New Plant Seismic Issues Resolution Program

Structural Tasks Working Meetings
Task S2.2 – Application of EPRI TR-102470 Reduction Procedure

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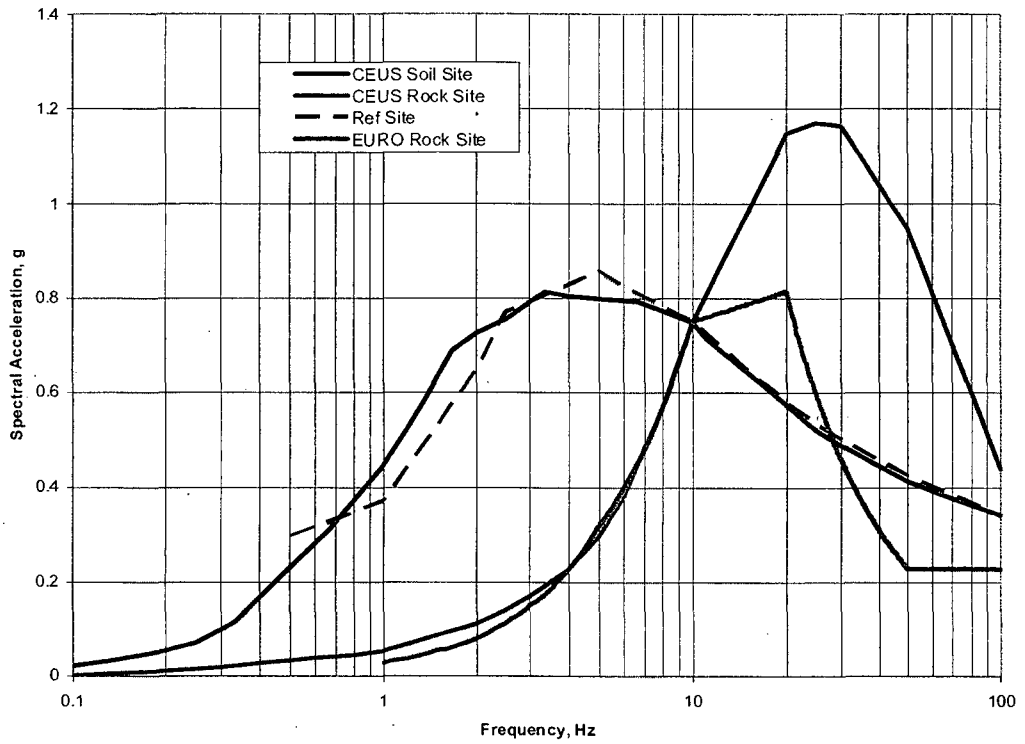
August 23, 2005

B-11

Reduction of Spectra for Non-Linear Behavior

- At the June 22 Meeting it was decided to apply the reduction procedure developed in EPRI TR-102470 to the example CEUS rock and soil site spectra.
- It was also decided to consider reduction of an additional moderate "reference" site spectrum
- All spectra were to be scaled to 0.75g at 10 Hz and the reduction procedure applied. Next, additional reduction cases with the same spectra scaled to 1.5 x 0.75g and 0.67 x 0.75g at 10 Hz were to be developed.
- As can be seen from the following slide, the CEUS soil and "reference" sites have the same spectral shape (> 10 Hz) when scaled the same 10 Hz spectral value
- Thus, in order to show the reduction procedure applied to other spectral shapes, a hard rock spectrum used in Europe was chosen


Example Sites
CEUS Soil Site
CEUS Rock Site
Ref Site
EURO Rock Site
Spectral Acceleration, g
Frequency, Hz
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0.1
1
10
100

Reduced Spectrum Procedure

- Given Sa_{ri}, F_{SM}, F_{SM}/e, f_f, $\beta_f = 0.05$, $\delta_u = 0.01$ inch, $\mu_w = \delta_u/\delta_y = 10$
- $Sa_C = F_{SM}\, Sa_{ri}$, or $Sa_C = (F_{SM}/e)\, Sa_{ri}$
- $A = (2\pi f_f)^2\, \delta_u / Sa_C$
- $X = 1/(1+A)$
- $X_e = 1-(1-X)^{1.6}$
- $\beta_e = (X/Xe)\, [X^{1/2}\beta_f) + (0.6/\pi)\, (1-X)(1-1/\mu_w))$
- $F_\mu = (X/X_e)\, [Sa(f_f,\beta_f)/Sa(f_e,\beta_e)]$
- $Sa_{ri+1} = Sa(f_f,\beta_f)/F_\mu$

Iteration loop

Application of Reduction Procedure

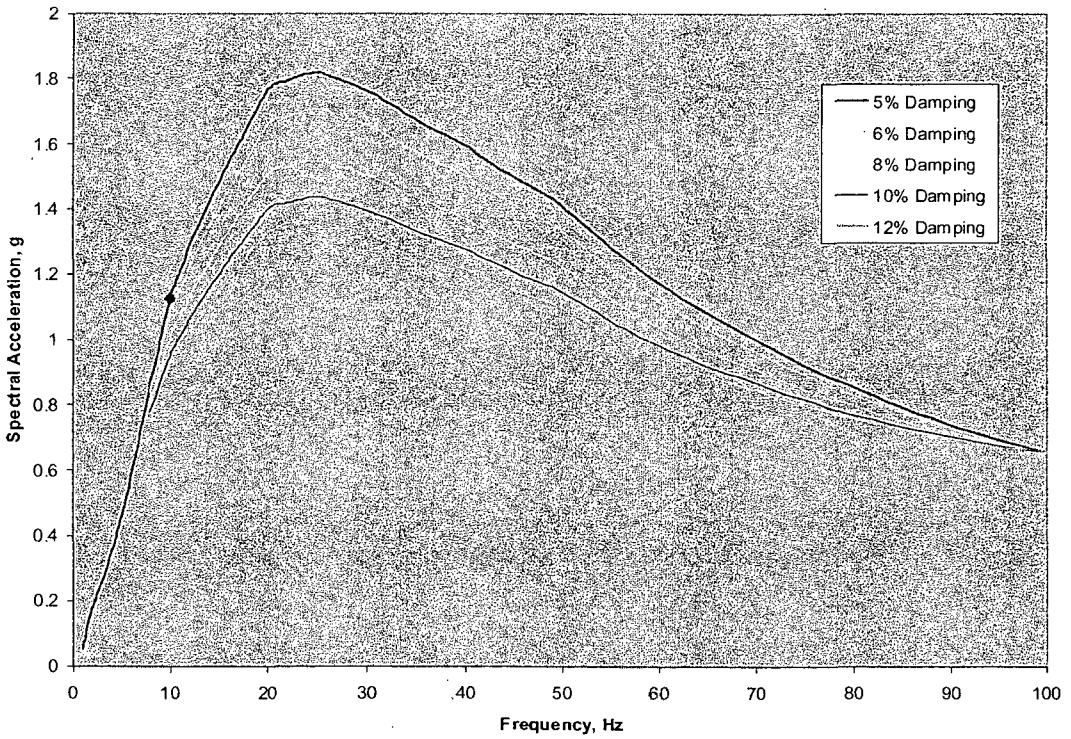
- A macro driven spreadsheet was developed to compute the reduced spectra for each F_{SM} (or F_{SM}/e) value
- The key step in this calculation is the ability to estimate the spectral acceleration, $Sa(f_e,\beta_e)$, for any value of f_e and β_e
- NUREG/CR-6728 recommends the following relation (6728 Equ. 4-13) for estimation of spectra with damping $\beta_e > 0.05$

$$Sa(f_e,\beta_e) = \{PGA^2 + [Sa(f_f,0.05)^2 - PGA^2][(1 + 4.9\beta_e f_e D)/(1 + 4.9(0.05)f_e D)]^{-0.82})^{1/2}$$

where PGA = Sa(100,0.05), D=10

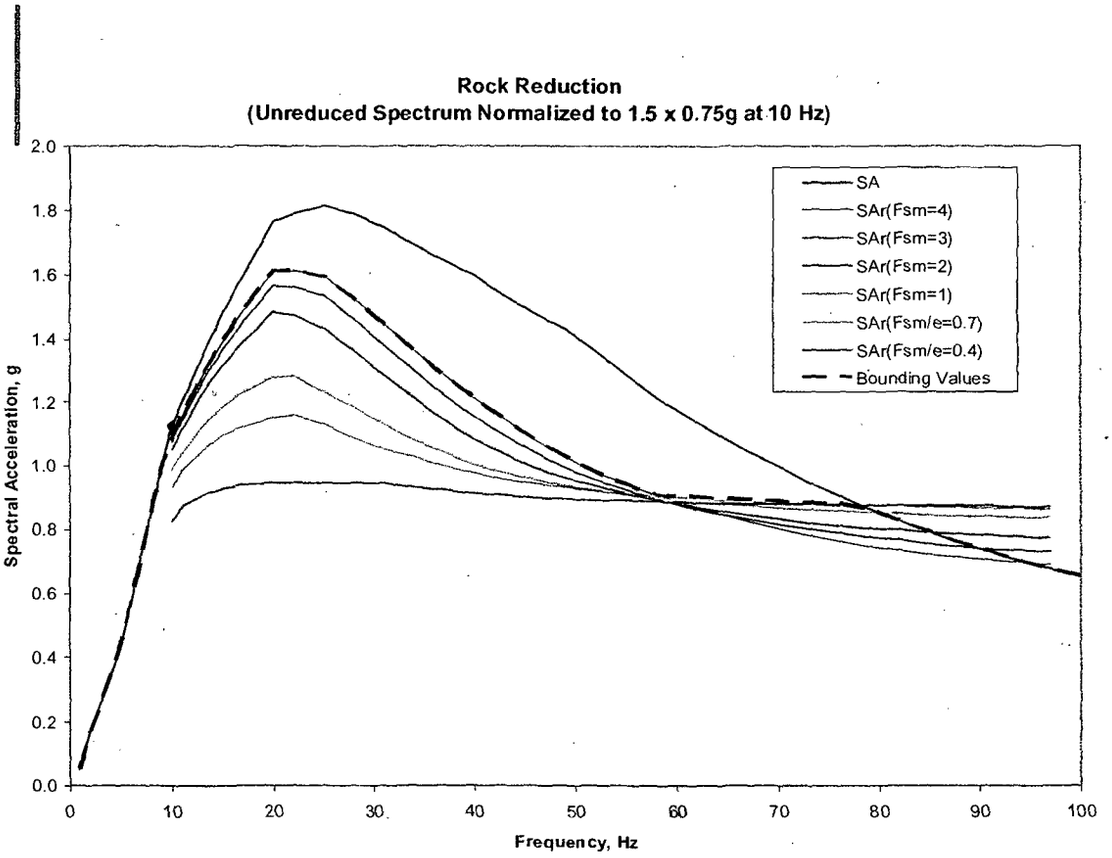
(D within range 5-10 provides the same approximate value of $Sa(f_e,\beta_e)$]

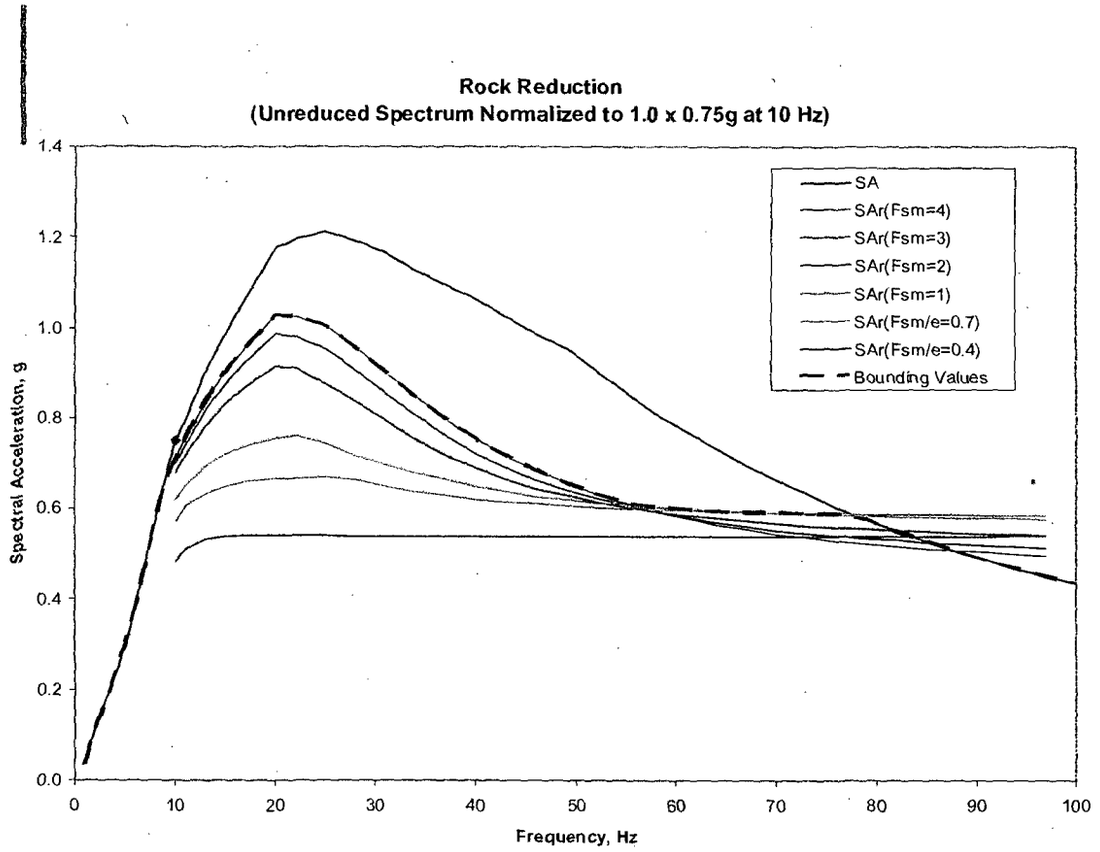
- The following plot provides the set of spectra determined for the CEUS rock site using 6728 Equ. 4-13

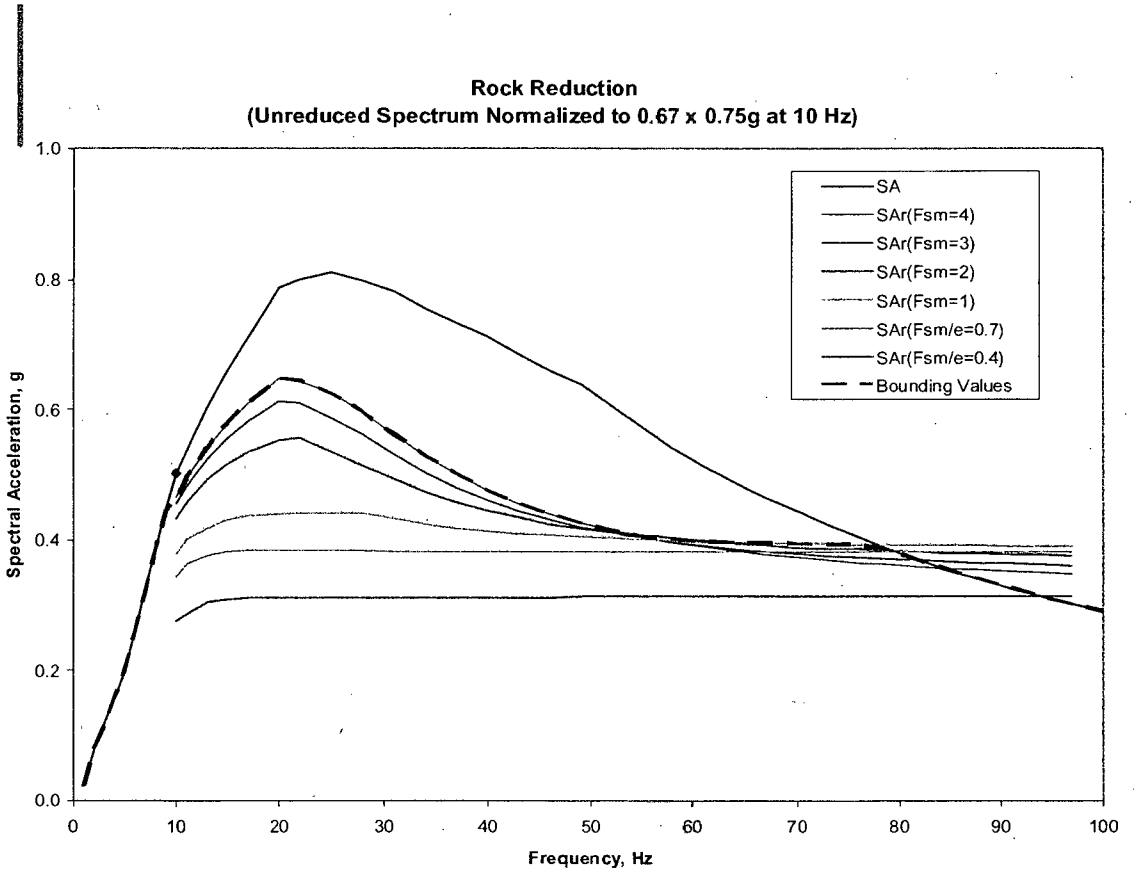

Rock Site Spectra
(5% Spectrum Normalized to 1.5 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
5% Damping
6% Damping
8% Damping
10% Damping
12% Damping
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
0
10
20
30
40
50
60
70
80
90
100

Reduced CEUS Rock Spectra

- The following set of plots provides the reduced spectra for the CEUS rock spectra scaled at 0.67 x, 1.0 x, and 1.5 x the spectra normalized to 0.75g at 10 Hz
- They are plotted for the range of (F_{SM}, F_{SM}/e) = 4.0 to 0.4
- Note that the plots cross over each other
- The bounding values of the reduced spectrum are determined by:
  - $Sa(f_f,\beta_f)$, $f_f < 10$ Hz
  - $Max\{Sa_r(F_{SM}, F_{SM}/e)\}$, $10 \text{ Hz} \le f_f \le f_f^*$
  - $Sa(f_f,\beta_f)$, $f_f > f_f^*$

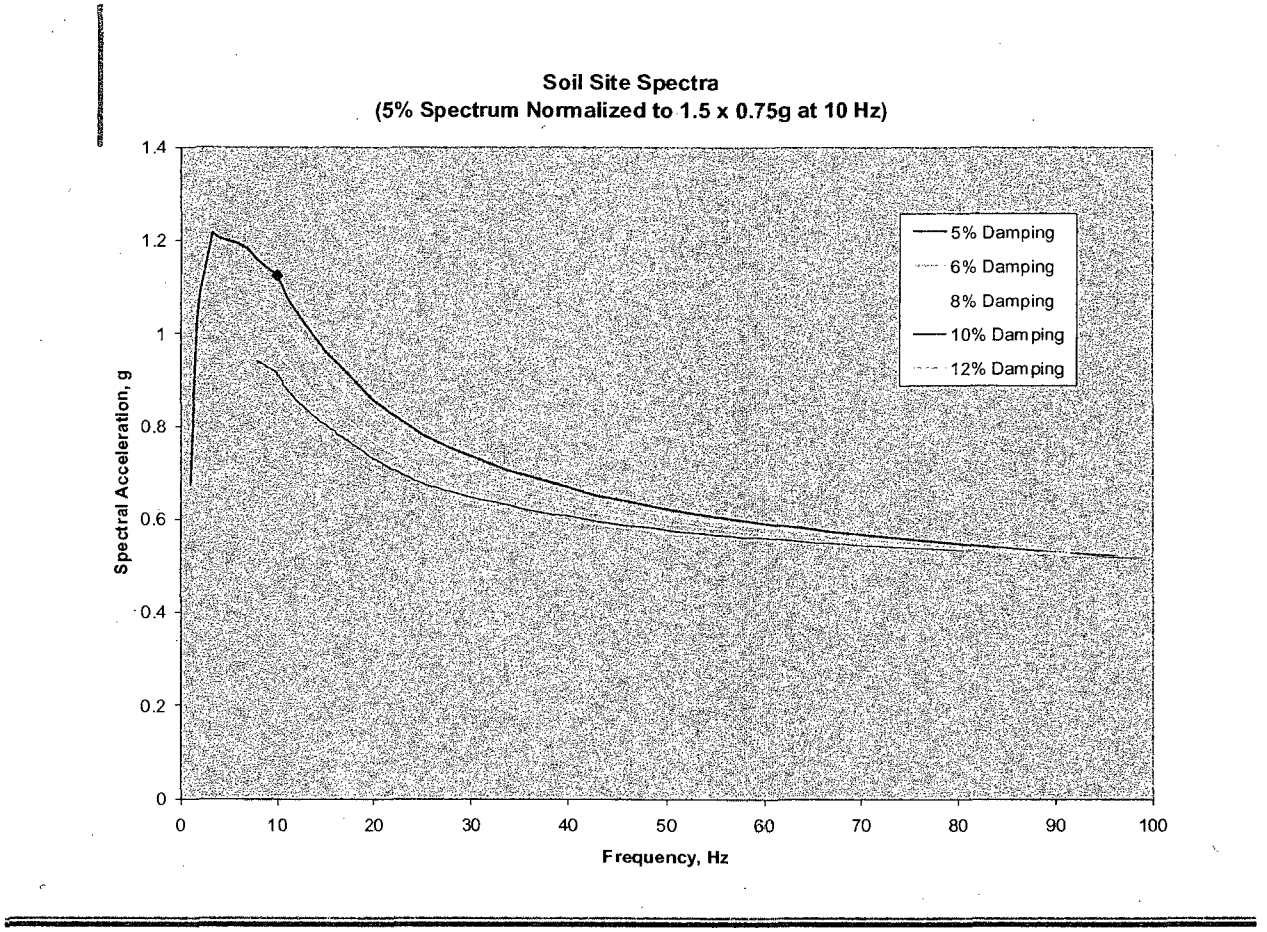

Rock Reduction
(Unreduced Spectrum Normalized to 1.5 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
SA
SAr(Fsm=4)
SAr(Fsm=3)
SAr(Fsm=2)
SAr(Fsm=1)
SAr(Fsm/e=0.7)
SAr(Fsm/e=0.4)
Bounding Values
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
10
20
30
40
50
60
70
80
90
100

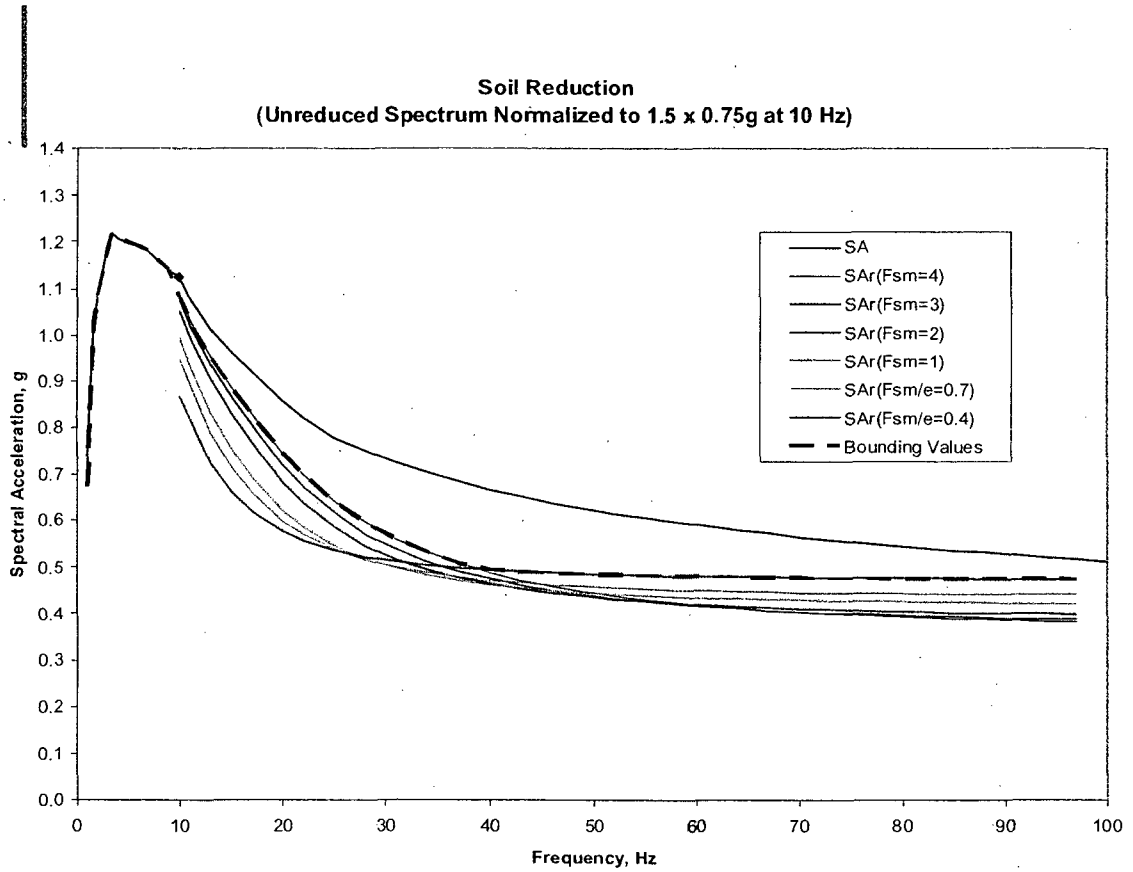

Rock Reduction
(Unreduced Spectrum Normalized to 1.0 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
SA
SAr(Fsm=4)
SAr(Fsm=3)
SAr(Fsm=2)
SAr(Fsm=1)
SAr(Fsm/e=0.7)
SAr(Fsm/e=0.4)
Bounding Values
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
10
20
30
40
50
60
70
80
90
100

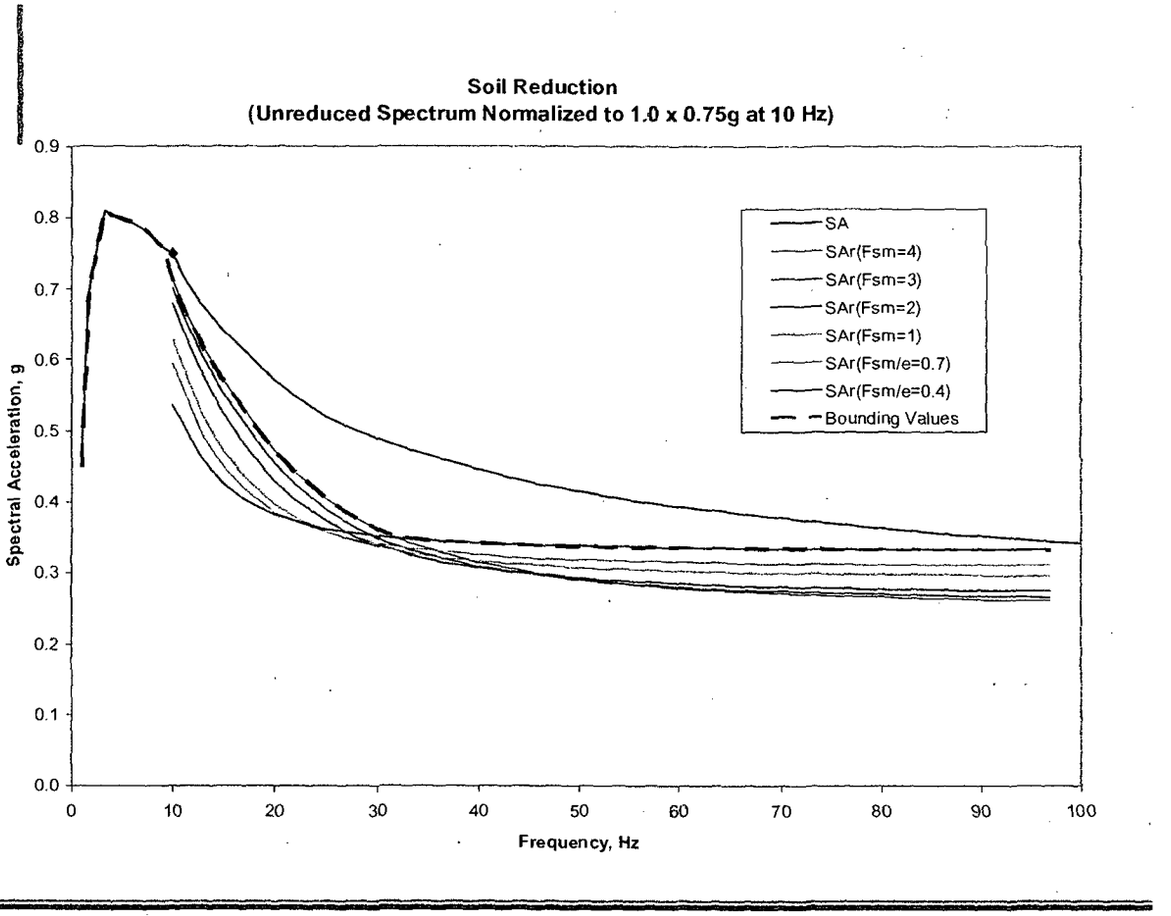

Rock Reduction
(Unreduced Spectrum Normalized to 0.67 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
80
90
100
SA
SAr(Fsm=4)
SAr(Fsm=3)
SAr(Fsm=2)
SAr(Fsm=1)
SAr(Fsm/e=0.7)
SAr(Fsm/e=0.4)
Bounding Values

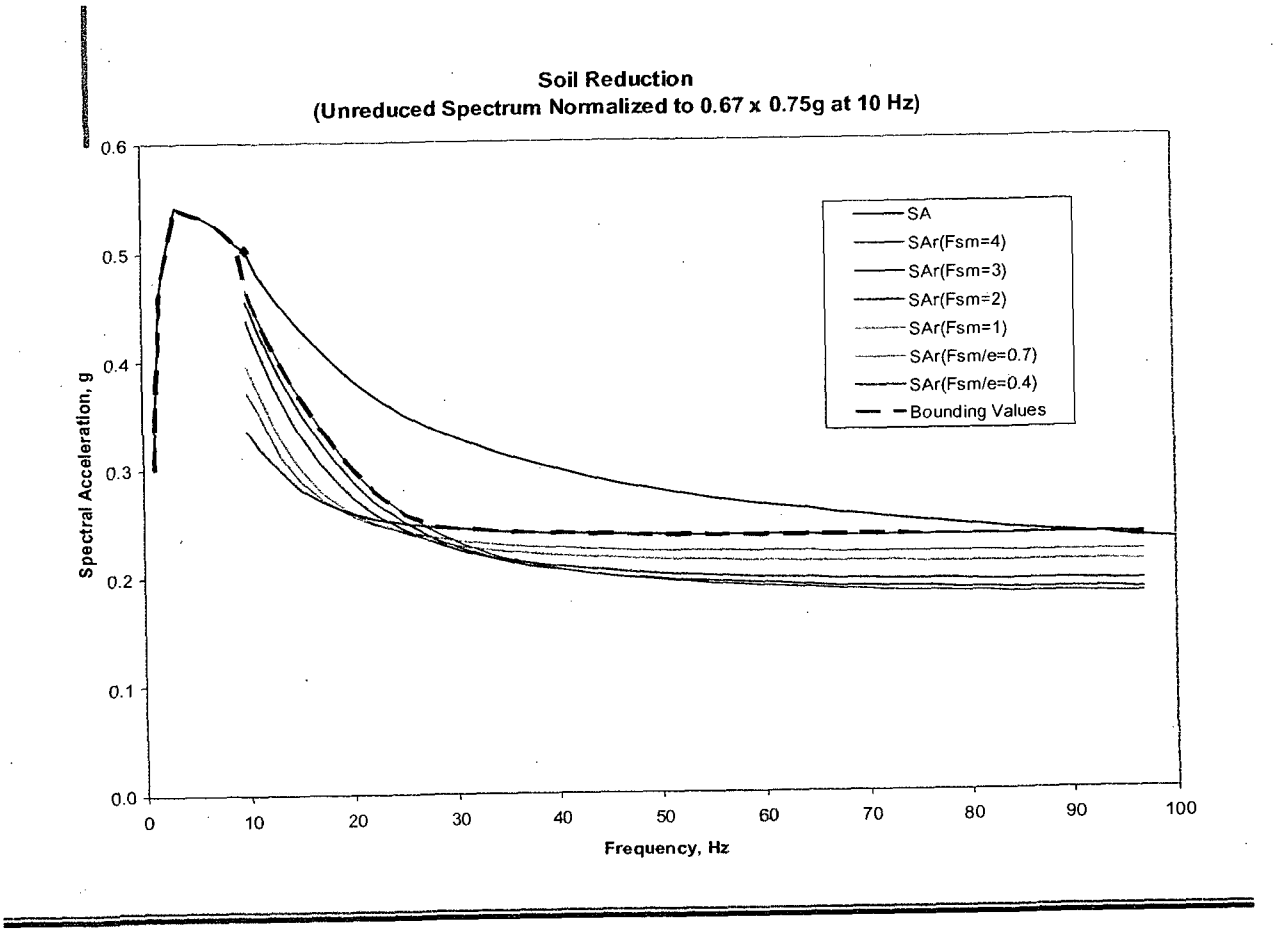
Reduced CEUS Soil Spectra

- The next plot provides the set of spectra determined for the CEUS soil site using 6728 Equ. 4-13
- The following set of plots provides the bounding reduced spectra for the CEUS soil spectra scaled at 0.67 x, 1.0 x, and 1.5 x the spectra normalized to 0.75g at 10 Hz


Soil Site Spectra
(5% Spectrum Normalized to 1.5 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
5% Damping
6% Damping
8% Damping
10% Damping
12% Damping
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
10
20
30
40
50
60
70
80
90
100

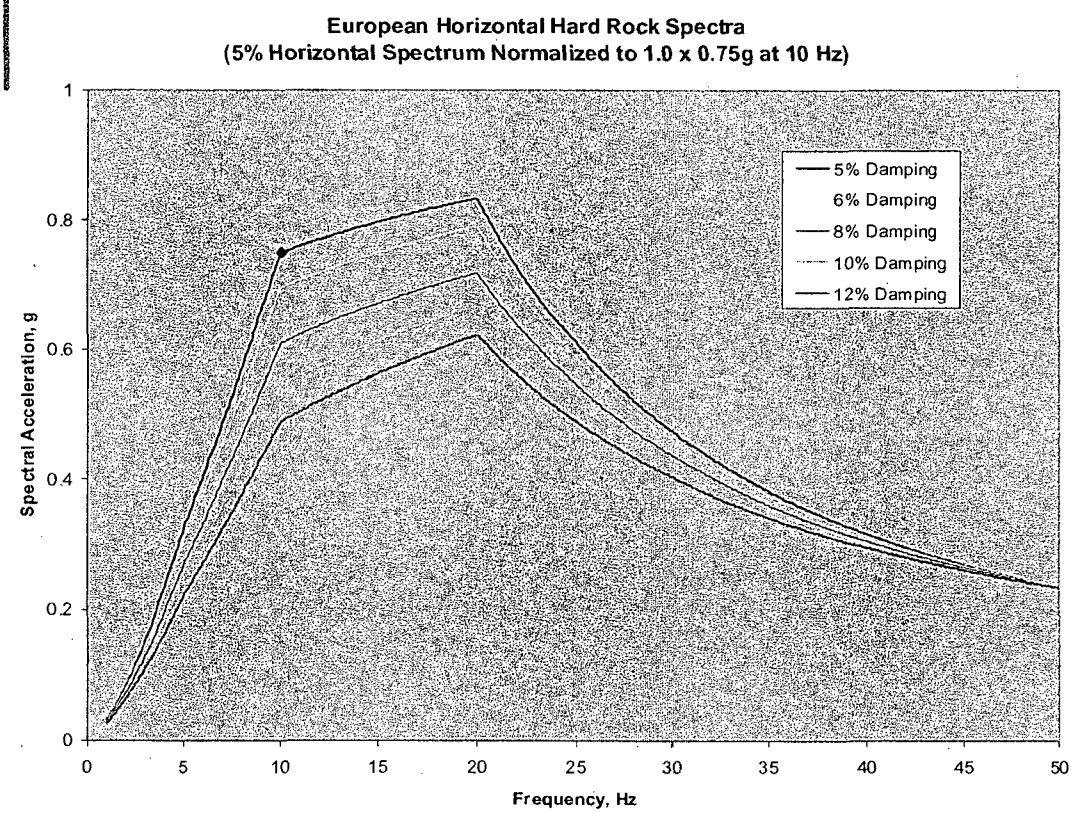

Soil Reduction
(Unreduced Spectrum Normalized to 1.5 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
SA
SAr(Fsm=4)
SAr(Fsm=3)
SAr(Fsm=2)
SAr(Fsm=1)
SAr(Fsm/e=0.7)
SAr(Fsm/e=0.4)
Bounding Values
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
0
10
20
30
40
50
60
70
80
90
100

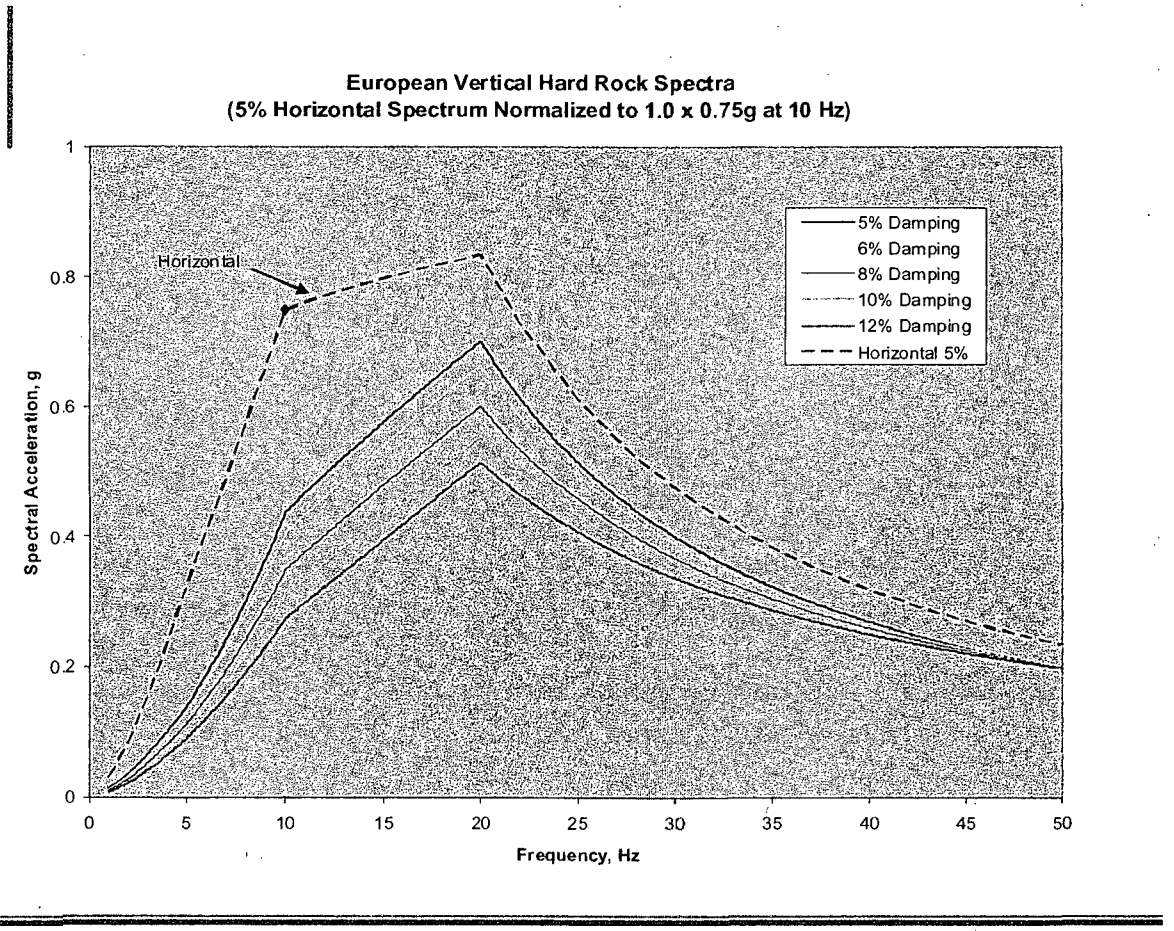

Soil Reduction
(Unreduced Spectrum Normalized to 1.0 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
SA
SAr(Fsm=4)
SAr(Fsm=3)
SAr(Fsm=2)
SAr(Fsm=1)
SAr(Fsm/e=0.7)
SAr(Fsm/e=0.4)
Bounding Values
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
10
20
30
40
50
60
70
80
90
100

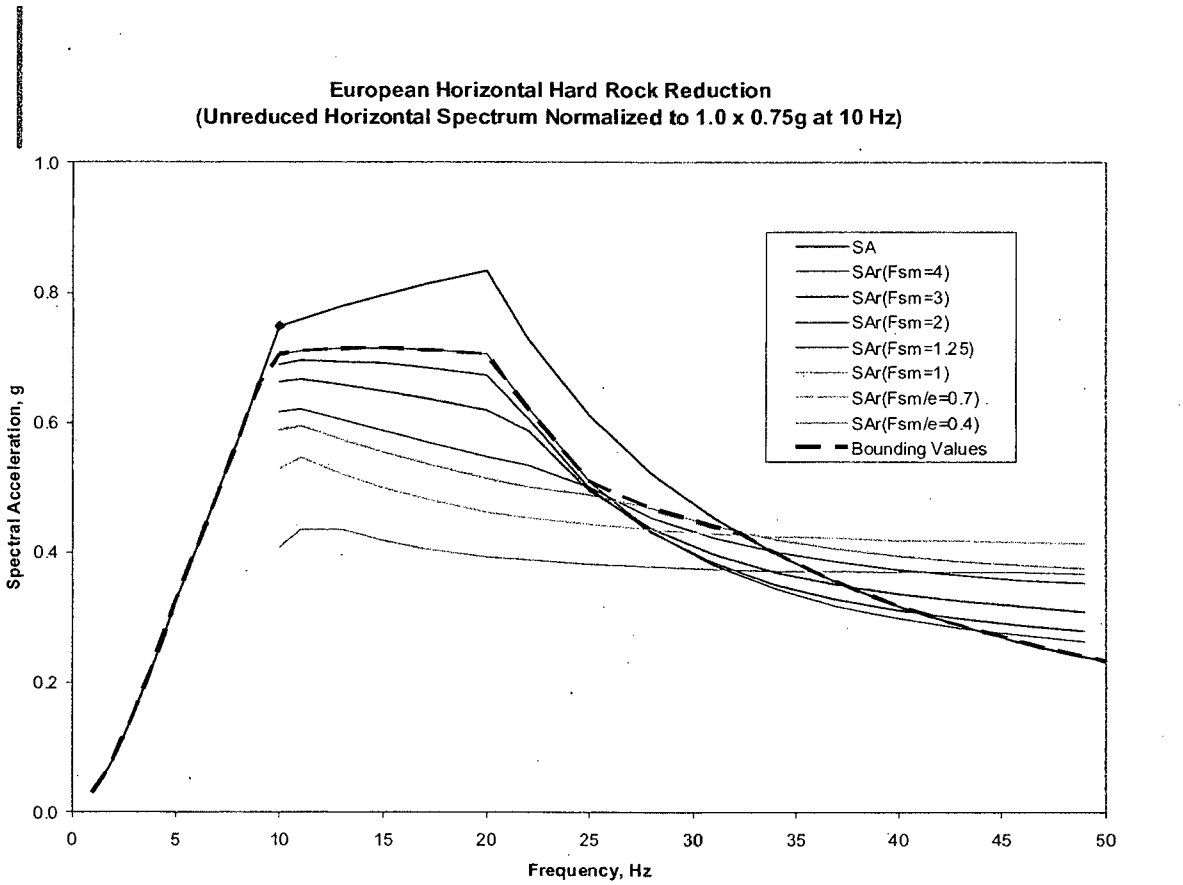

Soil Reduction
(Unreduced Spectrum Normalized to 0.67 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
10
20
30
40
50
60
70
80
90
100
SA
SAr(Fsm=4)
SAr(Fsm=3)
SAr(Fsm=2)
SAr(Fsm=1)
SAr(Fsm/e=0.7)
SAr(Fsm/e=0.4)
Bounding Values

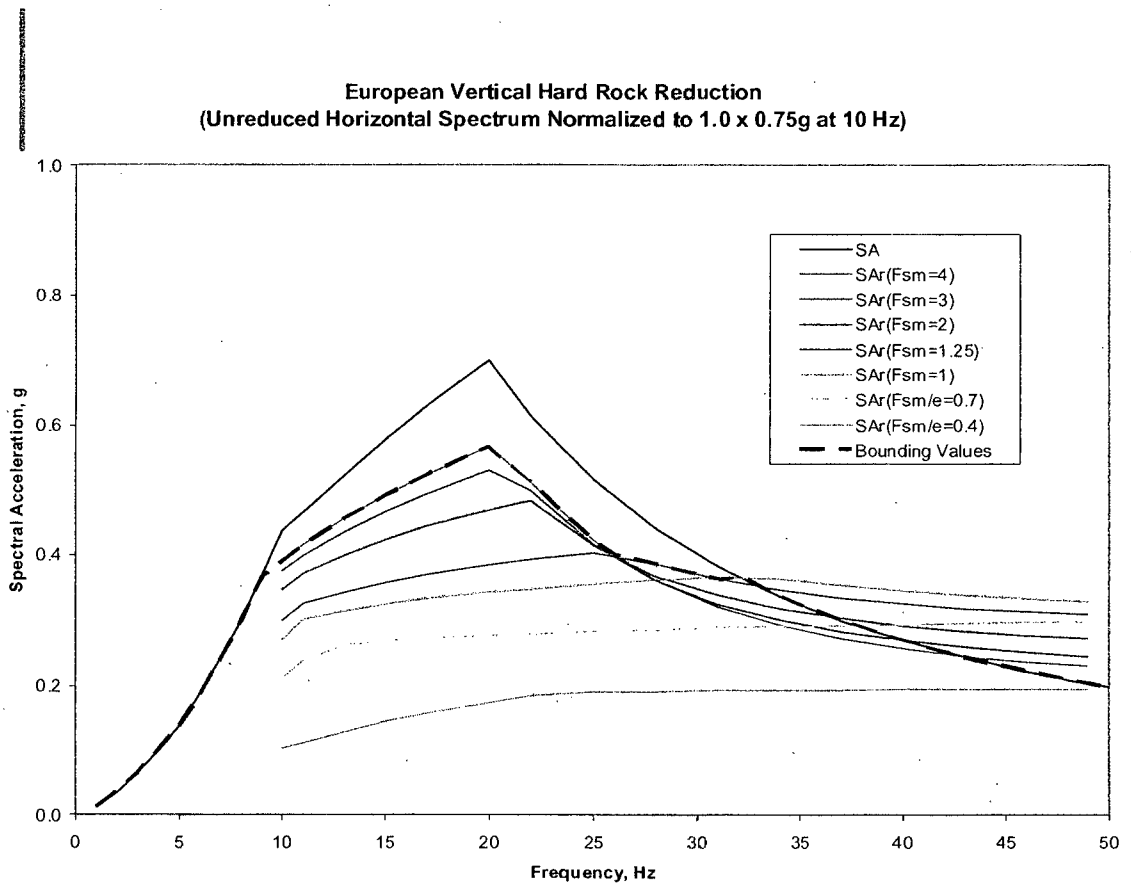
Reduced European Hard Rock Spectra

- These set of spectra (actually hazard spectra) are used for seismic evaluation of European Nuclear Power Plants
- They are defined for 5%, 7% and 10% damping, thus the values of $Sa(f_e,\beta_e)$ were interpolated between these given values (Equ. 4-13 was *not* used)
- A vertical spectrum shape is also defined. It was included to demonstrate reduction with two different shaped spectra
- The next two plots provide the set of spectra interpolated for different damping values for the European hard rock site. Note the horizontal shape has been scaled to 0.75g at 10 Hz and that the ratio of the vertical to horizontal shape has been maintained.
- The following set of plots provides the bounding reduced spectra for both the vertical and horizontal European hard rock site with the horizontal spectra scaled at 1.0 x the spectrum normalized to 0.75g at 10 Hz. (the 0.67 x and 1.5 x cases were not computed)


European Horizontal Hard Rock Spectra
(5% Horizontal Spectrum Normalized to 1.0 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
5% Damping
6% Damping
8% Damping
10% Damping
12% Damping
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30
35
40
45
50


European Vertical Hard Rock Spectra
(5% Horizontal Spectrum Normalized to 1.0 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
Horizontal
5% Damping
6% Damping
8% Damping
10% Damping
12% Damping
Horizontal 5%
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30
35
40
45
50


European Horizontal Hard Rock Reduction
(Unreduced Horizontal Spectrum Normalized to 1.0 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
50
SA
SAr(Fsm=4)
SAr(Fsm=3)
SAr(Fsm=2)
SAr(Fsm=1.25)
SAr(Fsm=1)
SAr(Fsm/e=0.7)
SAr(Fsm/e=0.4)
Bounding Values


European Vertical Hard Rock Reduction
(Unreduced Horizontal Spectrum Normalized to 1.0 x 0.75g at 10 Hz)
Spectral Acceleration, g
Frequency, Hz
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
50
SA
SAr(Fsm=4)
SAr(Fsm=3)
SAr(Fsm=2)
SAr(Fsm=1.25)
SAr(Fsm=1)
SAr(Fsm/e=0.7)
SAr(Fsm/e=0.4)
Bounding Values