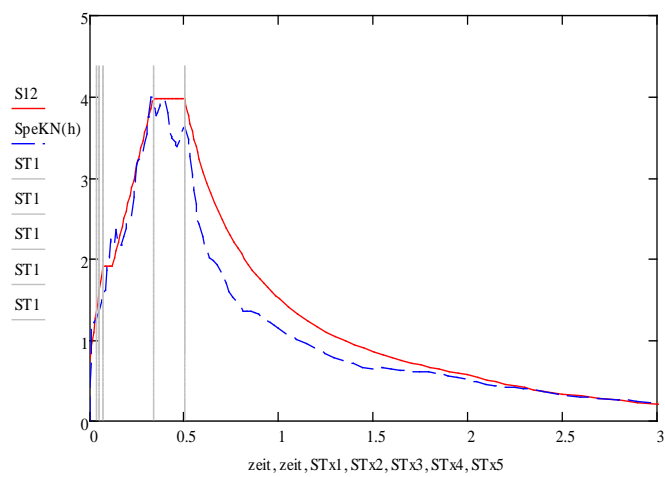
47.5m ($\xi_s = 10\%$)



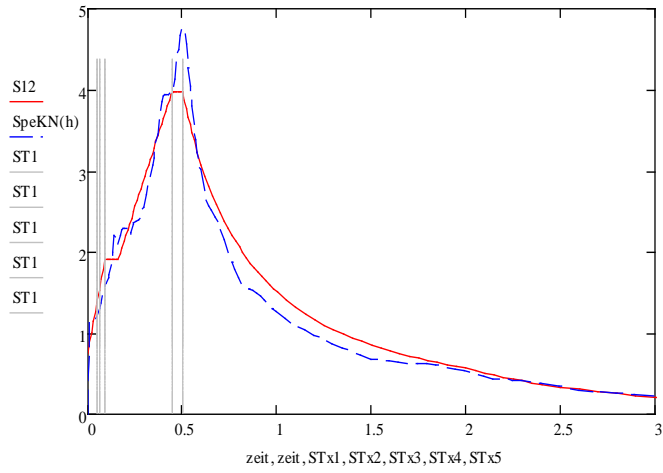
50m ($\xi_S = 10\%$)



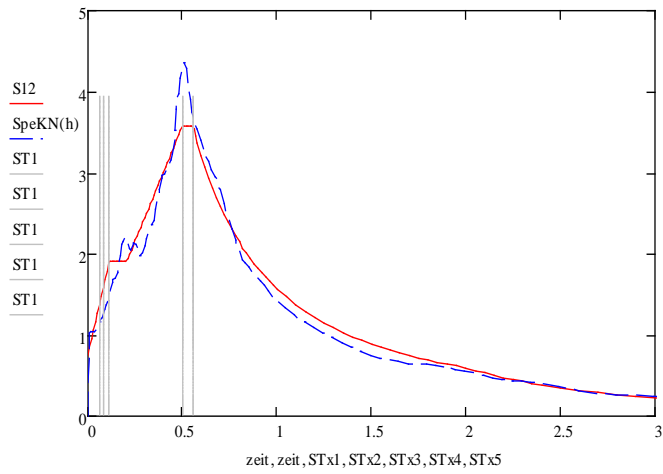
5m ($\xi_S = 15\%$)



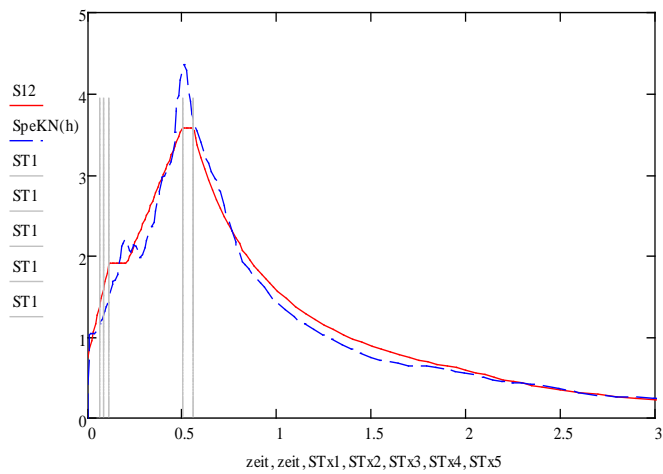
7.5m ($\xi_S = 15\%$)



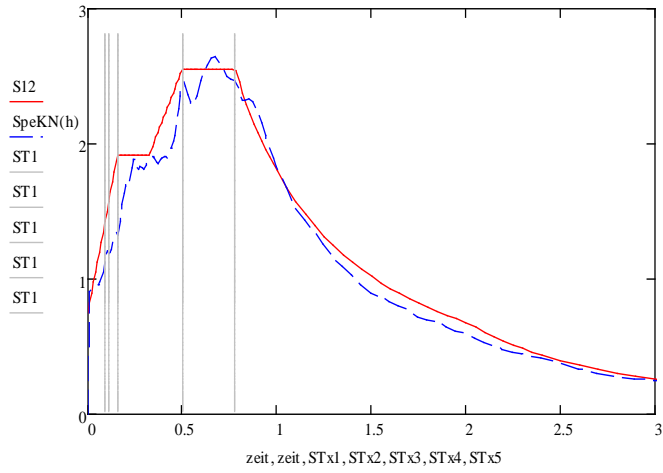
10m ($\xi_S = 15\%$)



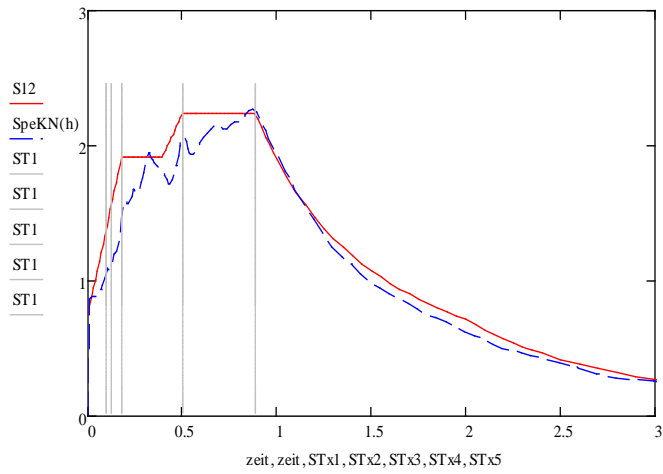
12.5m ($\xi_S = 15\%$)



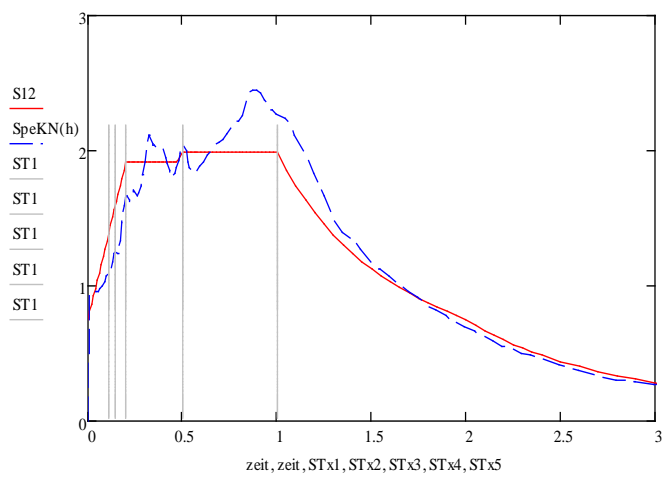
15m ($\xi_S = 15\%$)



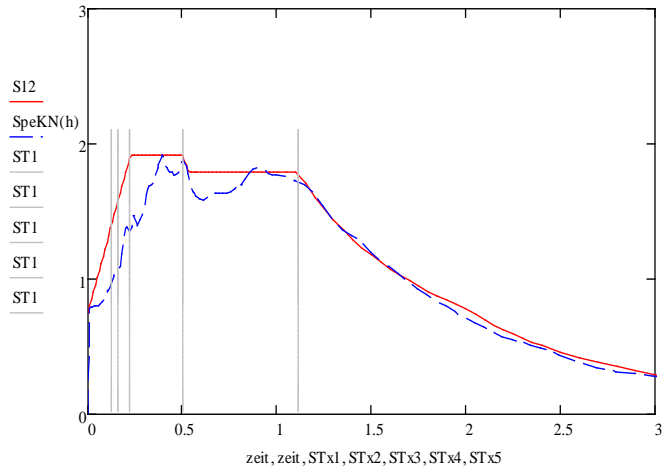
17.5m ($\xi_s= 15\%$)



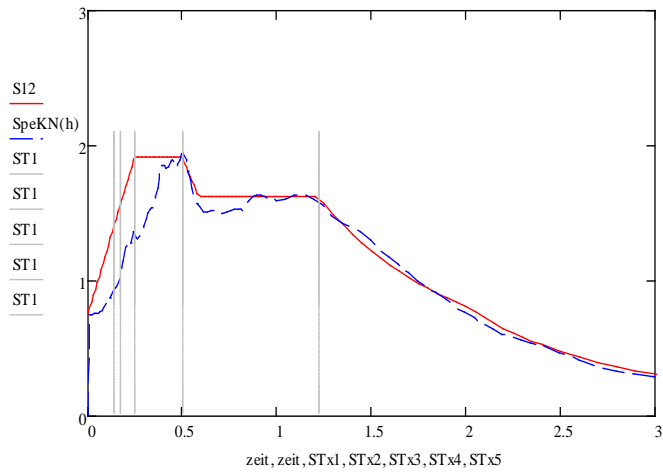
20m ($\xi_s= 15\%$)



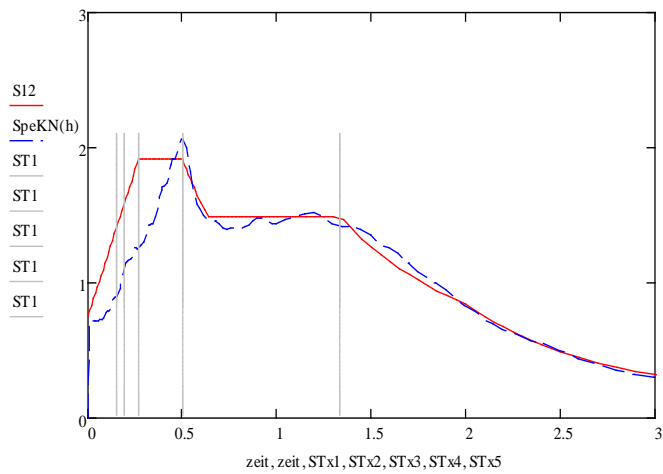
22.5m ($\xi_s= 15\%$)



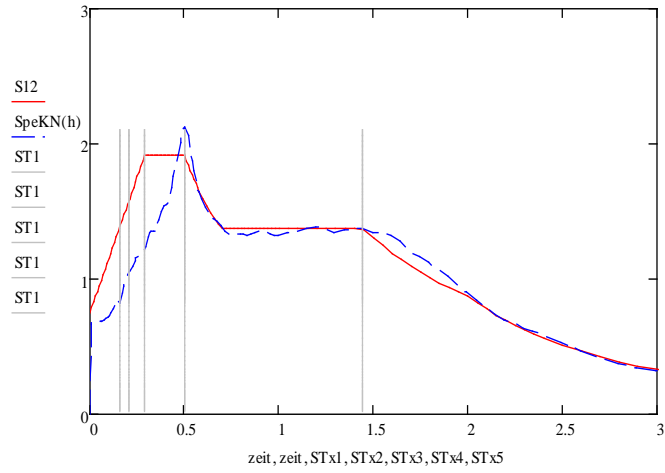
25m ($\xi_S = 15\%$)



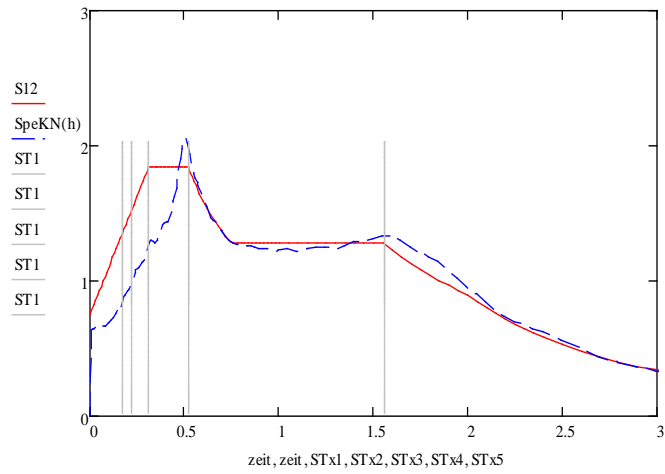
27.5m ($\xi_S = 15\%$)



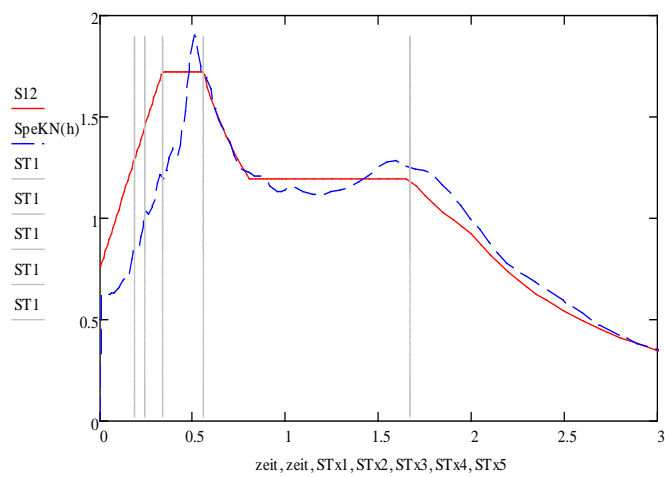
30m ($\xi_S = 15\%$)



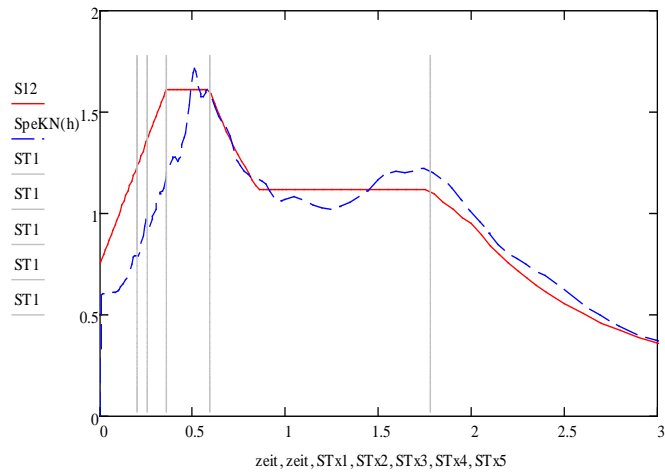
32.5m ($\xi_s = 15\%$)



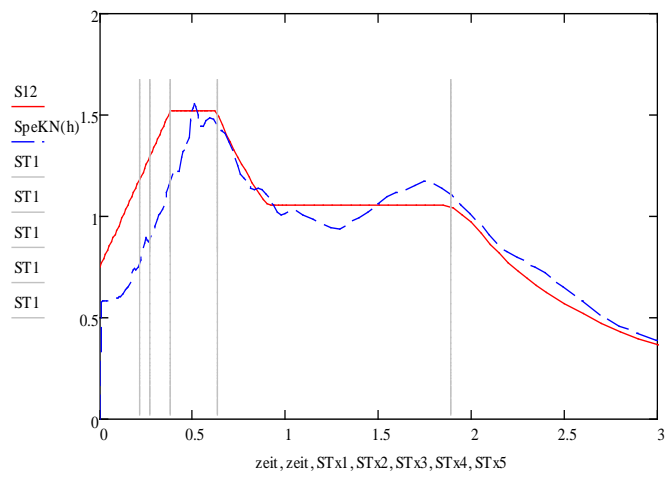
35m ($\xi_s = 15\%$)



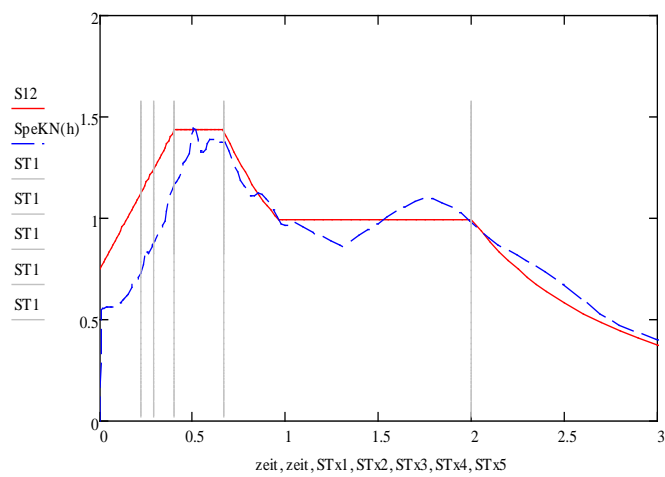
37.5m ($\xi_s = 15\%$)



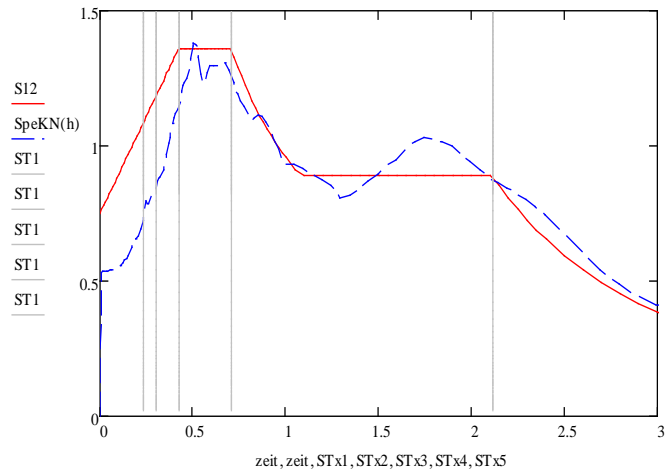
40m ($\xi_S = 15\%$)



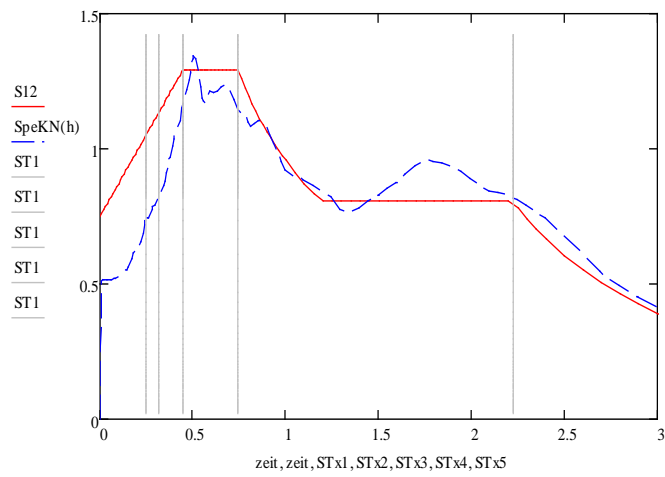
42.5m ($\xi_S = 15\%$)



45m ($\xi_S = 15\%$)

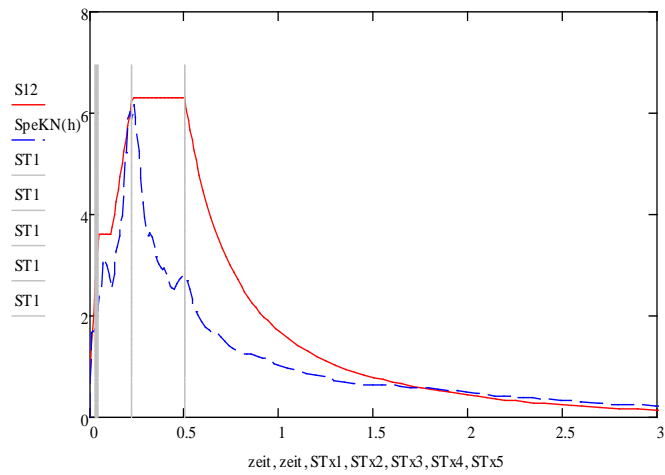


47.5m ($\xi_s = 15\%$)

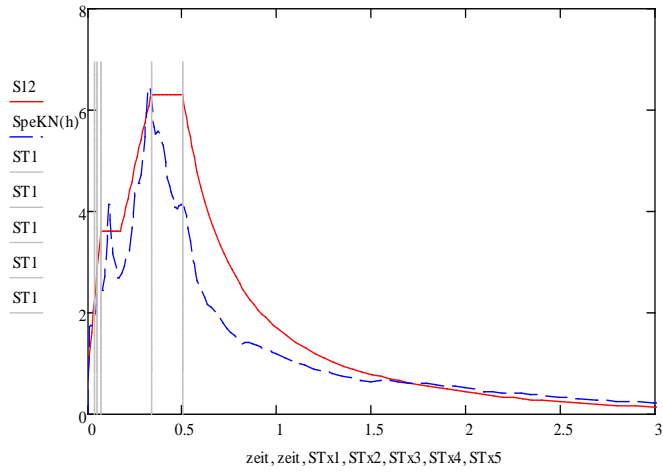


50m ($\xi_s = 15\%$)

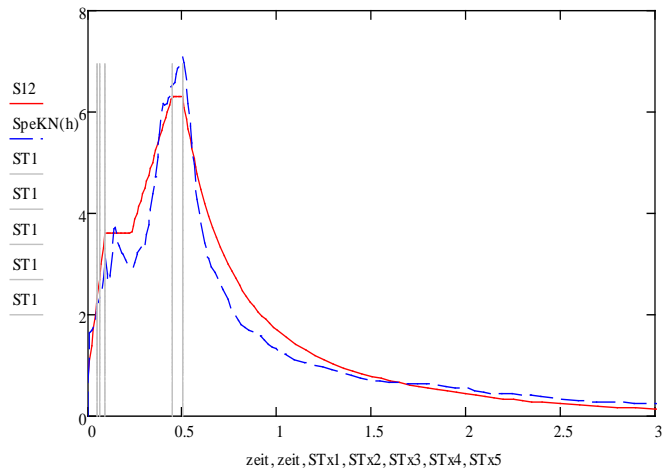
6.5.5 Bedrock shear wave velocity equal with 520 m/s



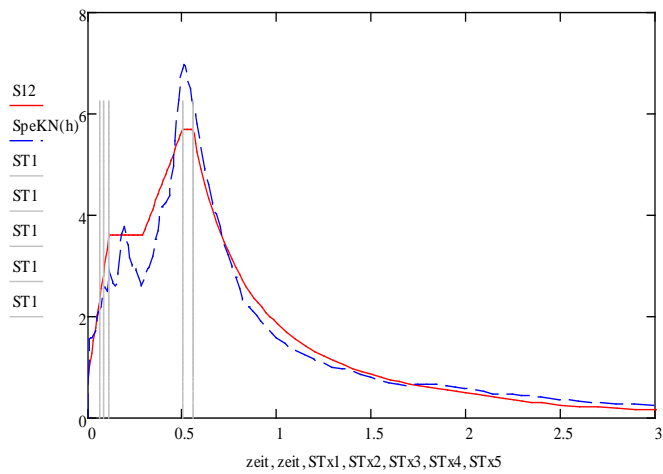
5m ($\xi_s = 5\%$)



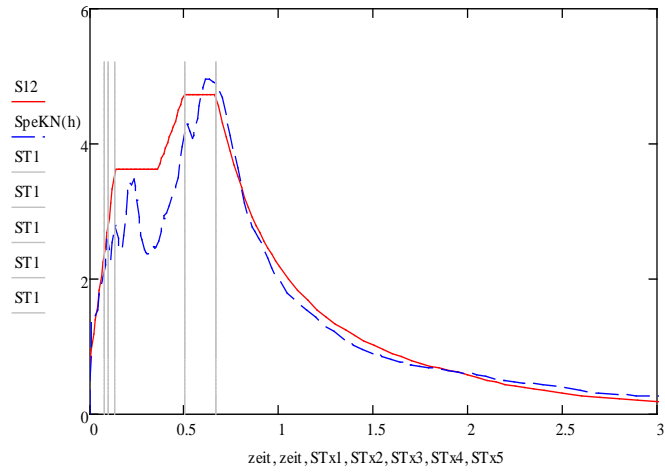
7.5m ($\xi_s= 5\%$)



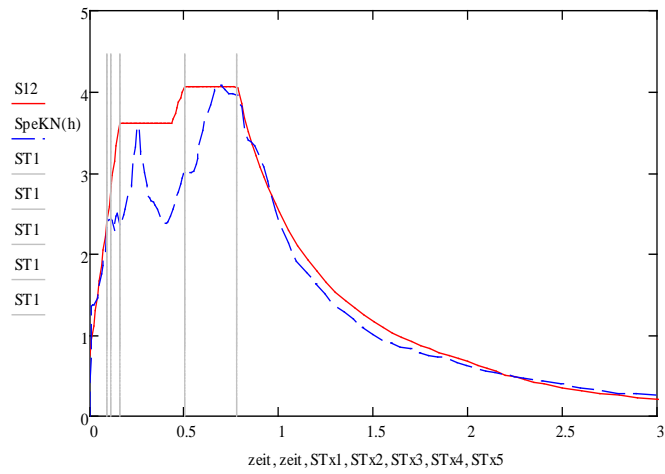
10m ($\xi_s= 5\%$)



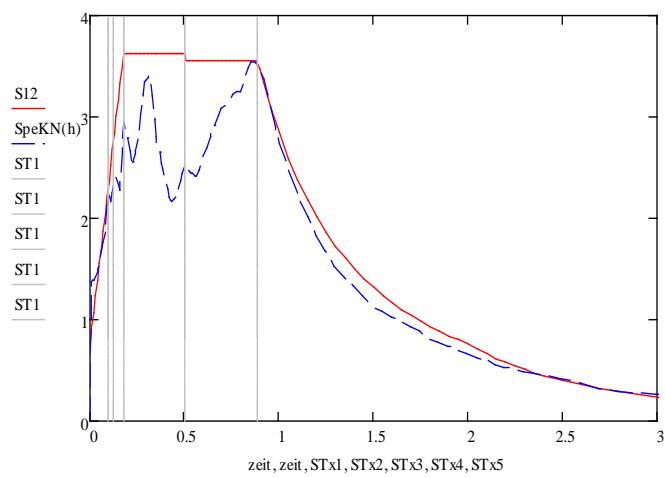
12.5m ($\xi_s= 5\%$)



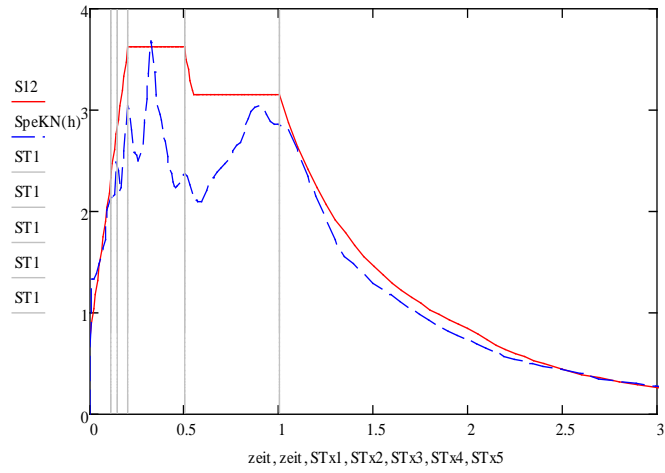
15m ($\xi_s = 5\%$)



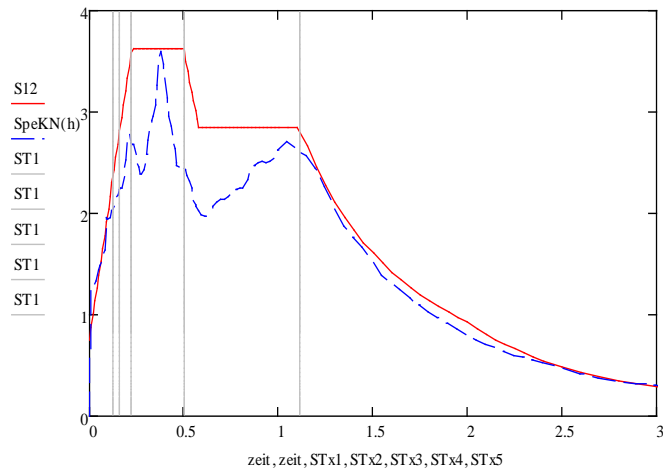
17.5m ($\xi_s = 5\%$)



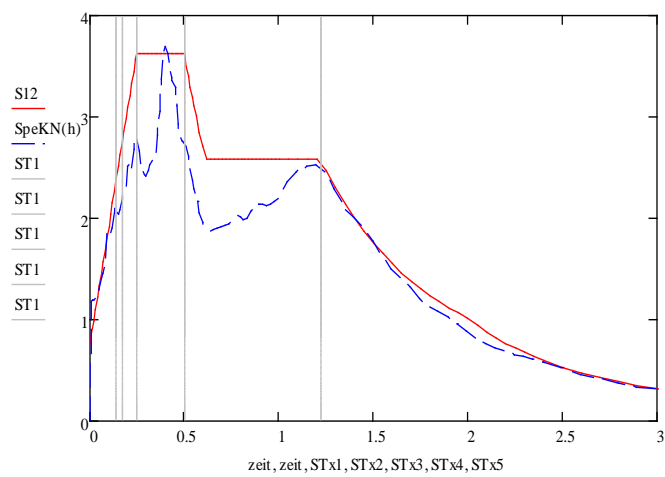
20m ($\xi_s = 5\%$)



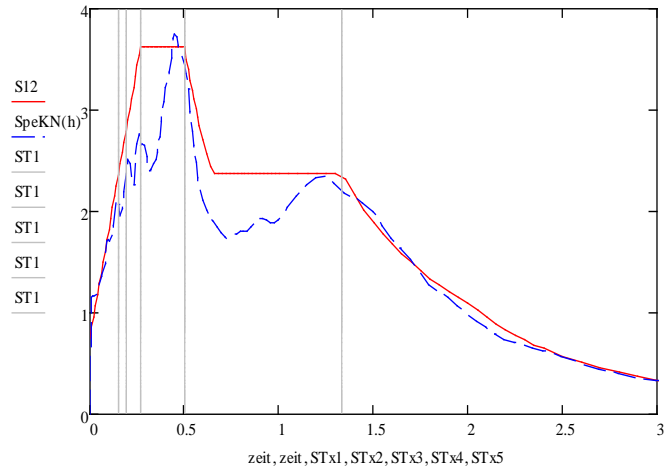
22.5m ($\xi_s = 5\%$)



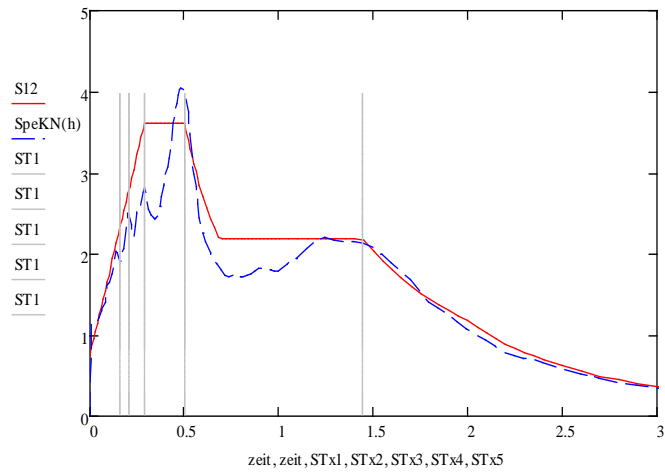
25m ($\xi_s = 5\%$)



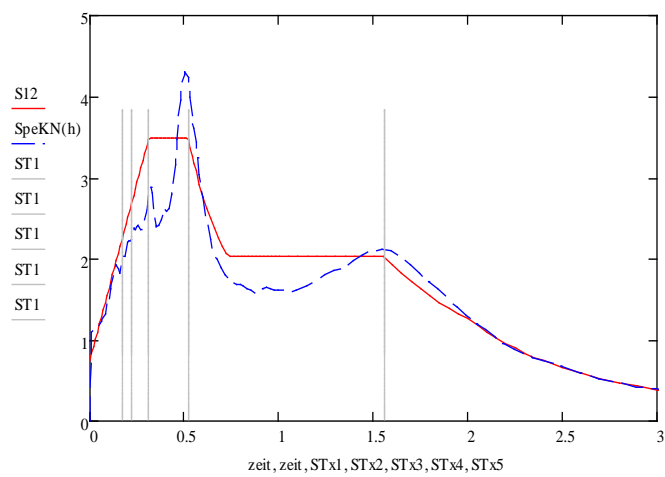
27.5m ($\xi_s = 5\%$)



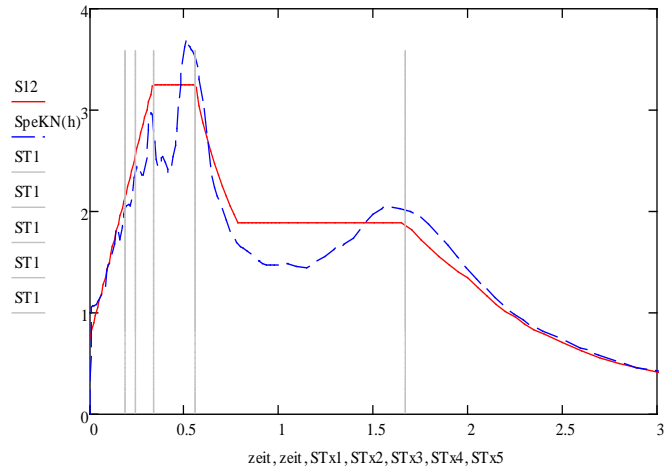
30m ($\xi_s = 5\%$)



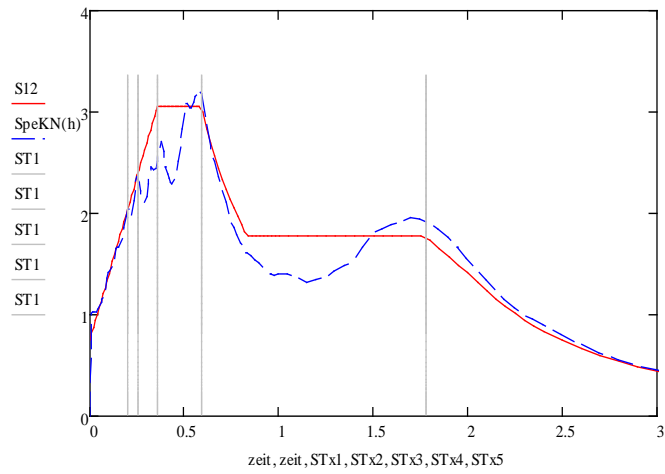
32.5m ($\xi_s = 5\%$)



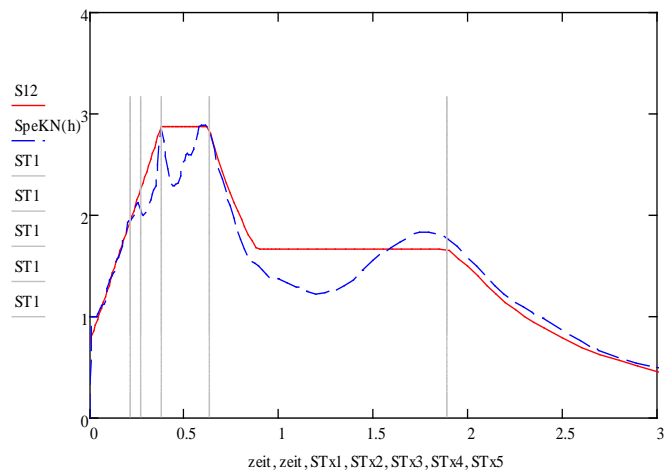
35m ($\xi_s = 5\%$)



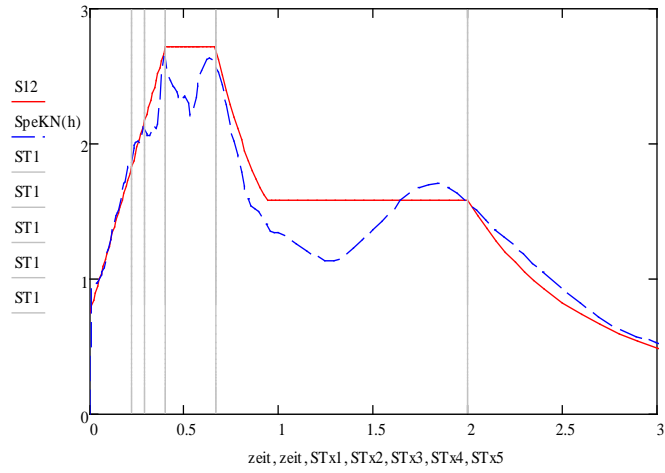
37.5m ($\xi_s = 5\%$)



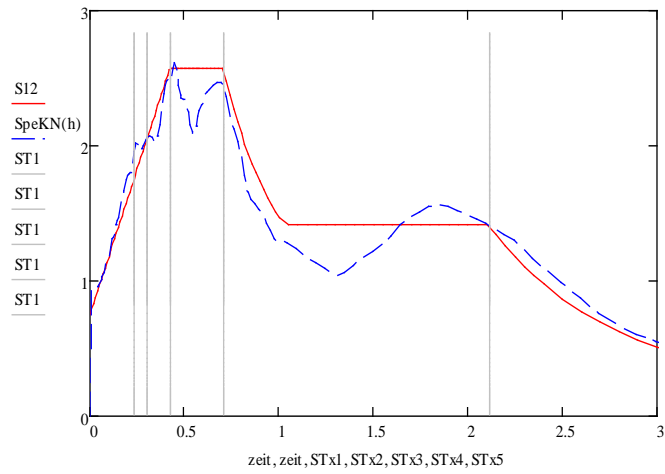
40m ($\xi_s = 5\%$)



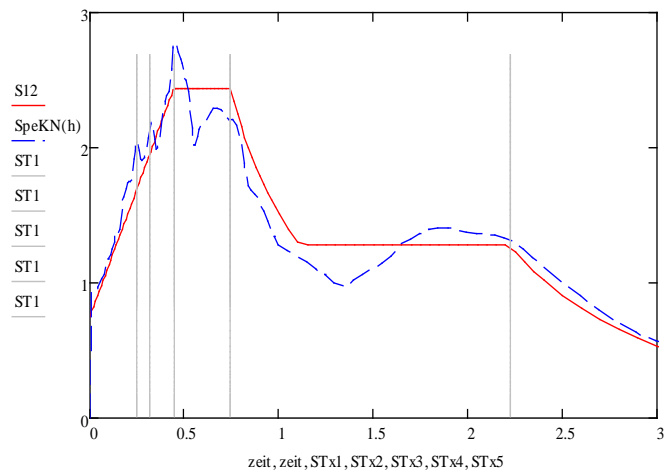
42.5m ($\xi_s = 5\%$)



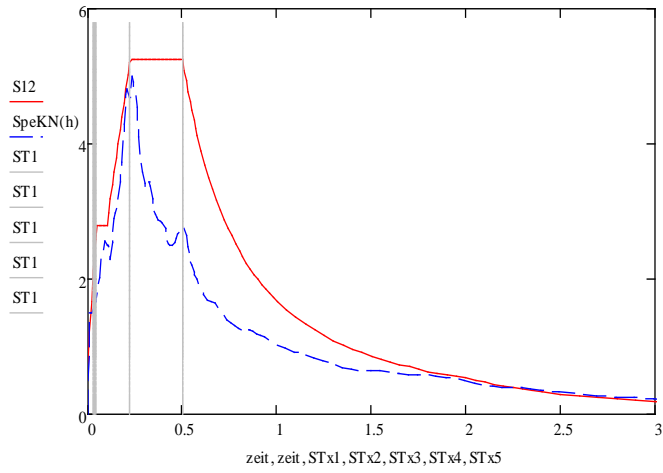
45m ($\xi_s = 5\%$)



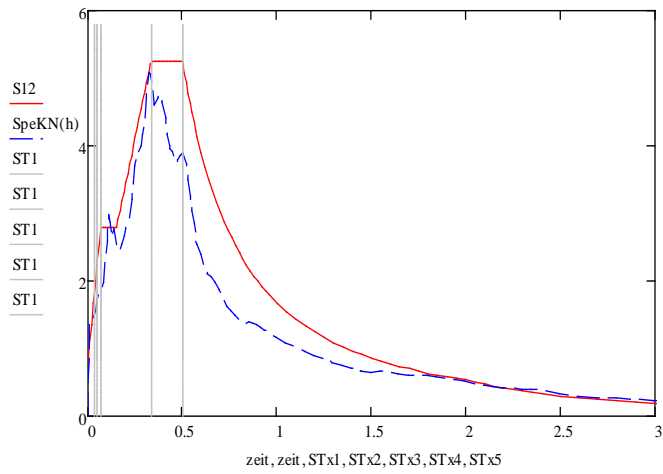
47.5m ($\xi_s = 5\%$)



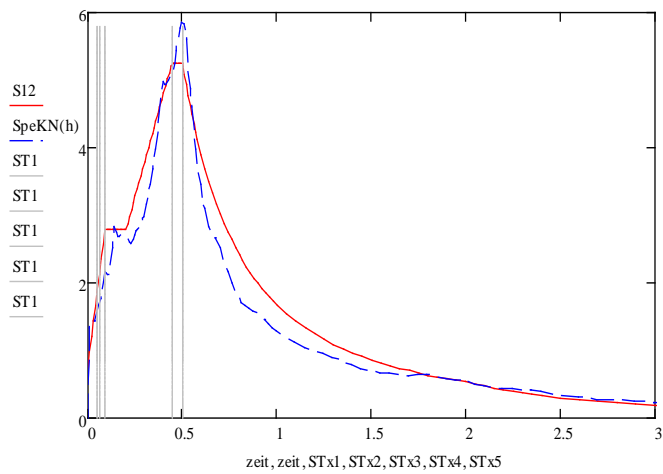
50m ($\xi_s = 5\%$)



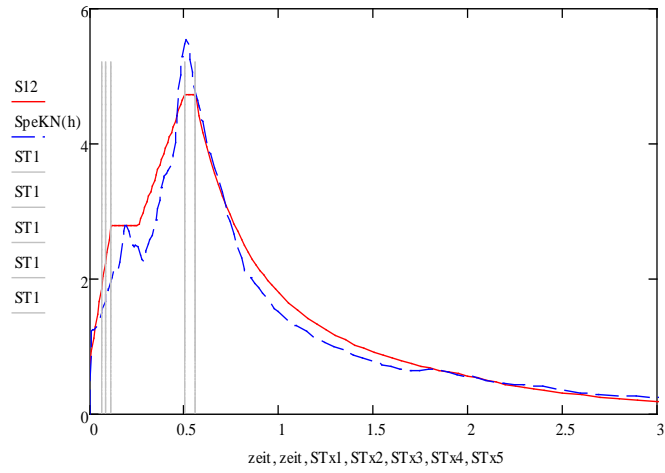
5m ($\xi_s = 10\%$)



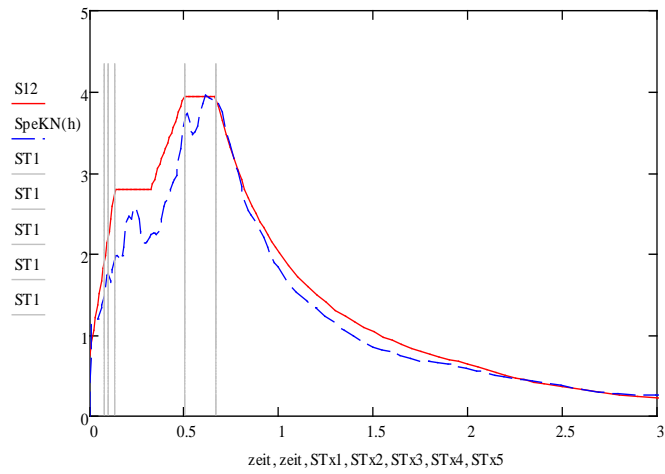
7.5m ($\xi_s = 10\%$)



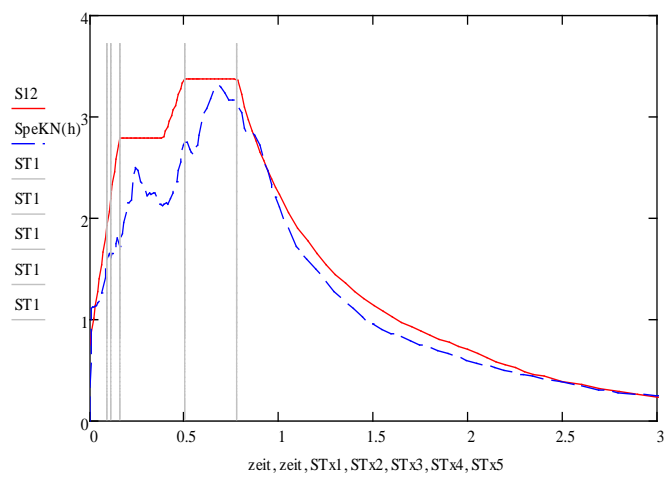
10m ($\xi_s = 10\%$)



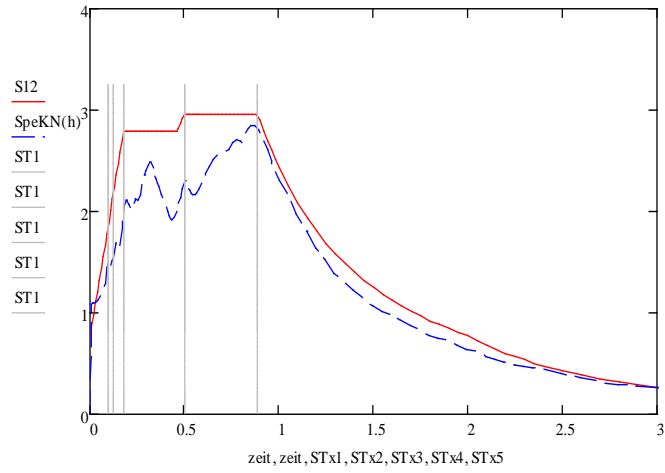
12.5m ($\xi_S= 10\%$)



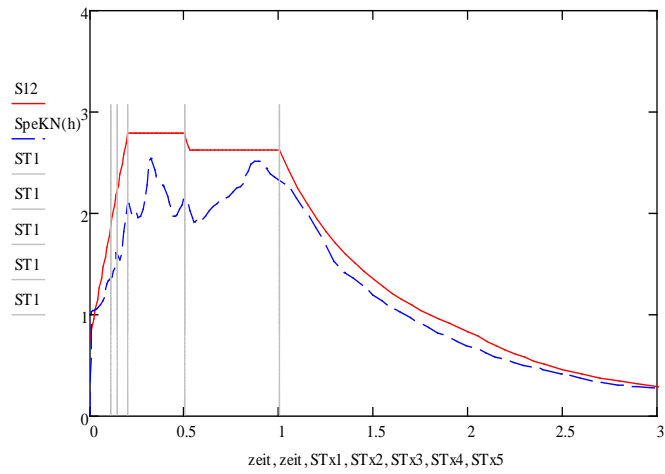
15m ($\xi_S= 10\%$)



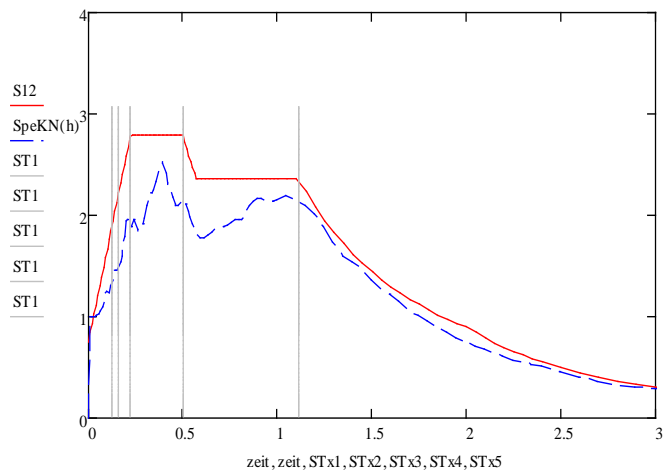
17.5m ($\xi_S= 10\%$)



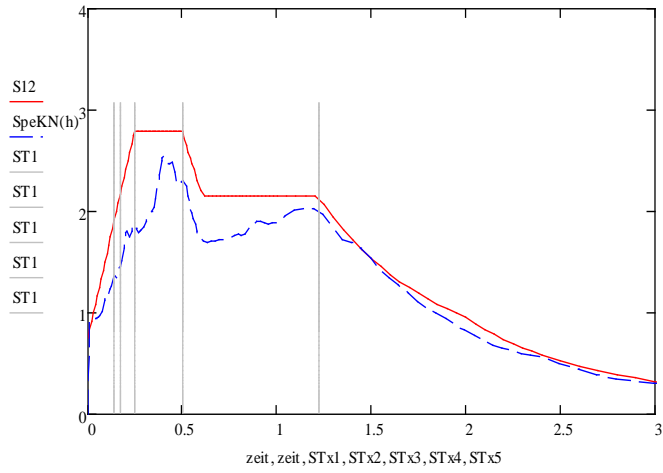
20m ($\xi_s = 10\%$)



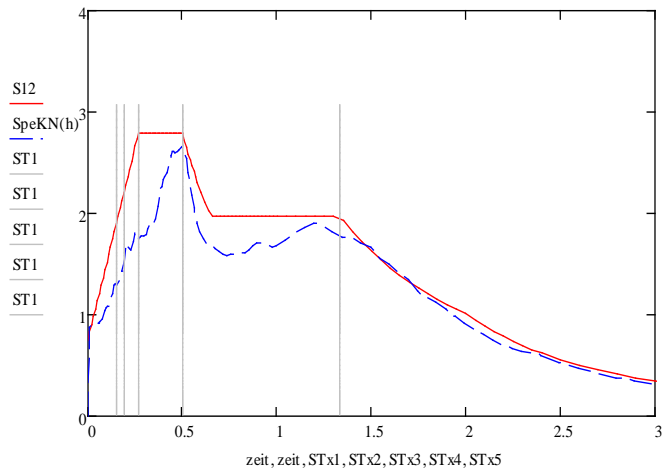
22.5m ($\xi_s = 10\%$)



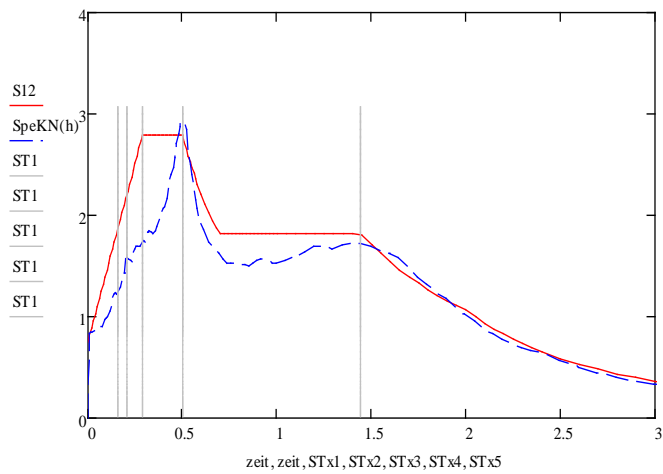
25m ($\xi_s = 10\%$)



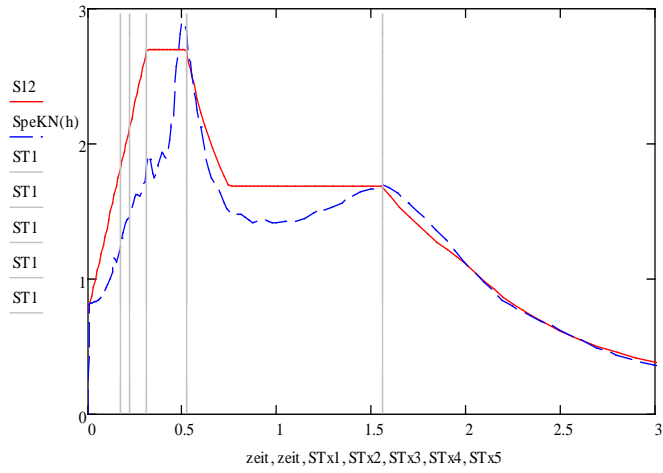
27.5m ($\xi_S=10\%$)



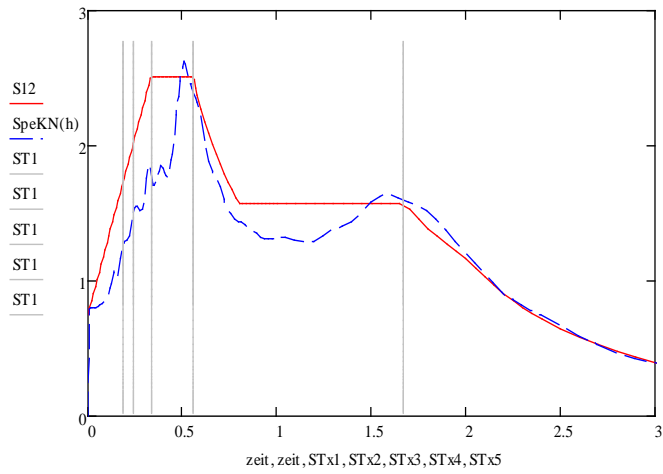
30m ($\xi_S=10\%$)



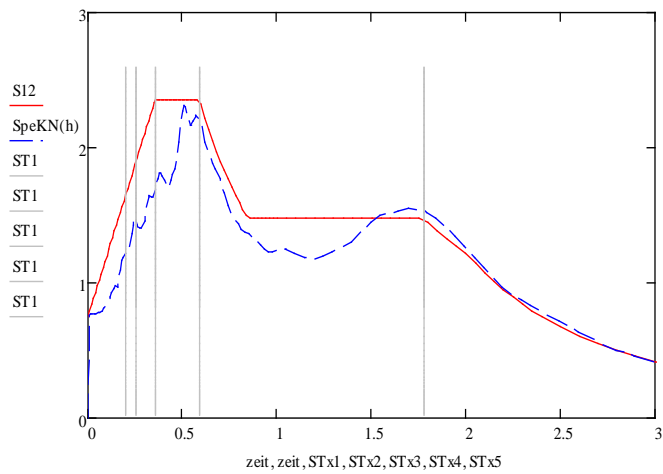
32.5m ($\xi_S=10\%$)



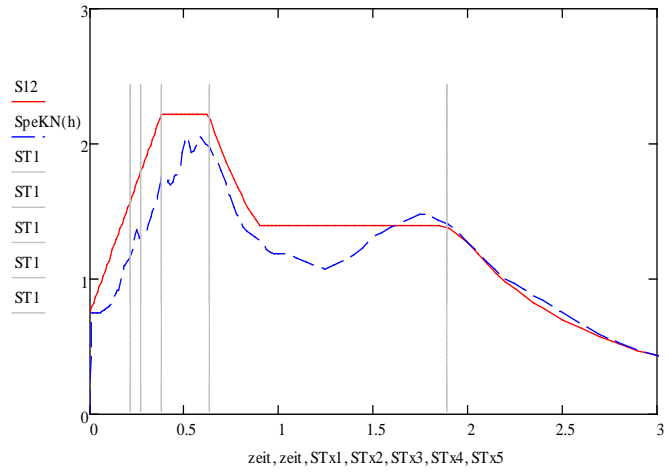
35m ($\xi_s=10\%$)



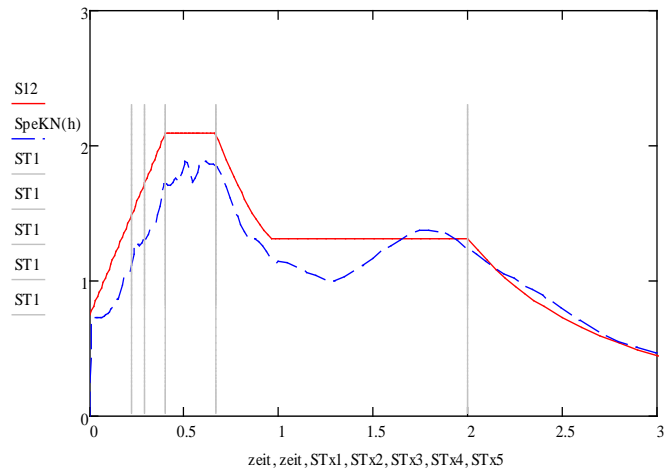
37.5m ($\xi_s=10\%$)



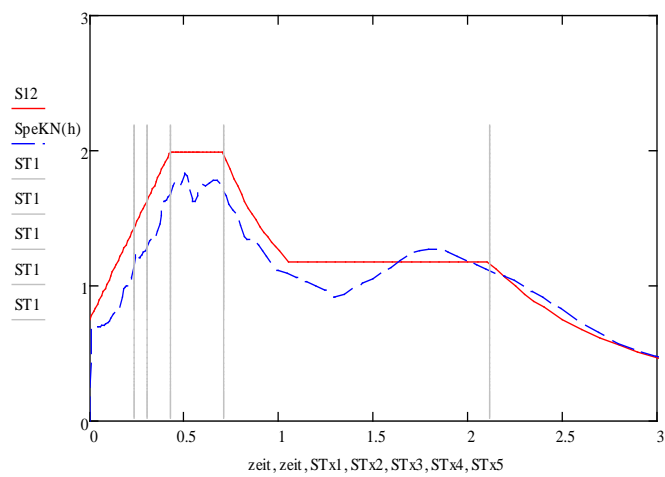
40m ($\xi_s=10\%$)



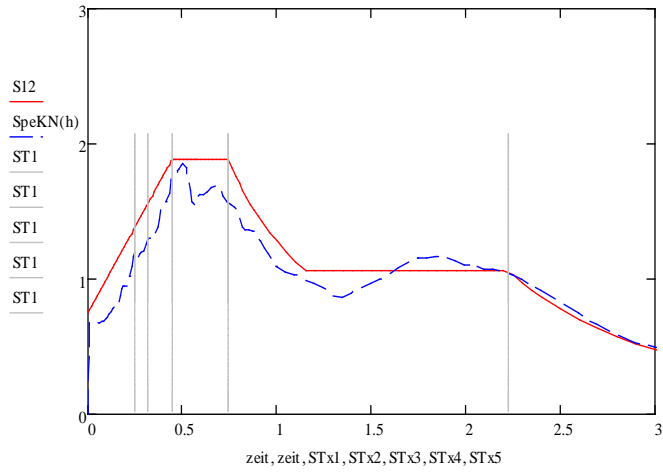
42.5m ($\xi_s = 10\%$)



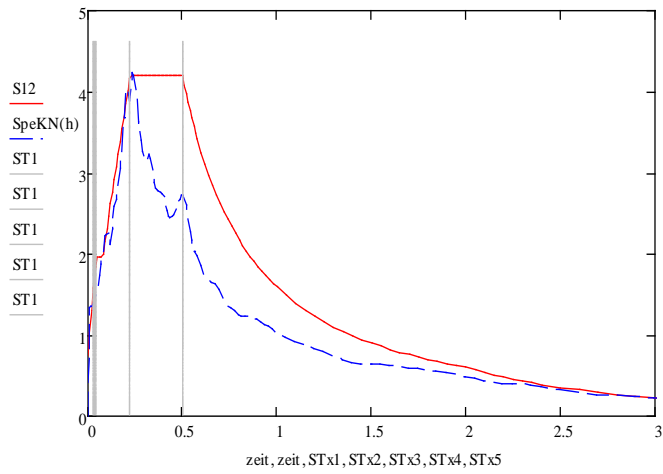
45m ($\xi_s = 10\%$)



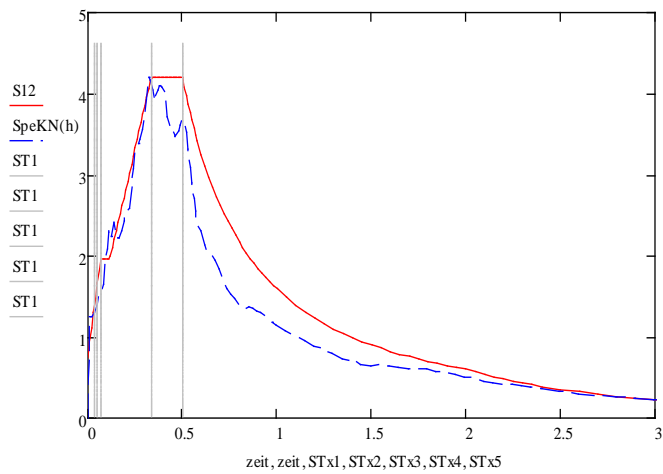
47.5m ($\xi_s = 10\%$)



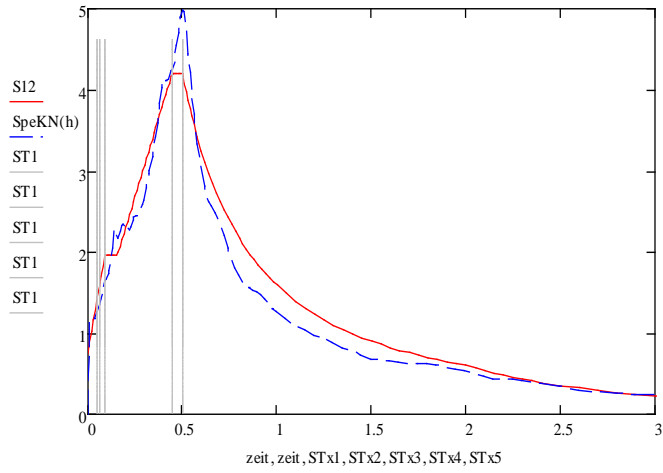
50m ($\xi_s = 10\%$)



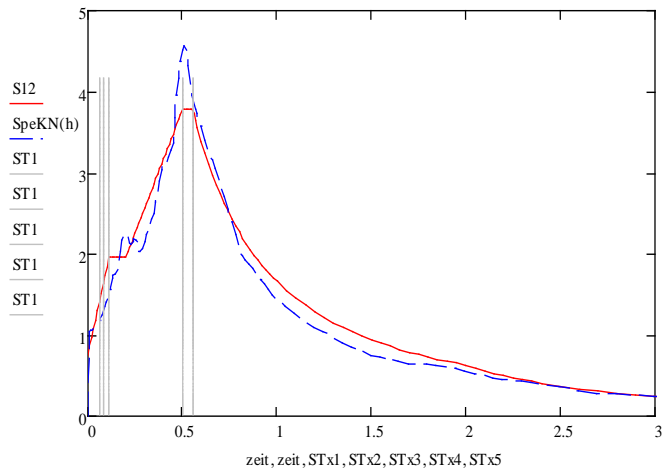
5m ($\xi_s = 15\%$)



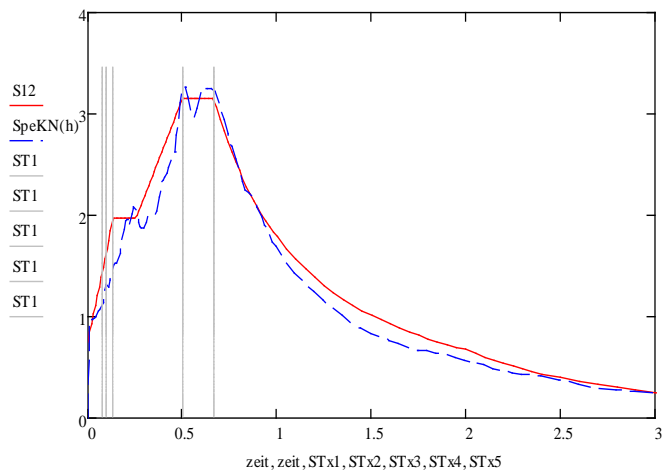
7.5m ($\xi_s = 15\%$)



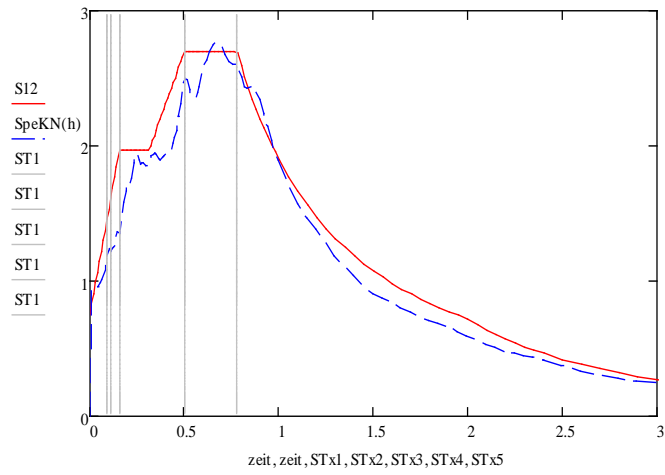
10m ($\xi_S = 15\%$)



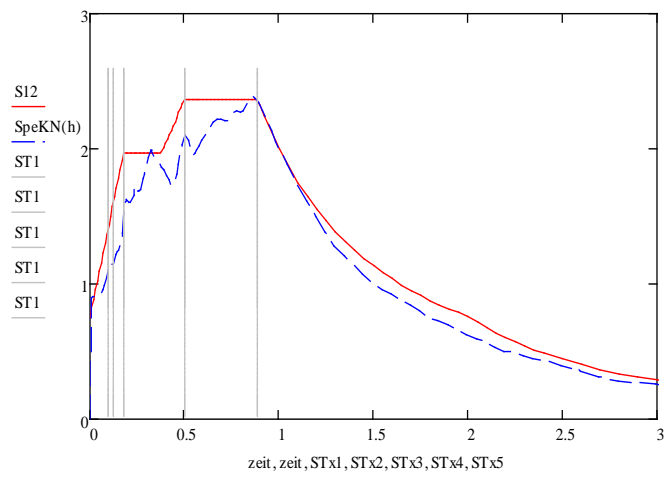
12.5m ($\xi_S = 15\%$)



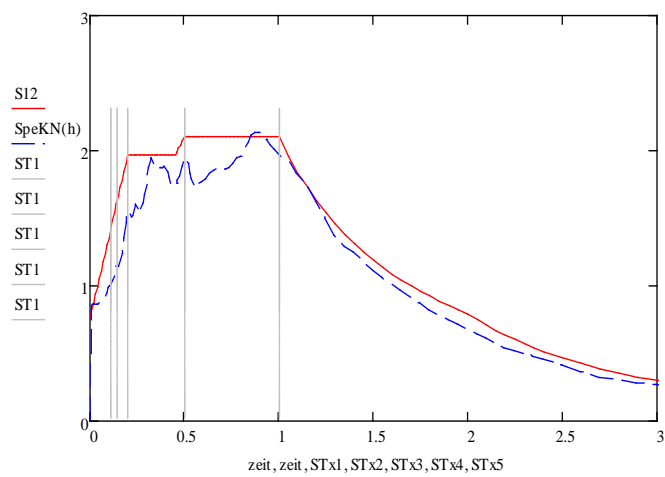
15m ($\xi_S = 15\%$)



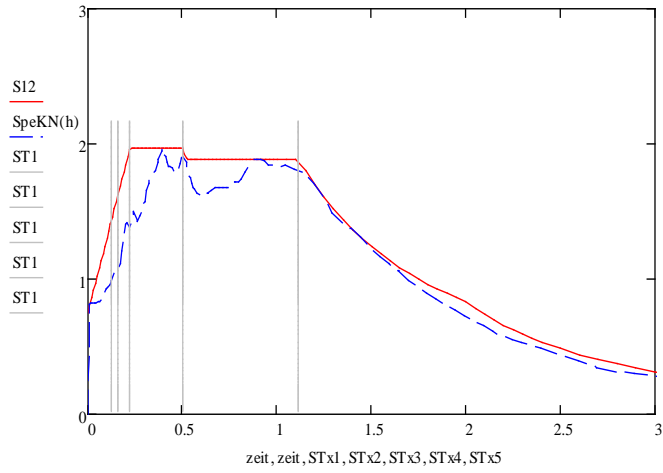
17.5m ($\xi_s = 15\%$)



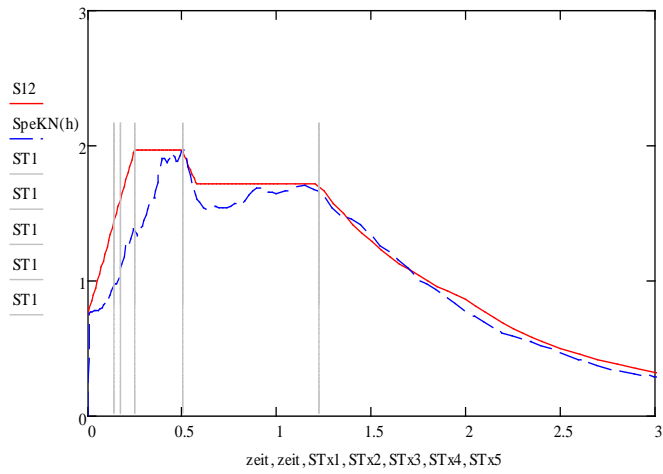
20m ($\xi_s = 15\%$)



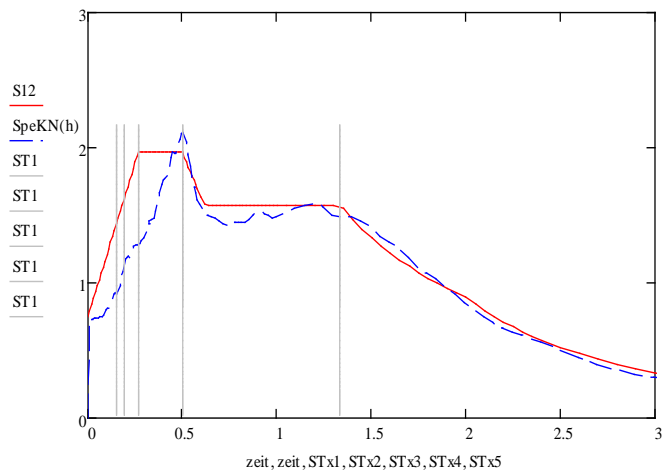
22.5m ($\xi_s = 15\%$)



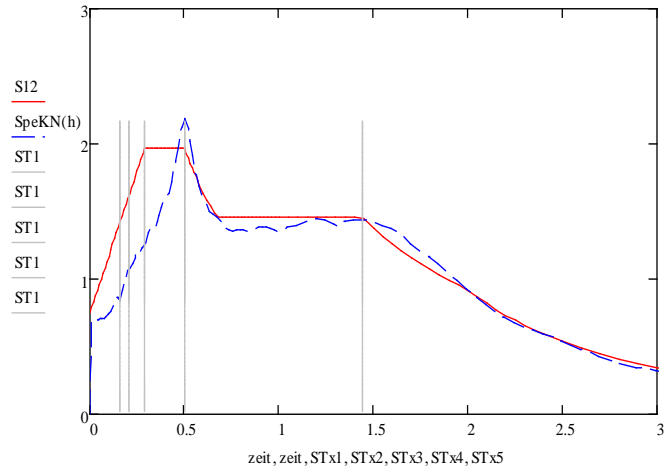
25m ($\xi_S = 15\%$)



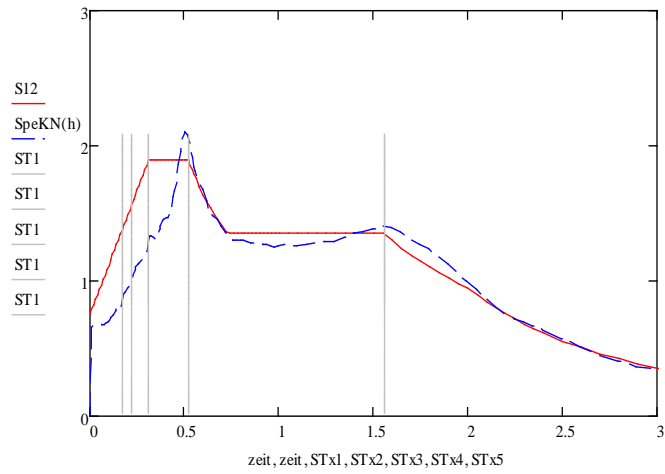
27.5m ($\xi_S = 15\%$)



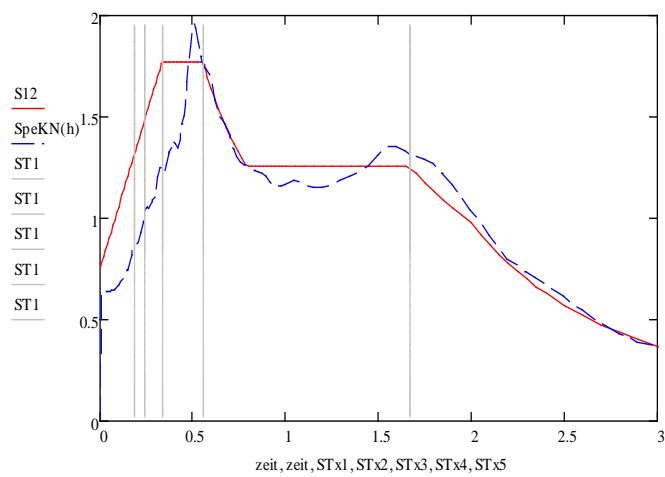
30m ($\xi_S = 15\%$)



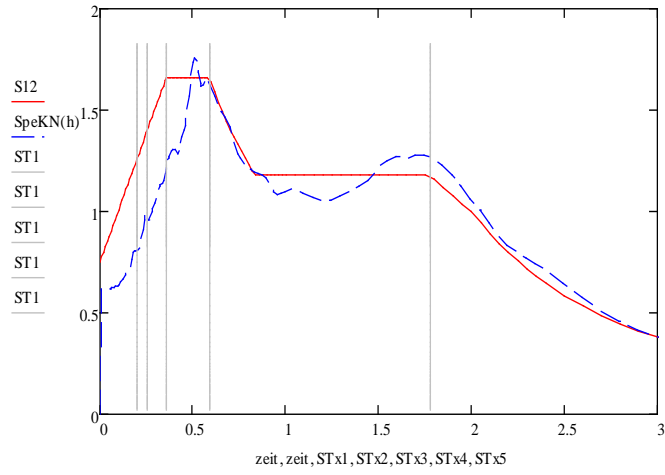
32.5m ($\xi_s = 15\%$)



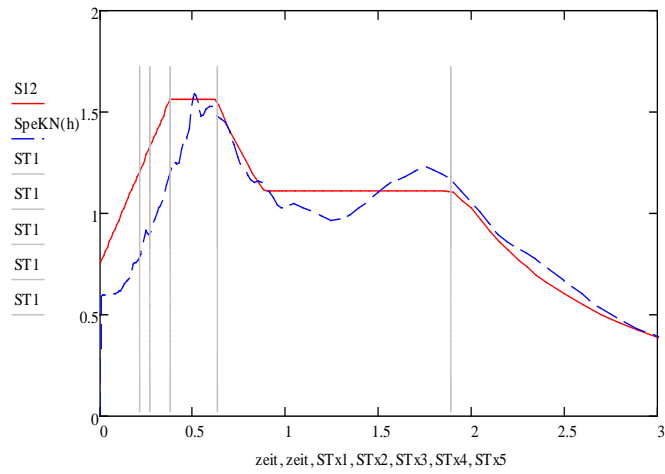
35m ($\xi_s = 15\%$)



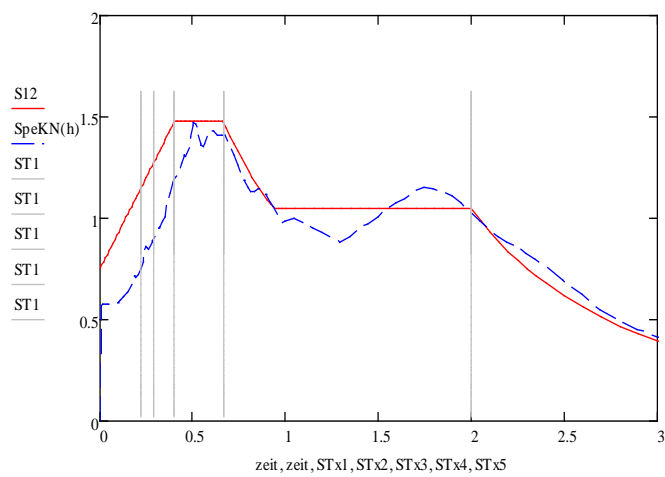
37.5m ($\xi_s = 15\%$)



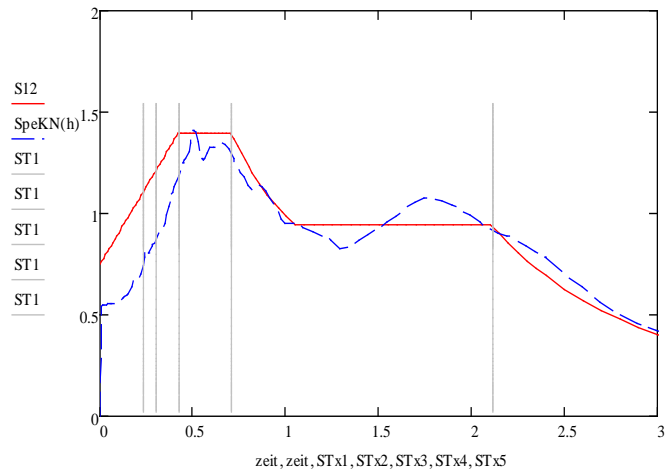
40m ($\xi_S = 15\%$)



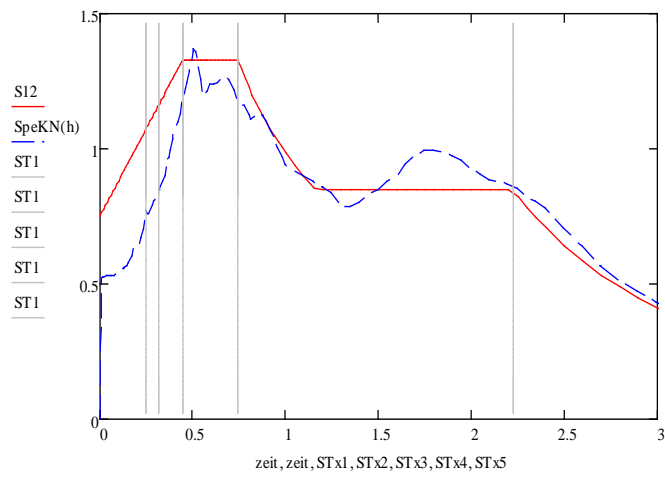
42.5m ($\xi_S = 15\%$)



45m ($\xi_S = 15\%$)

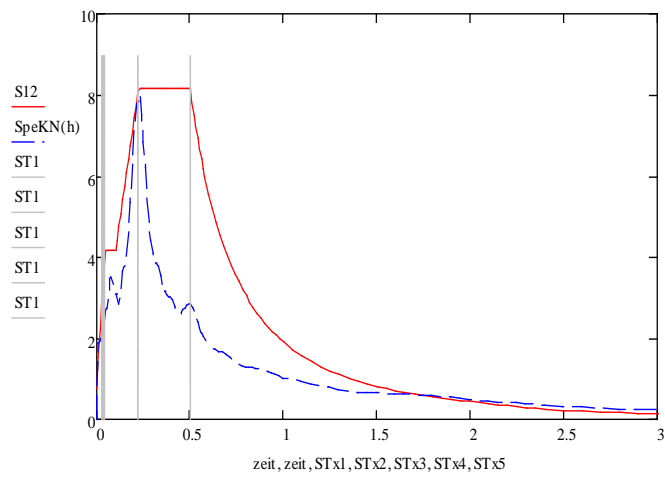


47.5m ($\xi_s = 15\%$)

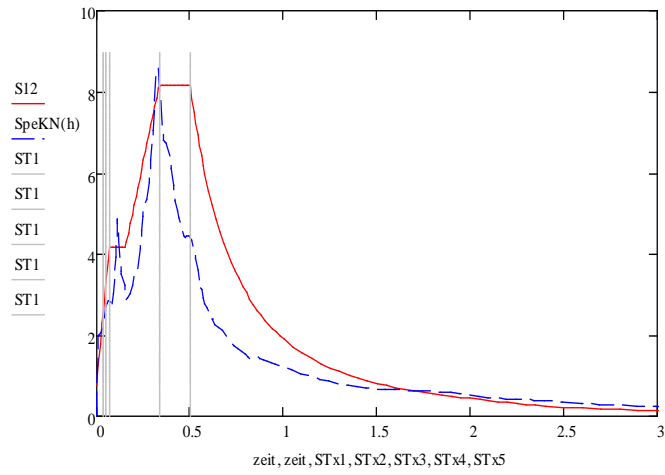


50m ($\xi_s = 15\%$)

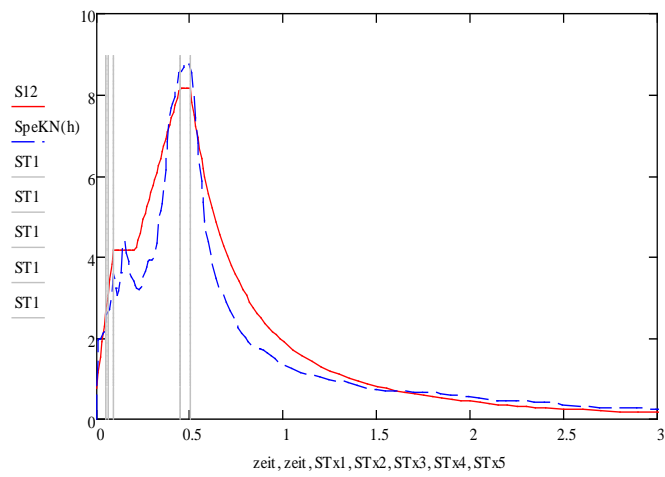
6.5.6 Bedrock shear wave velocity equal with 1000 m/s



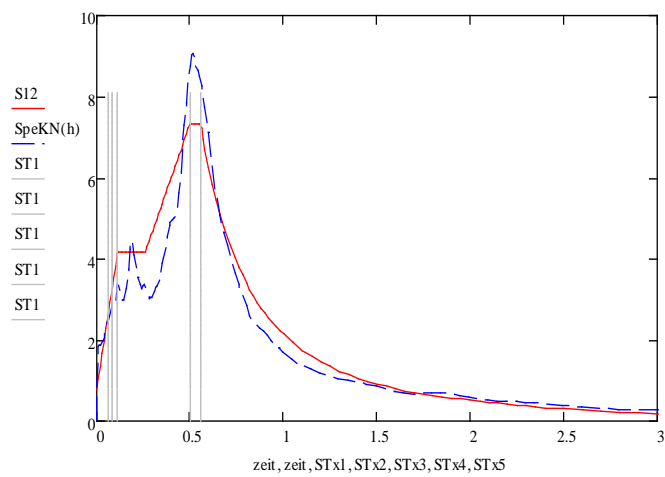
5m ($\xi_s = 5\%$)



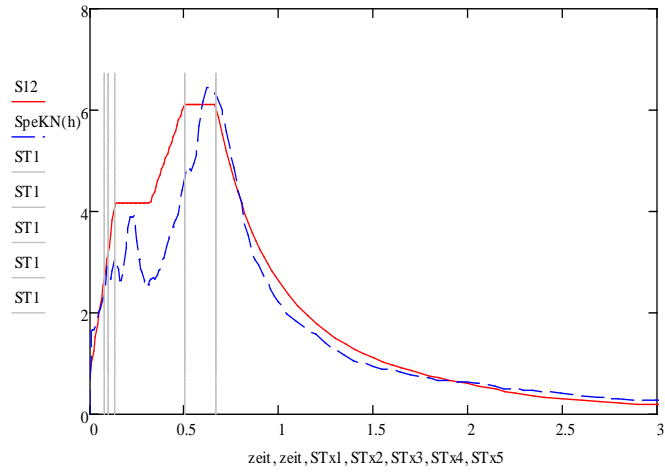
7.5m ($\xi_s = 5\%$)



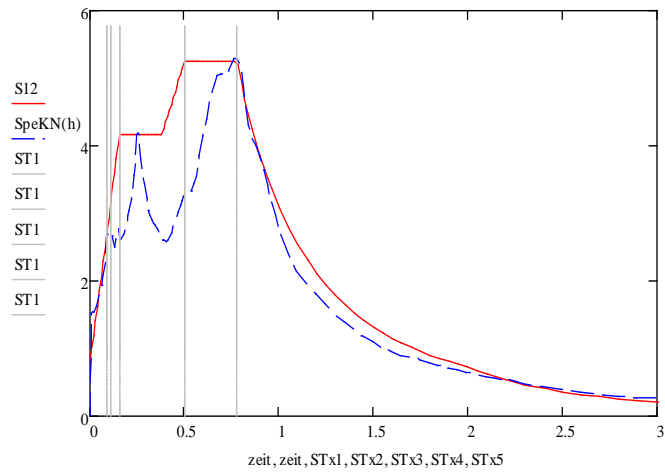
10m ($\xi_s = 5\%$)



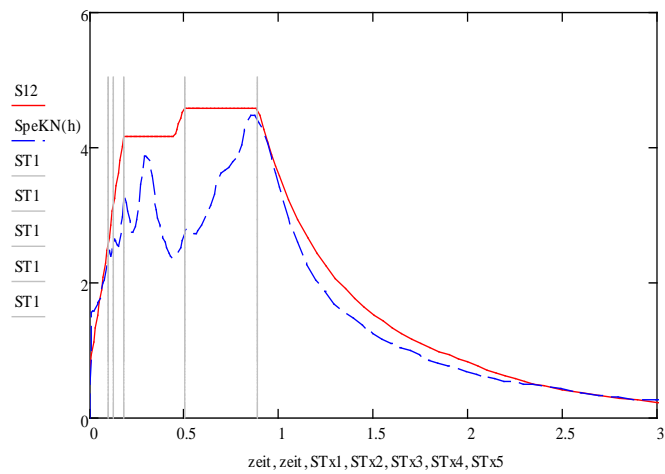
12.5m ($\xi_s = 5\%$)



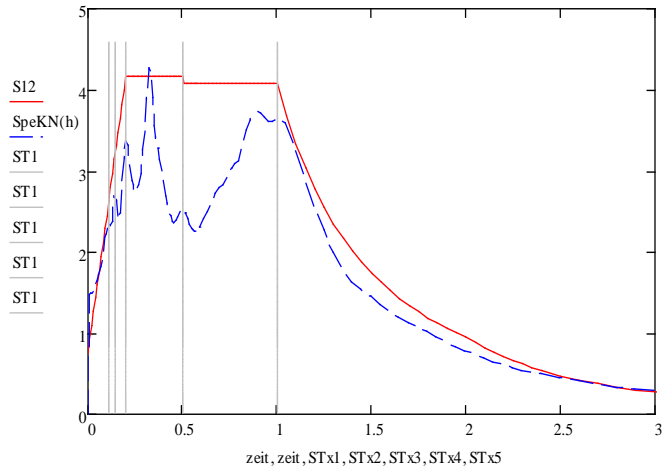
15m ($\xi_s = 5\%$)



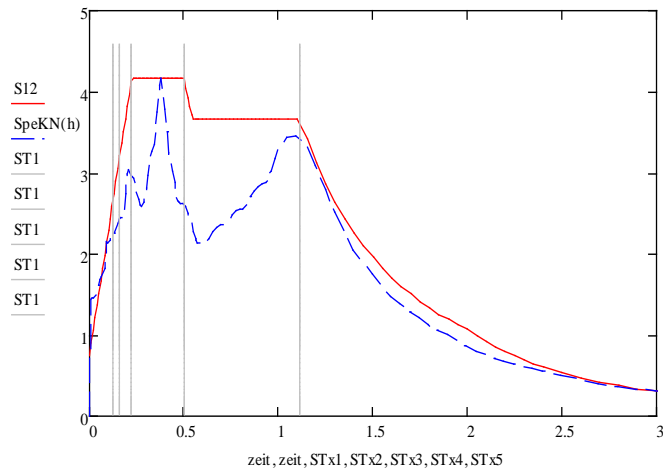
17.5m ($\xi_s = 5\%$)



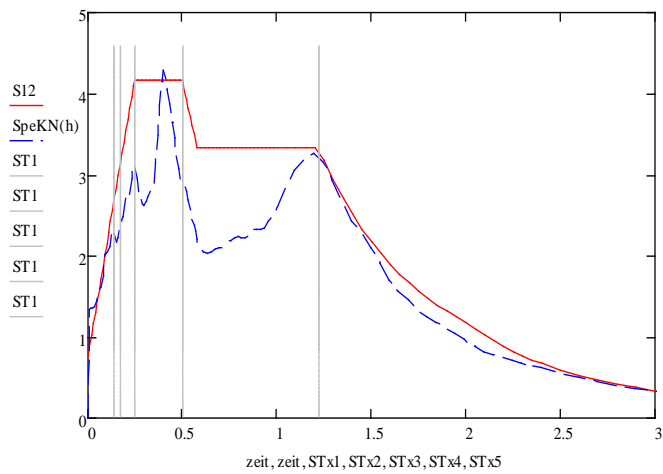
20m ($\xi_s = 5\%$)



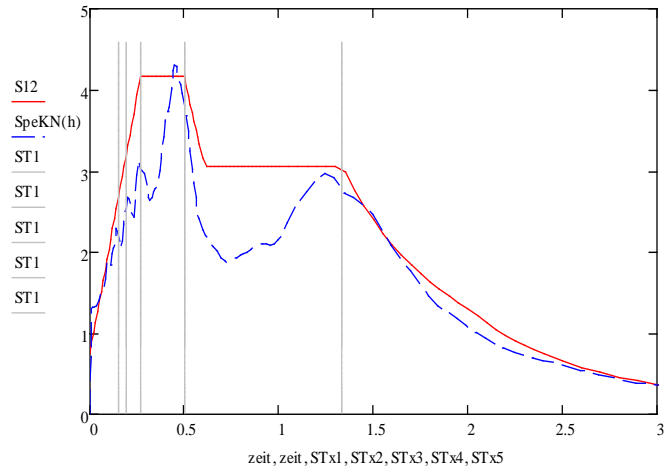
22.5m ($\xi_s = 5\%$)



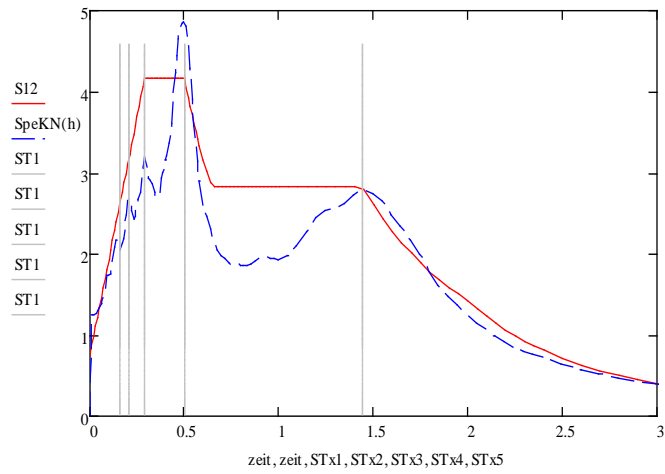
25m ($\xi_s = 5\%$)



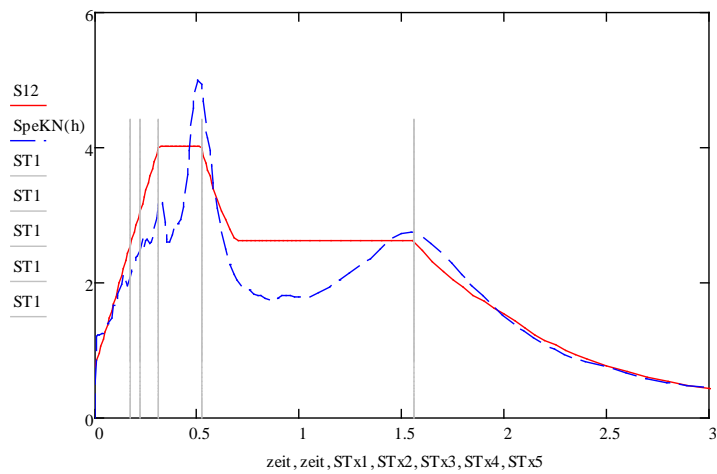
27.5m ($\xi_s = 5\%$)



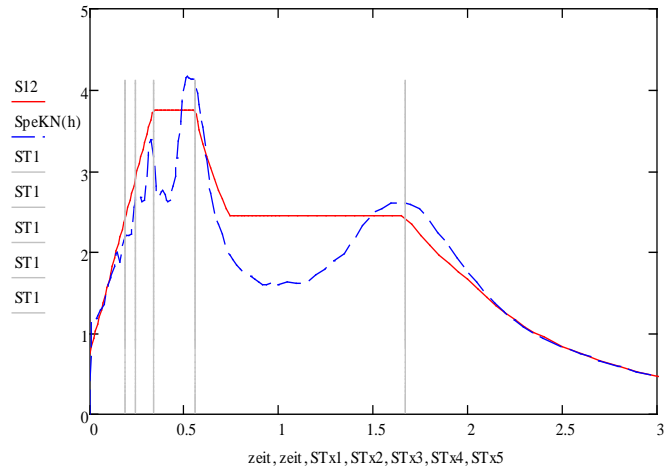
30m ($\xi_s = 5\%$)



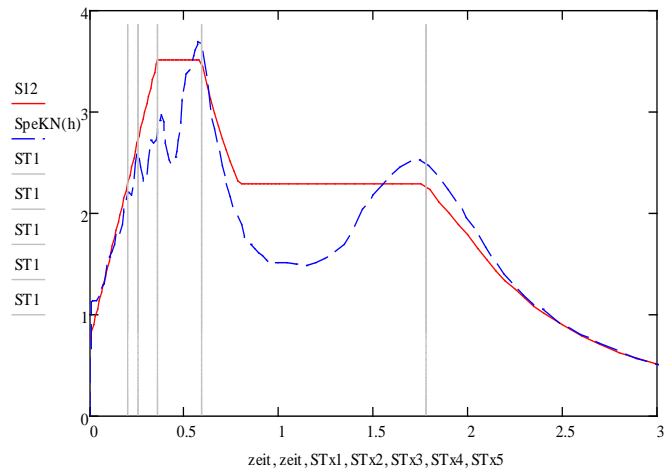
32.5m ($\xi_s = 5\%$)



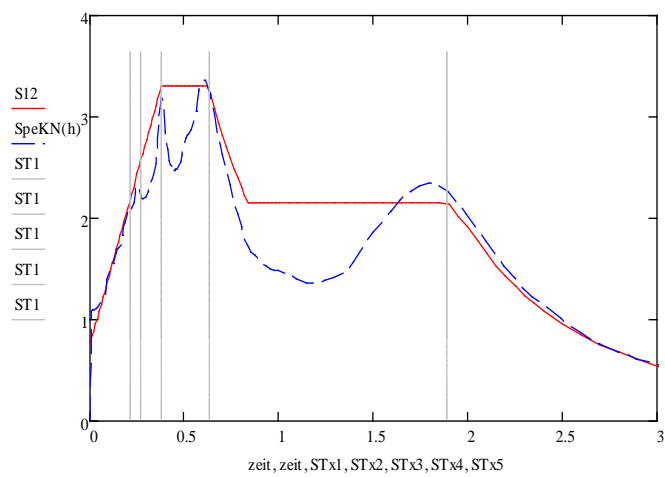
35m ($\xi_s = 5\%$)



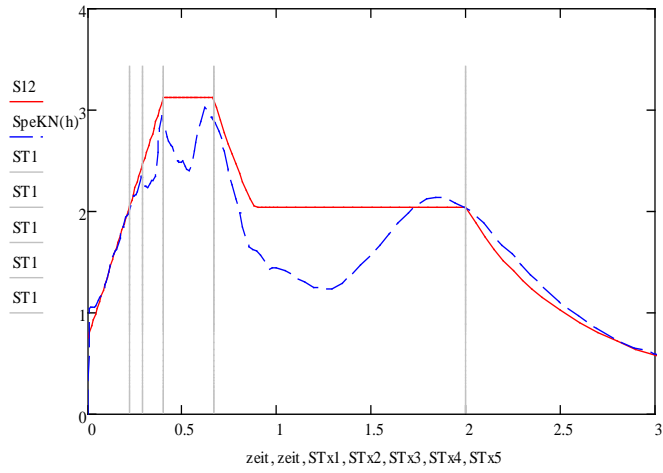
37.5m ($\xi_s = 5\%$)



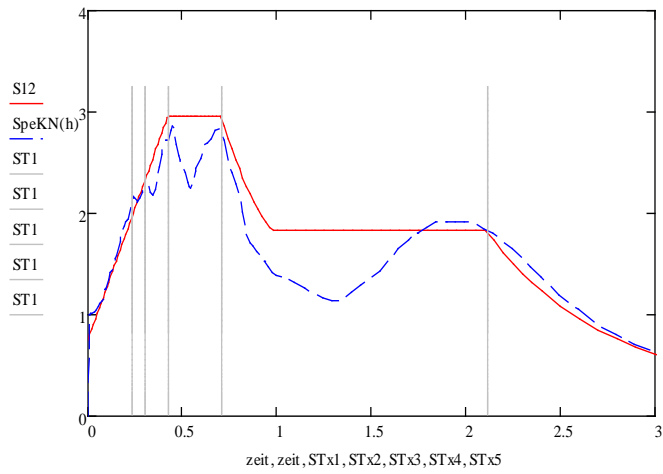
40m ($\xi_s = 5\%$)



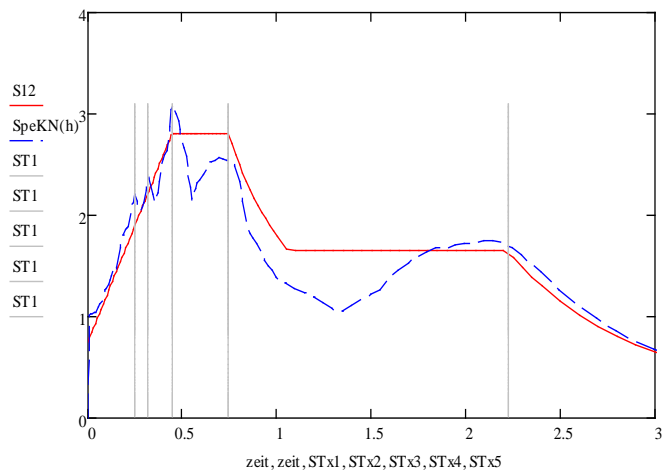
42.5m ($\xi_s = 5\%$)



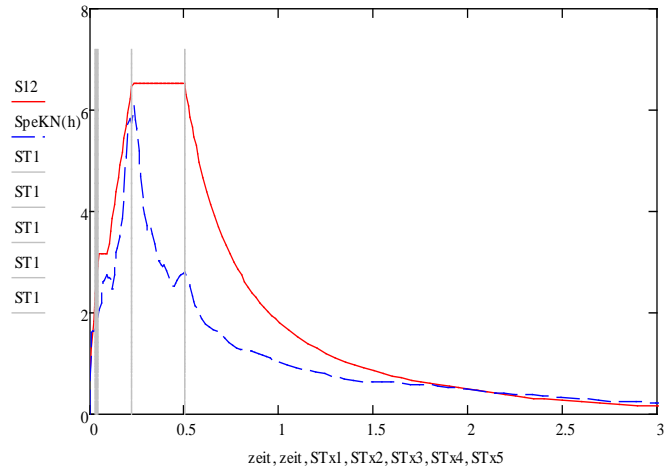
45m ($\xi_s = 5\%$)



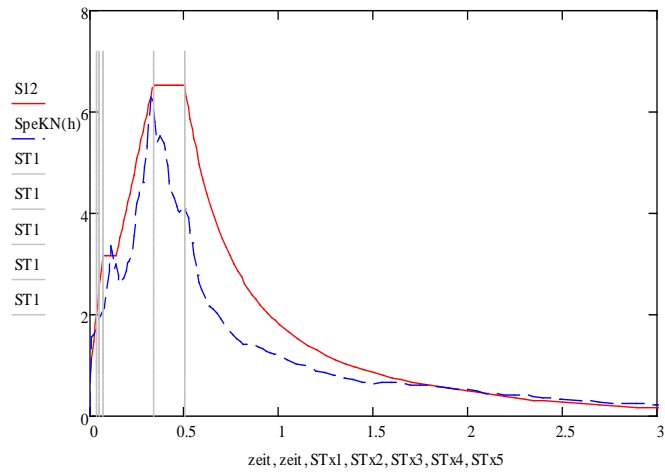
47.5m ($\xi_s = 5\%$)



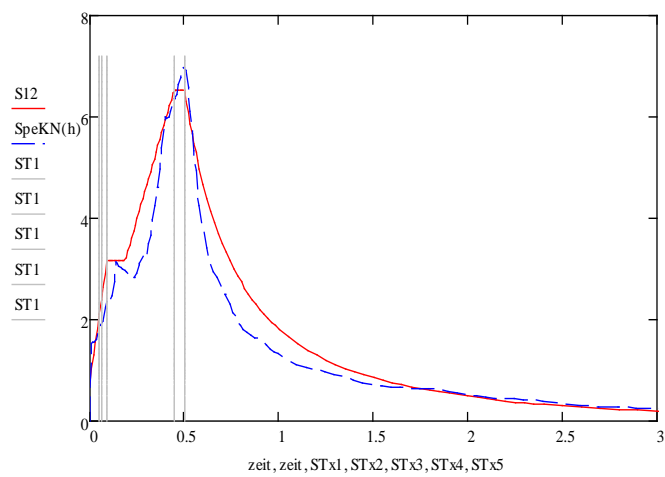
50m ($\xi_s = 5\%$)



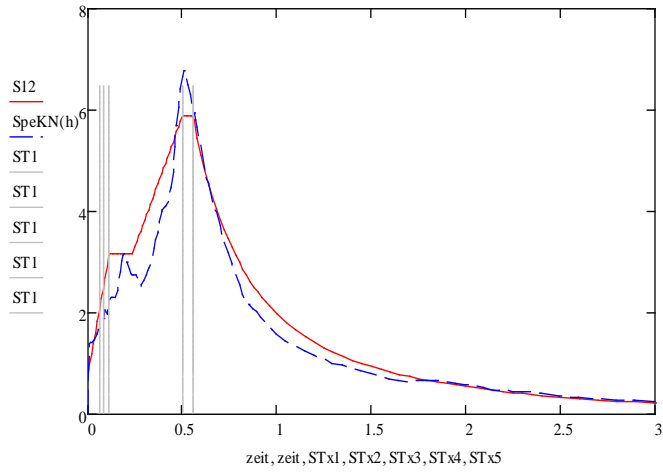
5m ($\xi_S = 10\%$)



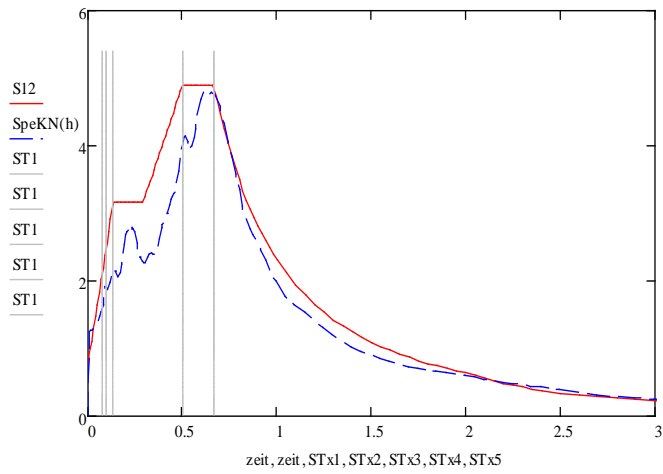
7.5m ($\xi_S = 10\%$)



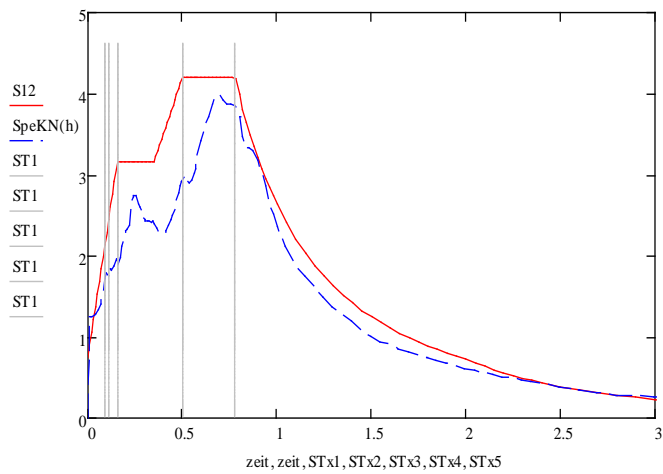
10m ($\xi_S = 10\%$)



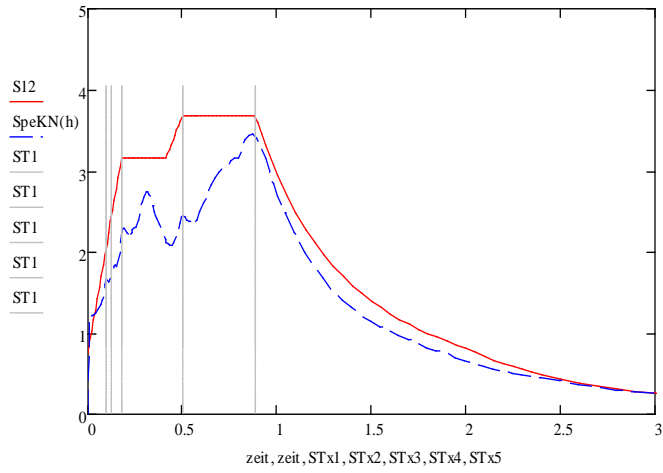
12.5m ($\xi_s = 10\%$)



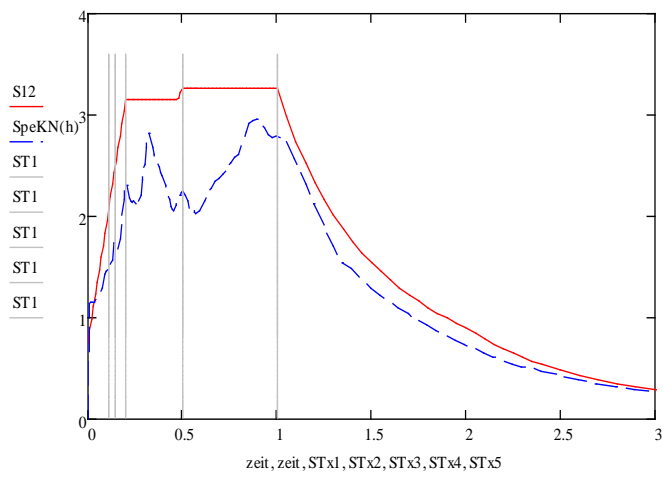
15m ($\xi_s = 10\%$)



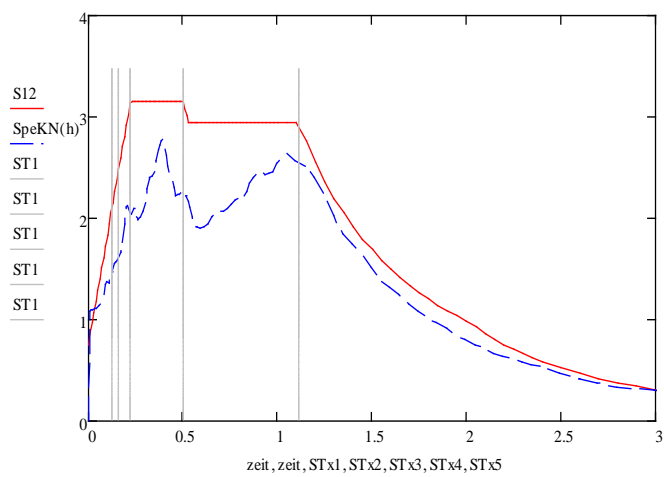
17.5m ($\xi_s = 10\%$)



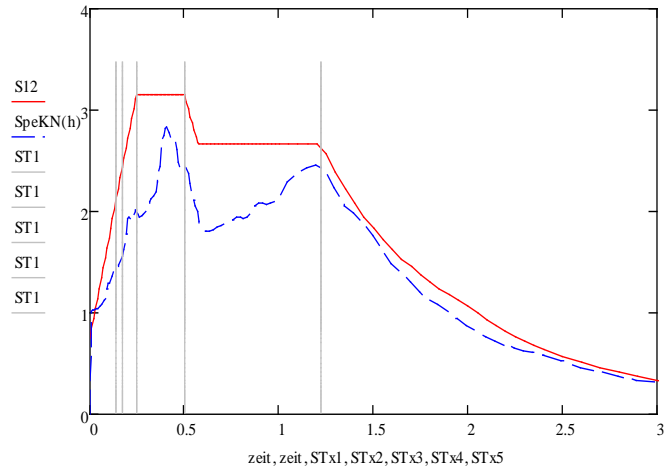
20m ($\xi_S = 10\%$)



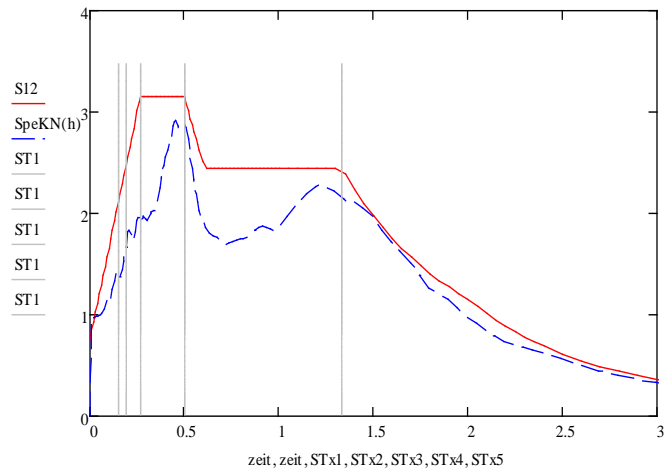
22.5m ($\xi_S = 10\%$)



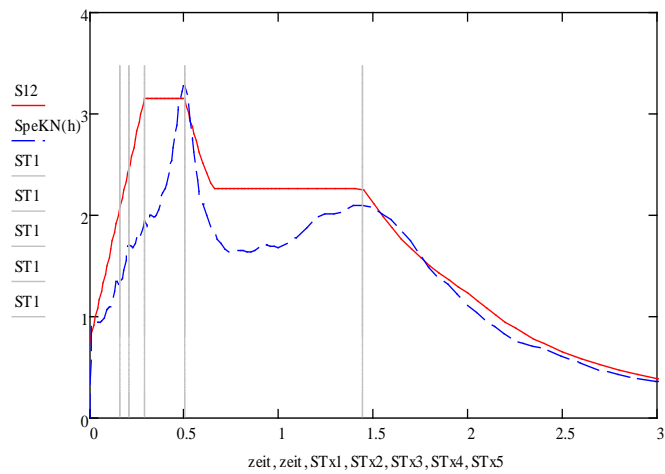
25m ($\xi_S = 10\%$)



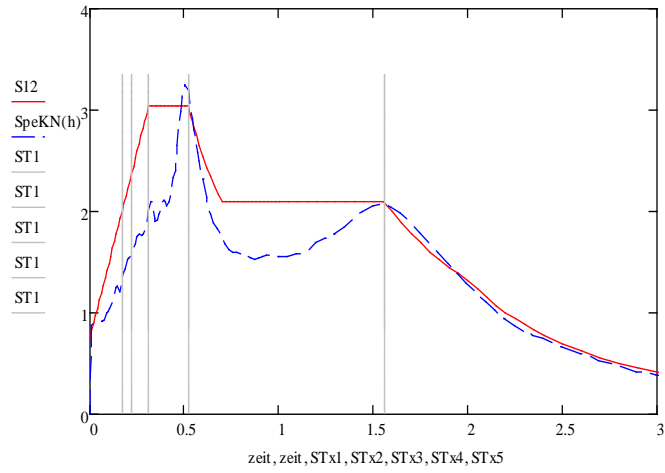
27.5m ($\xi_S= 10\%$)



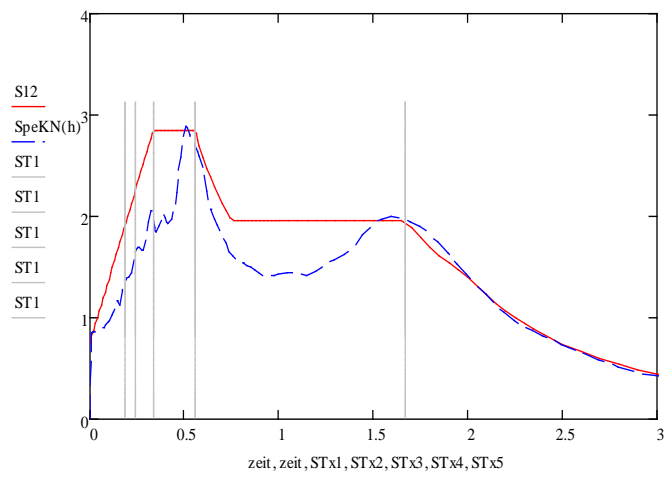
30m ($\xi_S= 10\%$)



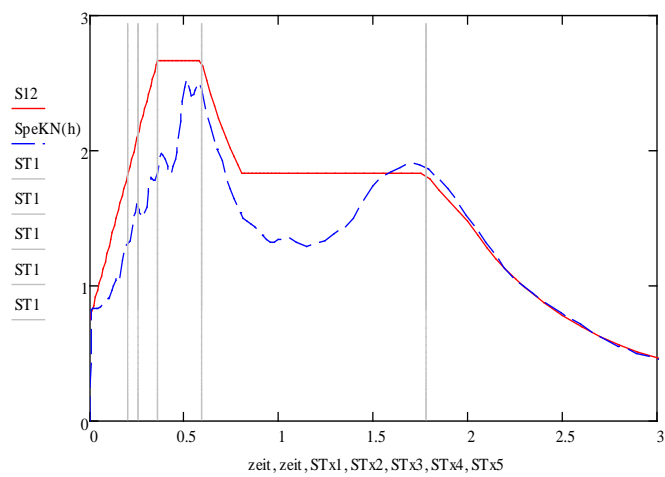
32.5m ($\xi_S= 10\%$)



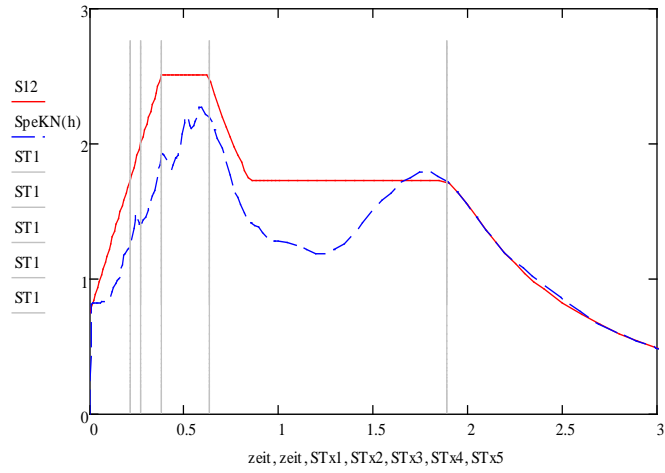
35m ($\xi_s= 10\%$)



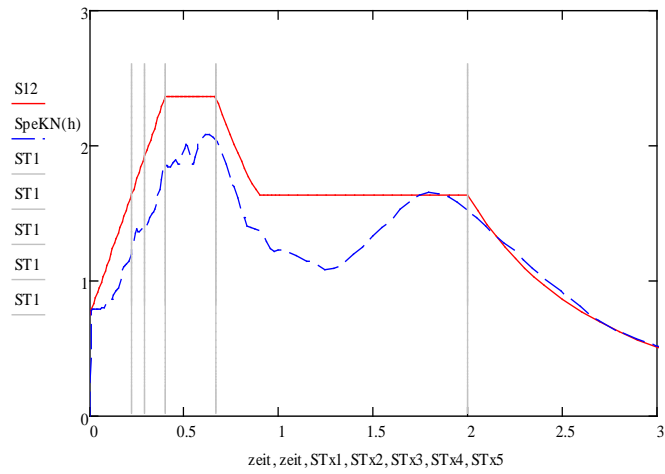
37.5m ($\xi_s= 10\%$)



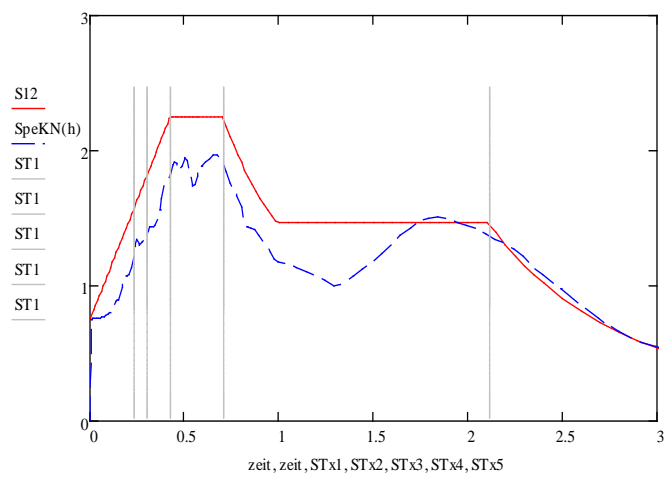
40m ($\xi_s= 10\%$)



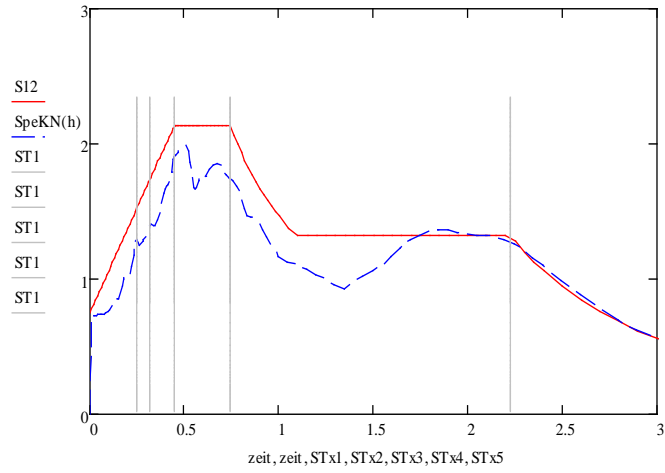
42.5m ($\xi_S = 10\%$)



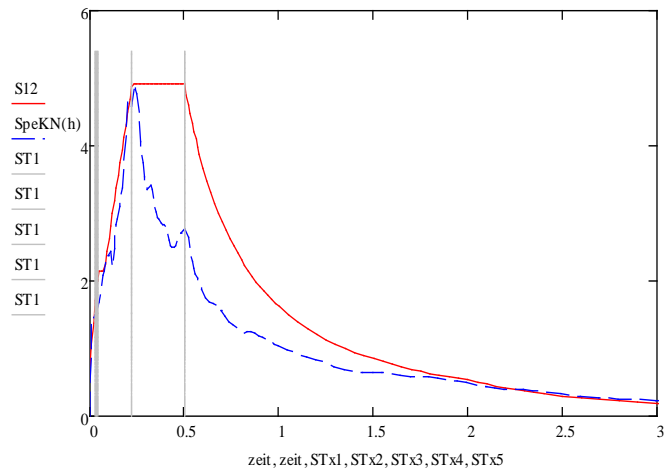
45m ($\xi_S = 10\%$)



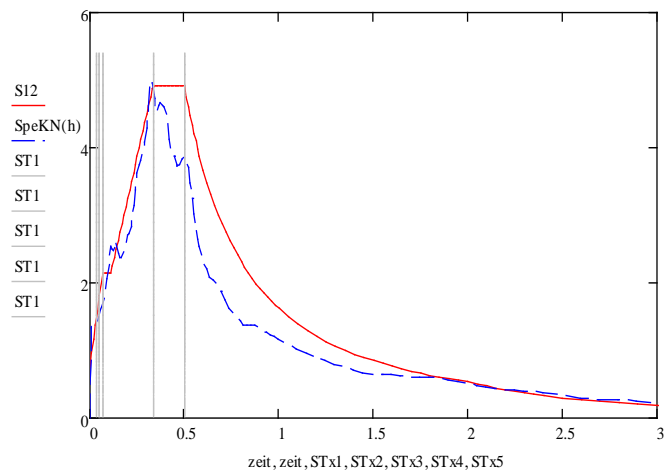
47.5m ($\xi_S = 10\%$)



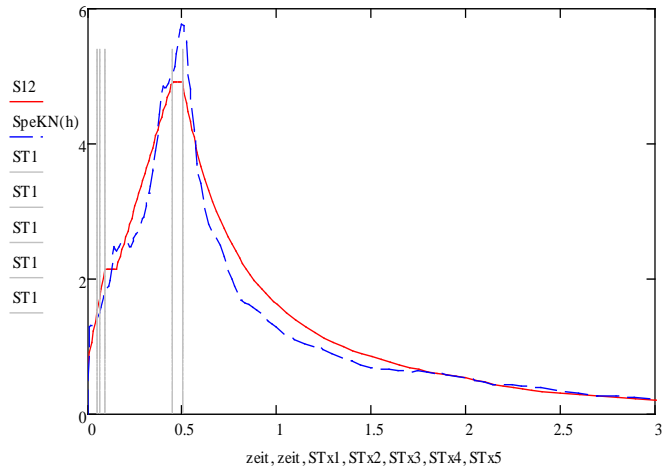
50m ($\xi_s = 10\%$)



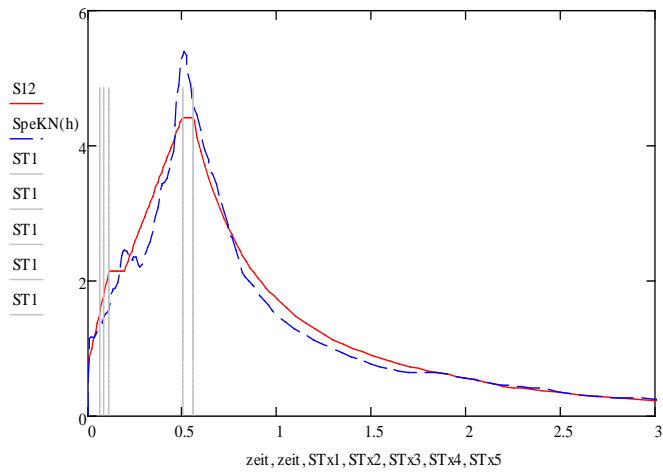
5m ($\xi_s = 15\%$)



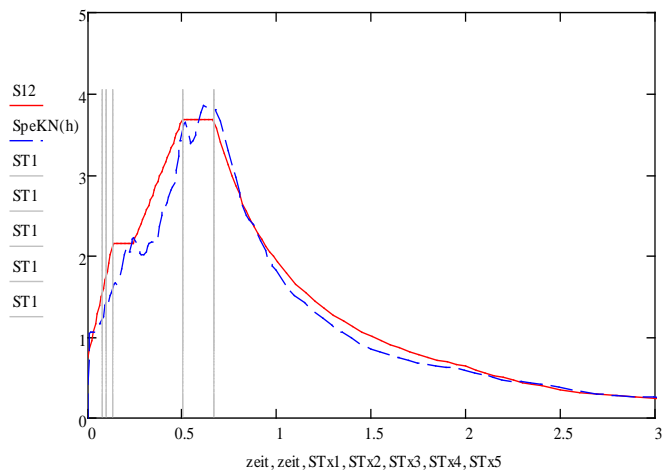
7.5m ($\xi_s = 15\%$)



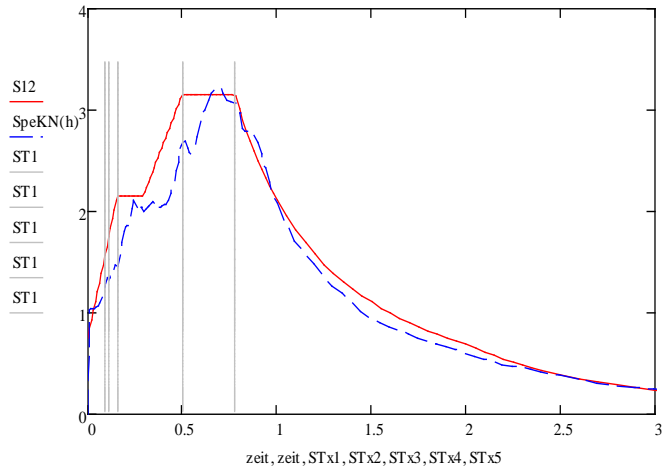
10m ($\xi_S = 15\%$)



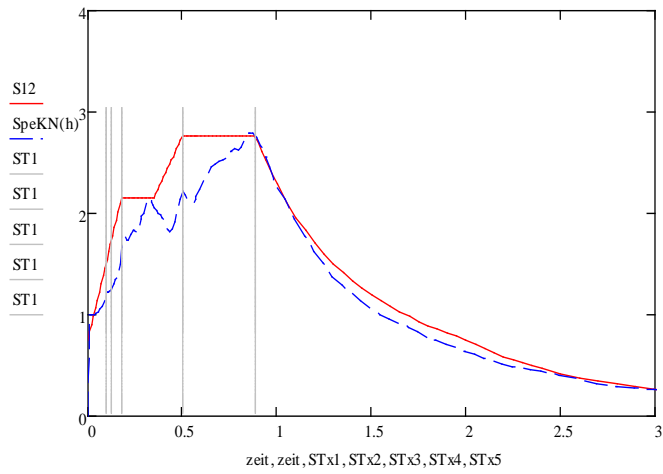
12.5m ($\xi_S = 15\%$)



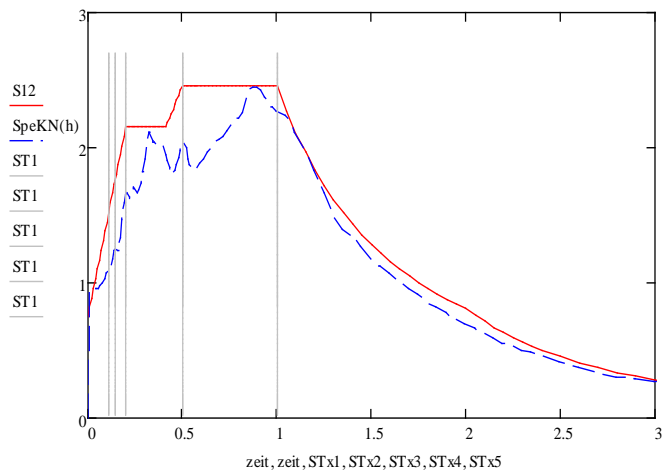
15m ($\xi_S = 15\%$)



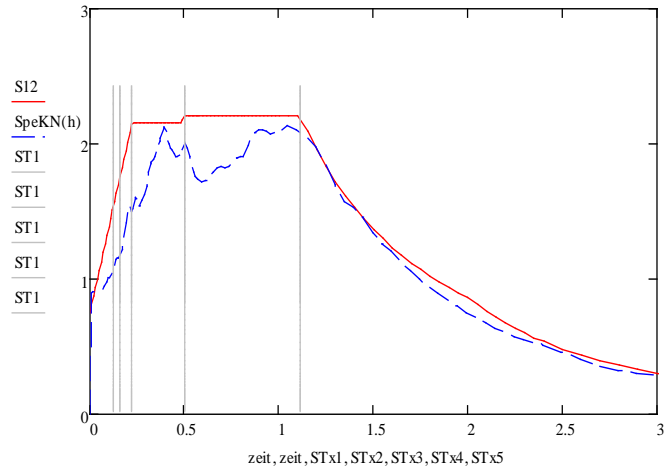
17.5m ($\xi_s = 15\%$)



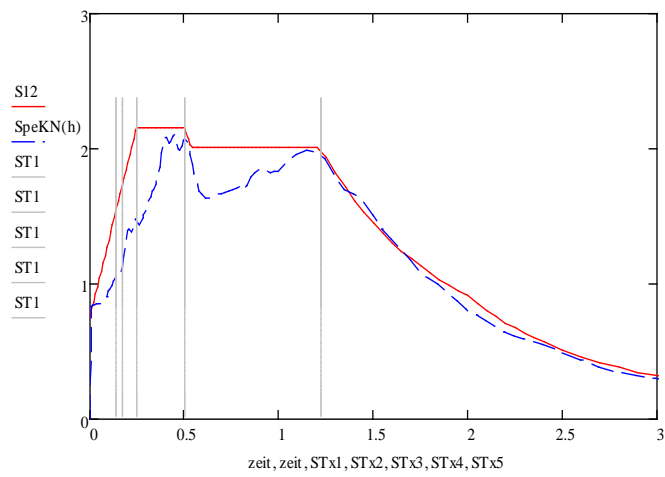
20m ($\xi_s = 15\%$)



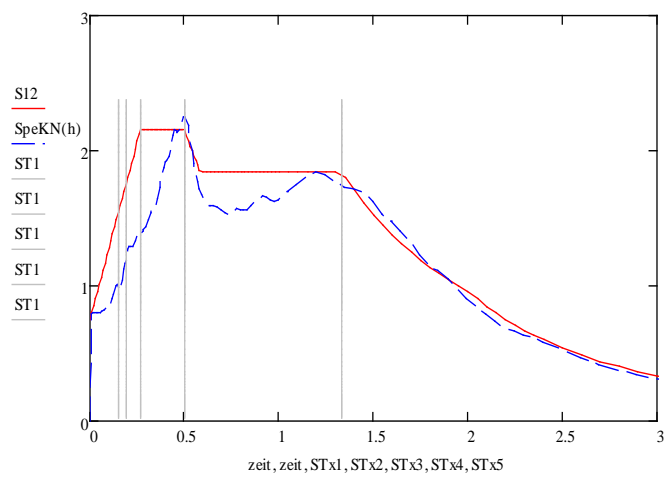
22.5m ($\xi_s = 15\%$)



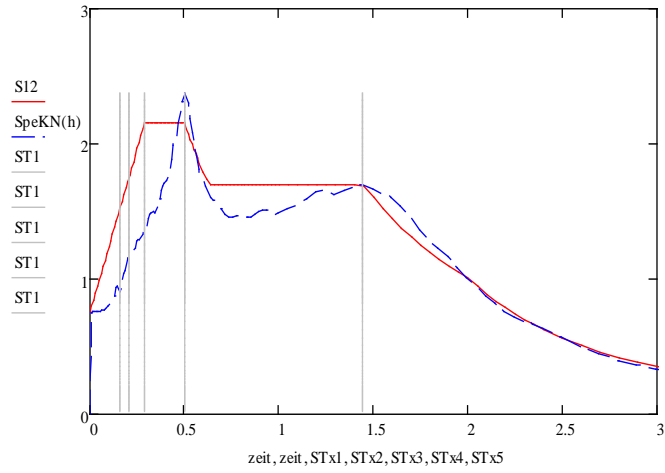
25m ($\xi_S = 15\%$)



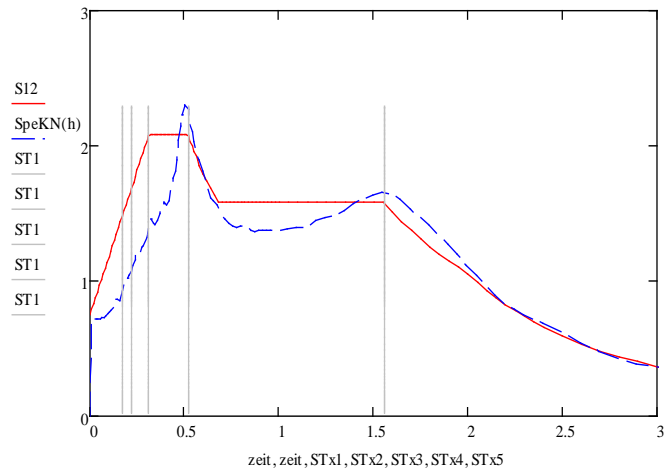
27.5m ($\xi_S = 15\%$)



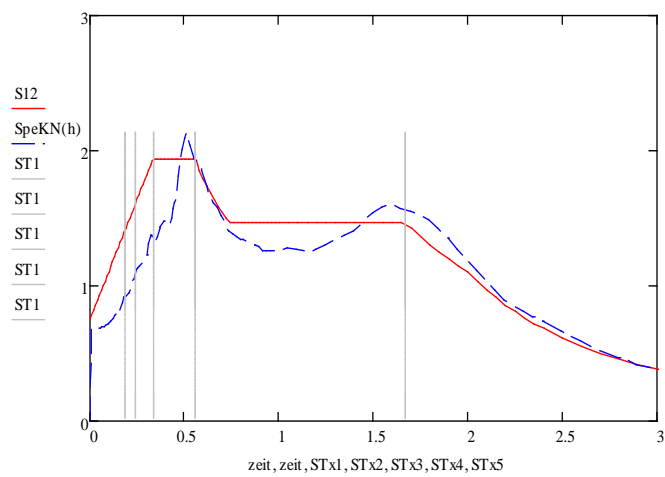
30m ($\xi_S = 15\%$)



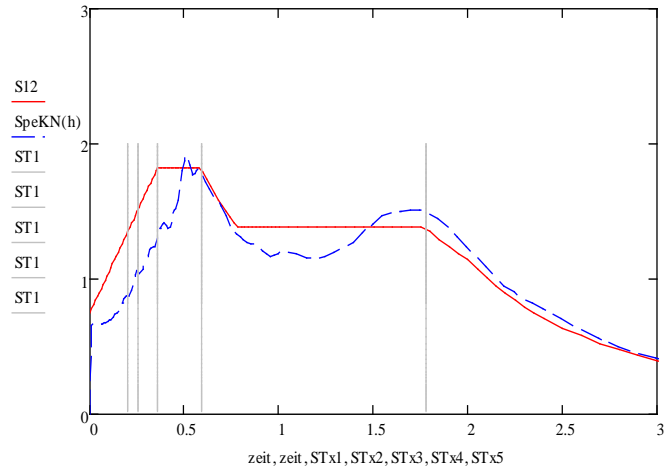
32.5m ($\xi_s = 15\%$)



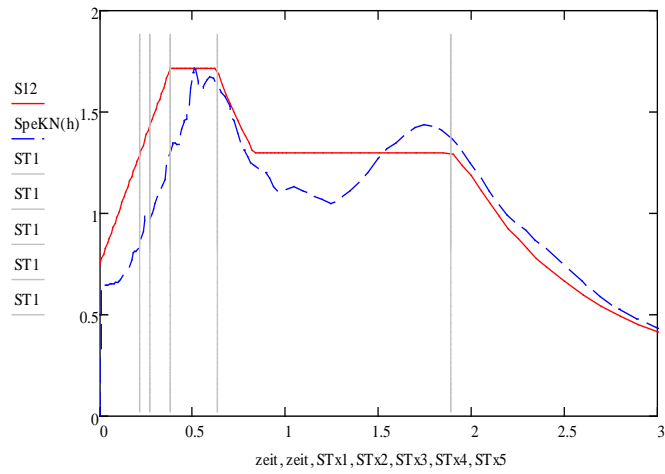
35m ($\xi_s = 15\%$)



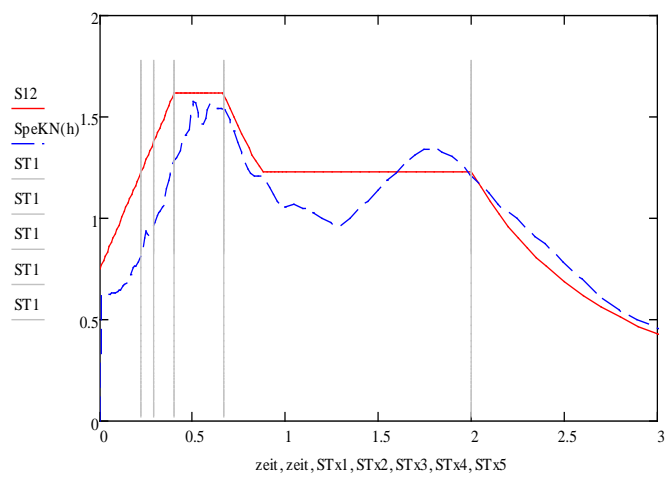
37.5m ($\xi_s = 15\%$)



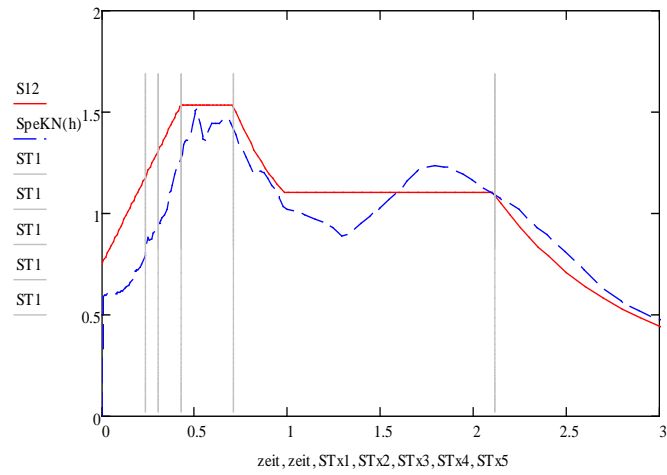
40m ($\xi_S = 15\%$)



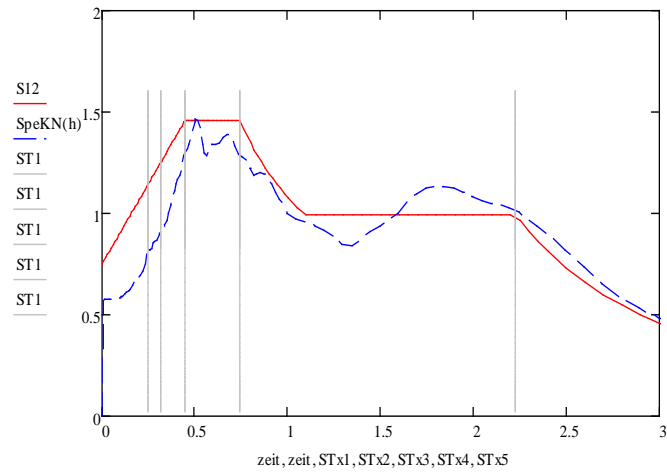
42.5m ($\xi_S = 15\%$)



45m ($\xi_S = 15\%$)



47.5m ($\xi_s=15\%$)



50m ($\xi_s=15\%$)

7 CONCLUSIONS

An easy-to-handle method for constructing horizontal acceleration response spectra for a viscoelastic layer on a half-space based on EC 8 and the German NAD [3] has been developed. The results agree well with the results of those of the one-dimensional SH wave theory. Extension of the material presented in the paper to other ground conditions and soil profiles is possible.

LITERATURE

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- [3] DIN EN 1998-1 (EC8) mit DIN EN 1998-1/NA-2011-1 (National Annex EC8).
- [4] Werkle, H., Kornmeyer, M. u. Berner, U.: Standortabhängige Erdbebenantwortspektren für Konstanzer Seeton. Bauingenieur 88 201) (in German)
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