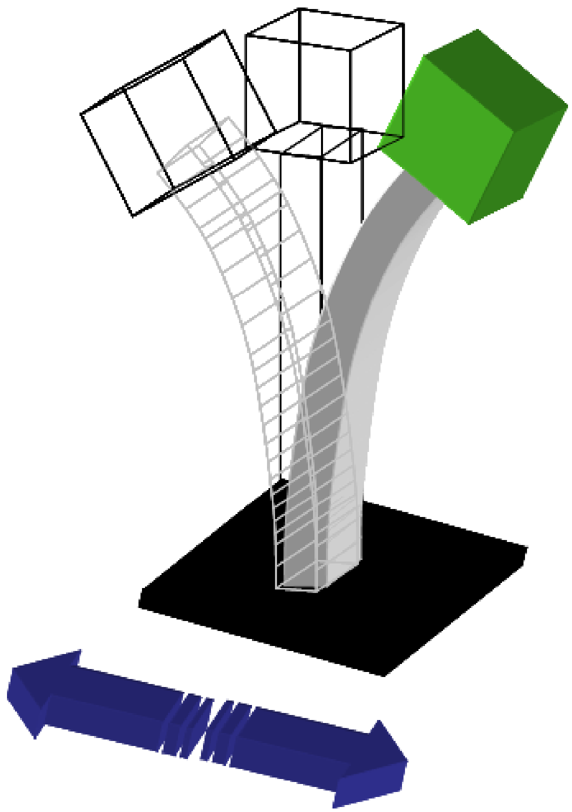
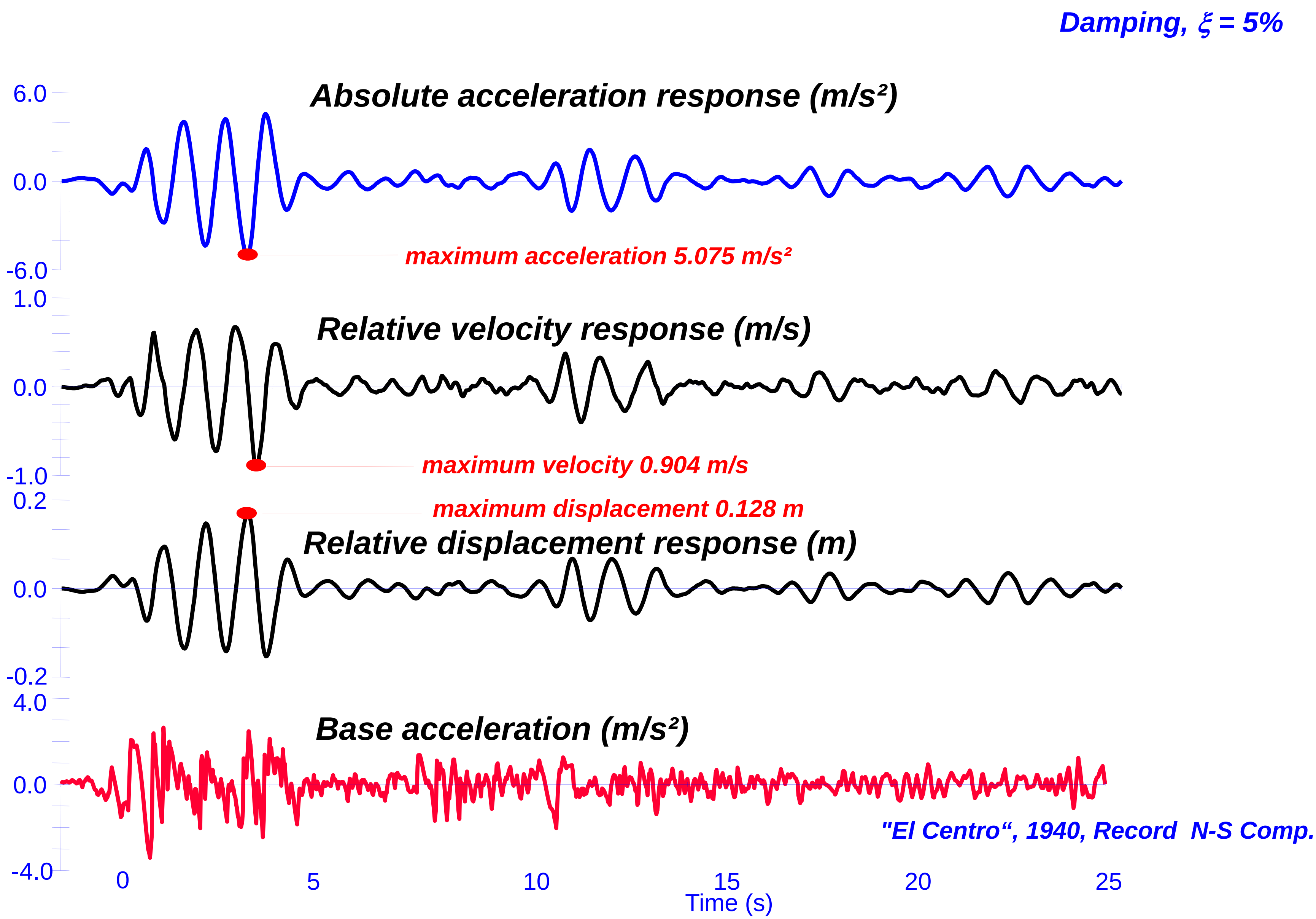
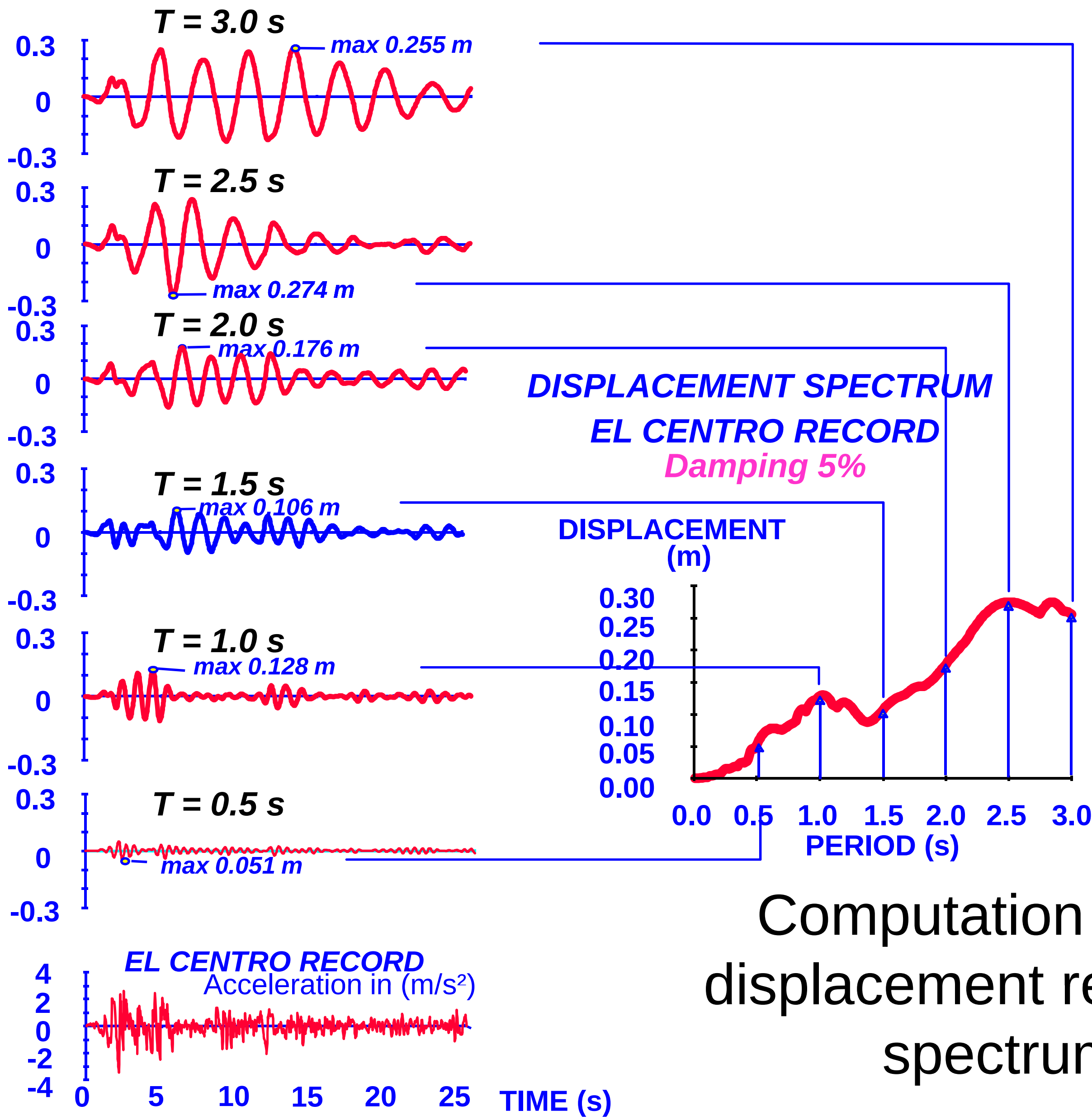
Response of Structures to Earthquake Ground Motions



Response of a SDOF with 1.0 sec natural period

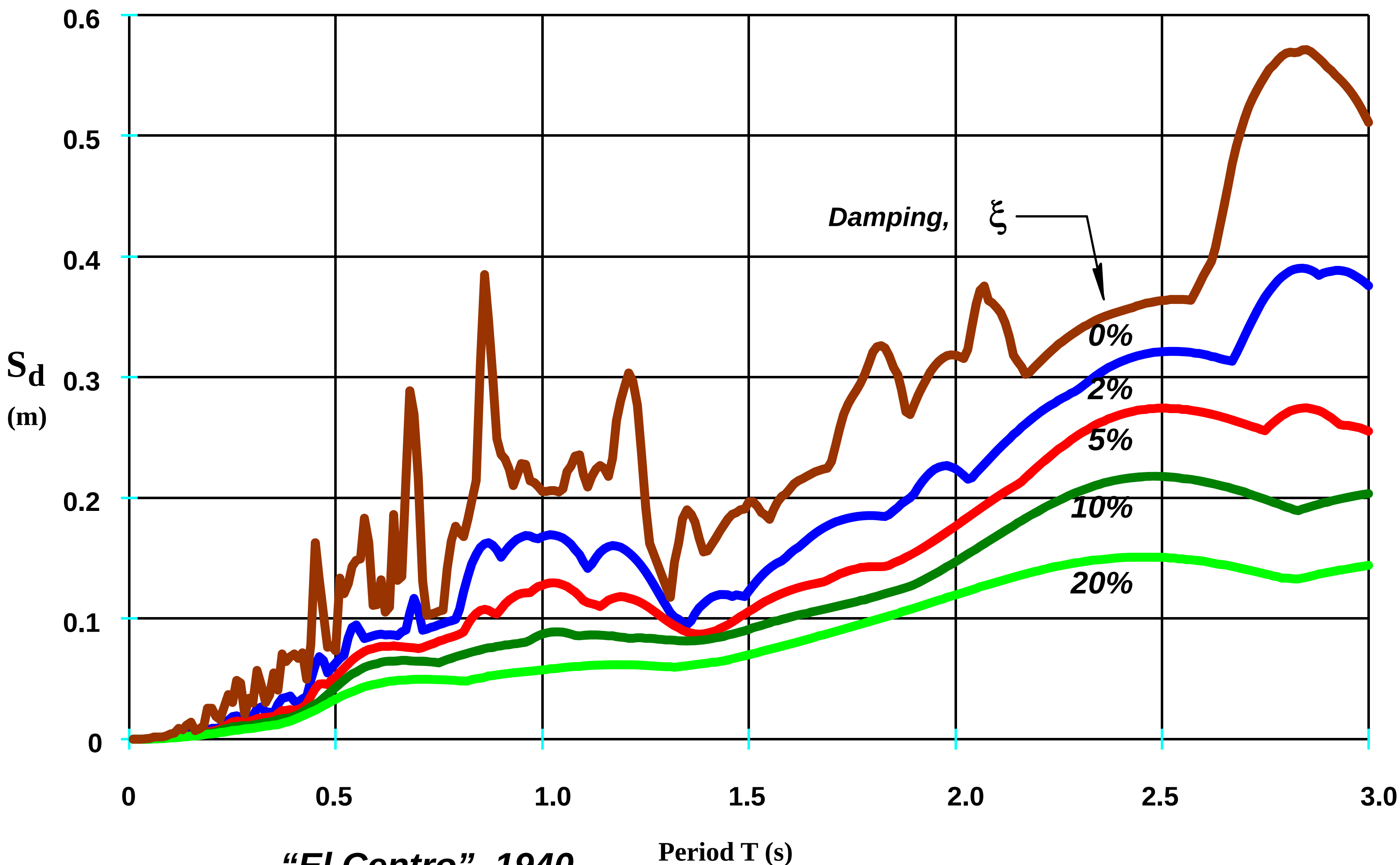


Displacement Response Spectrum



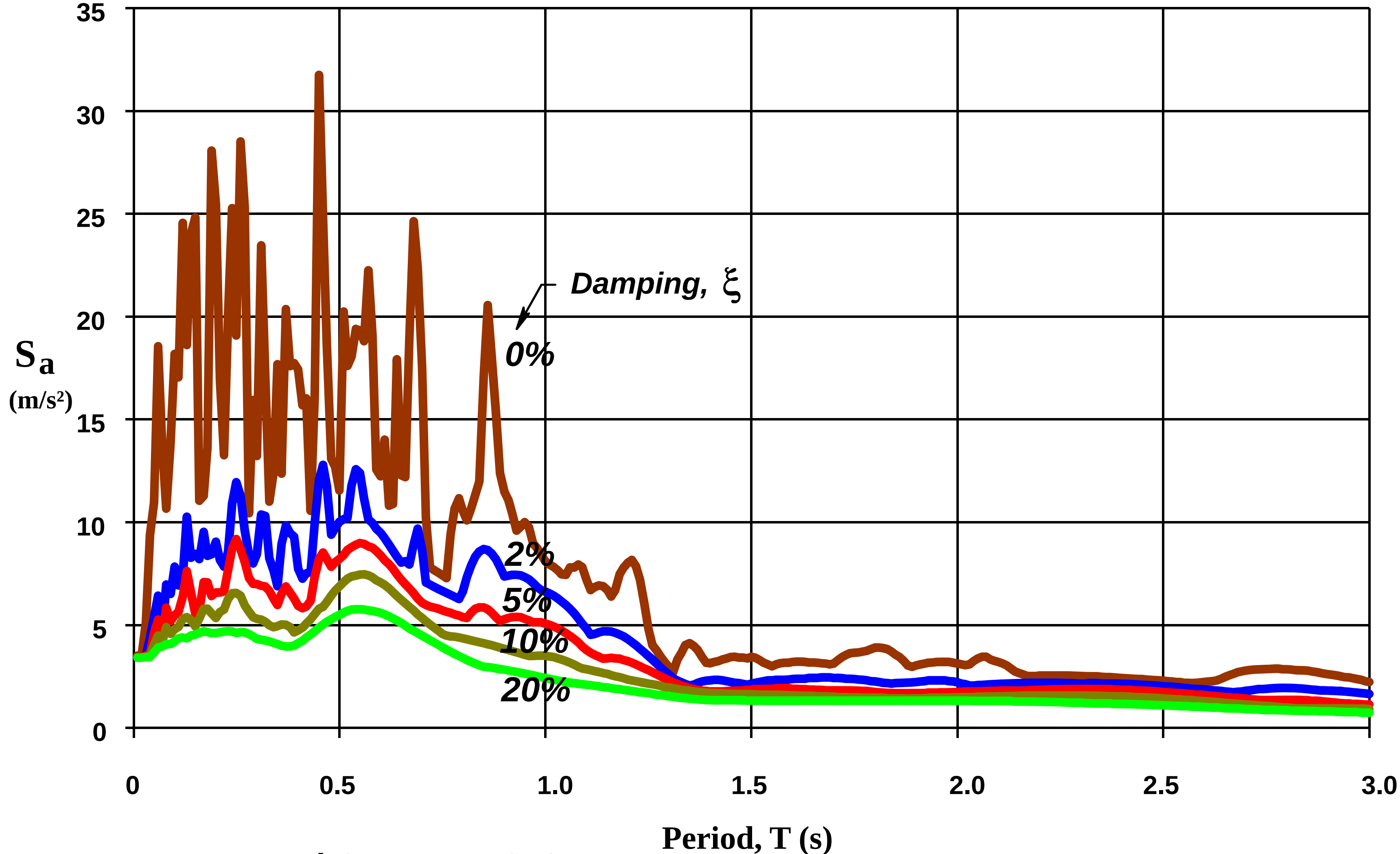
Computation of the displacement response spectrum

Displacement Response Spectra

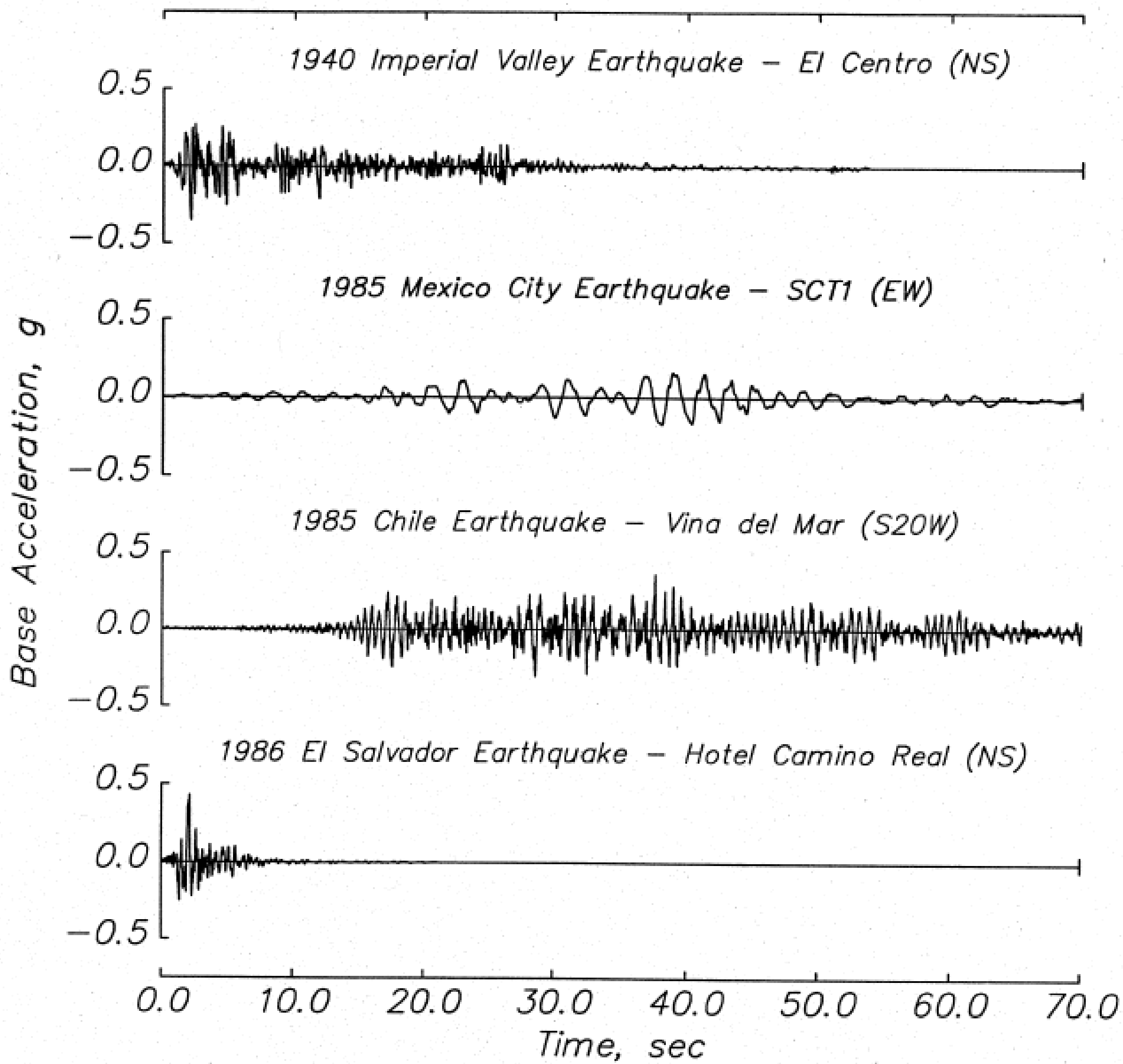


"El Centro", 1940

Acceleration Response Spectra

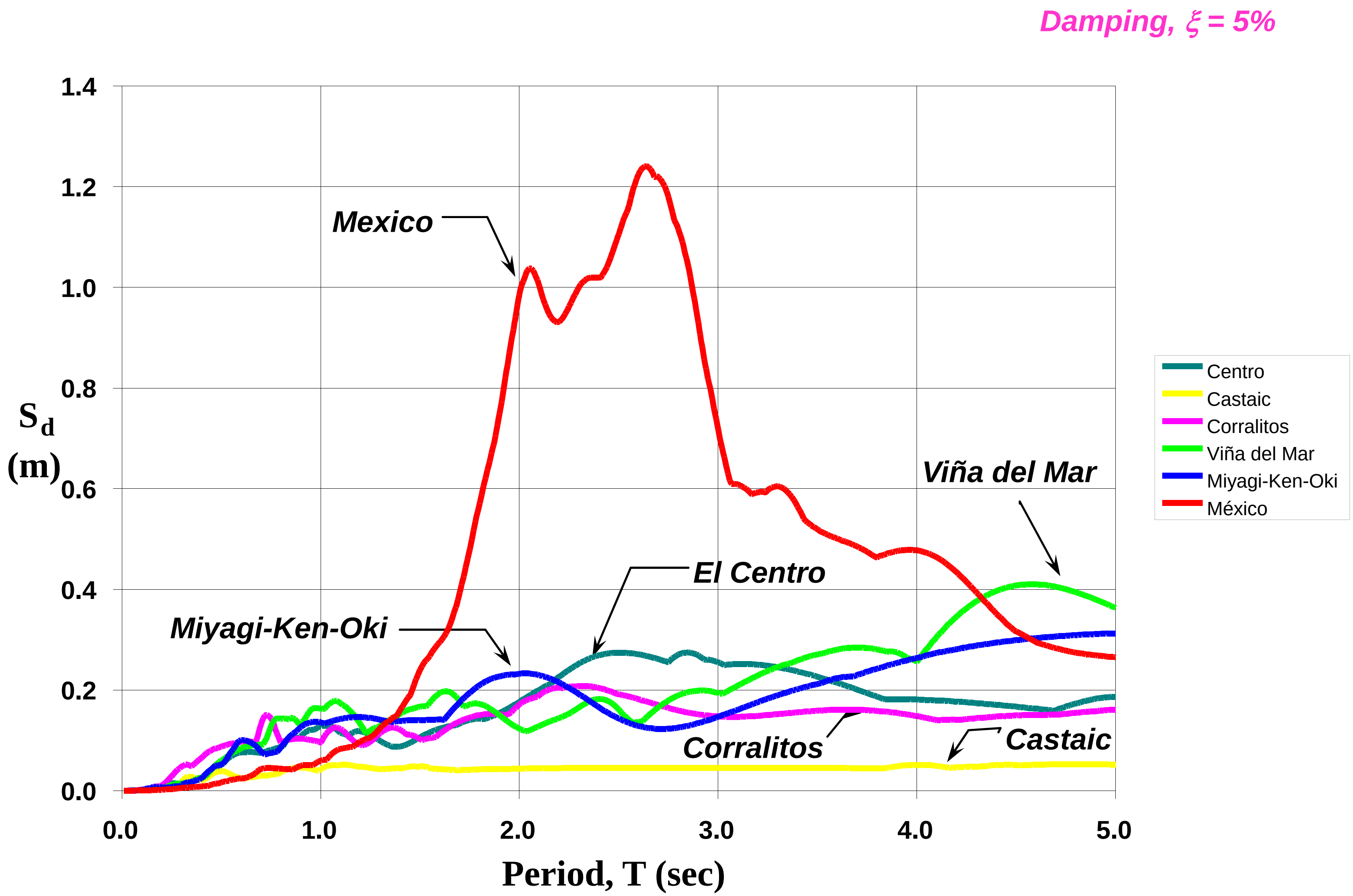


"El Centro", 1940

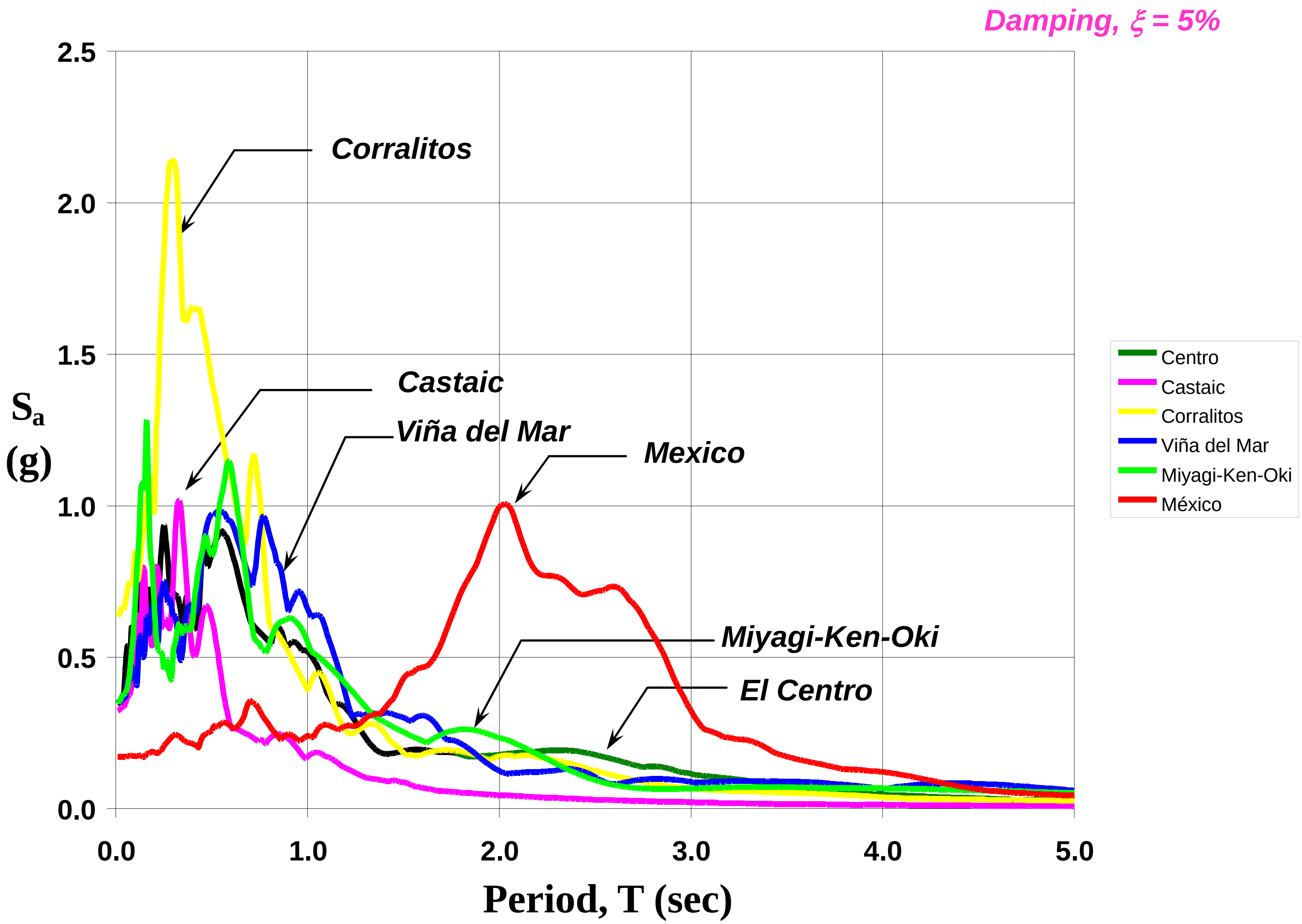


1940 Imperial Valley Earthquake – El Centro (NS)
1985 Mexico City Earthquake – SCT1 (EW)
1985 Chile Earthquake – Vina del Mar (S20W)
1986 El Salvador Earthquake – Hotel Camino Real (NS)
Base Acceleration, g
0.5
0.0
−0.5
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
Time, sec

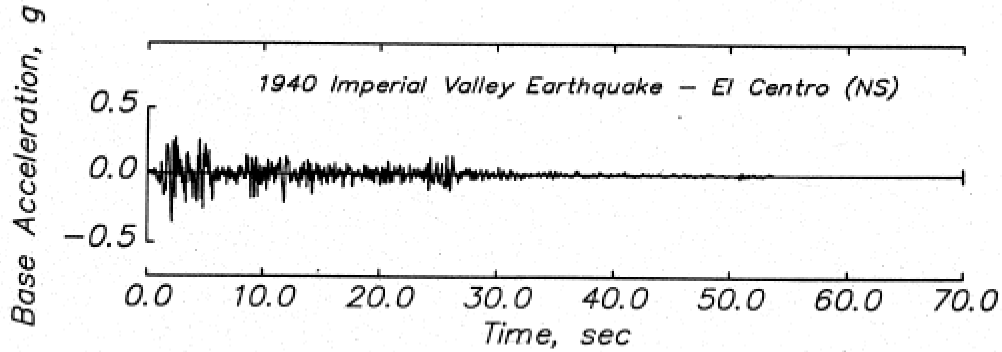
Displacement Response Spectra

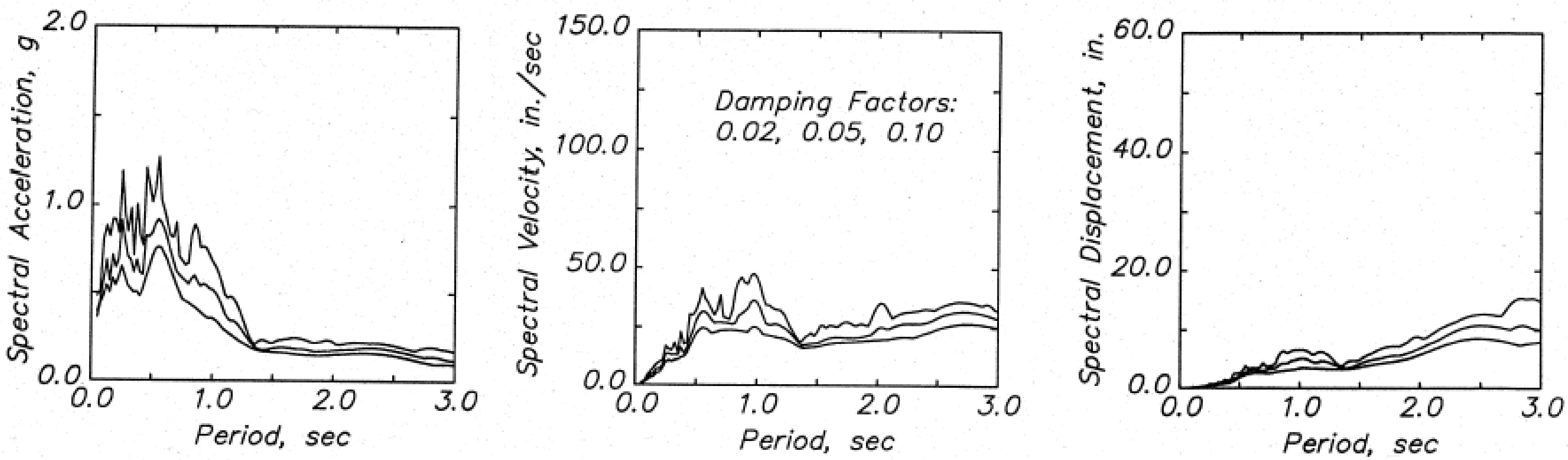


Acceleration Response Spectra

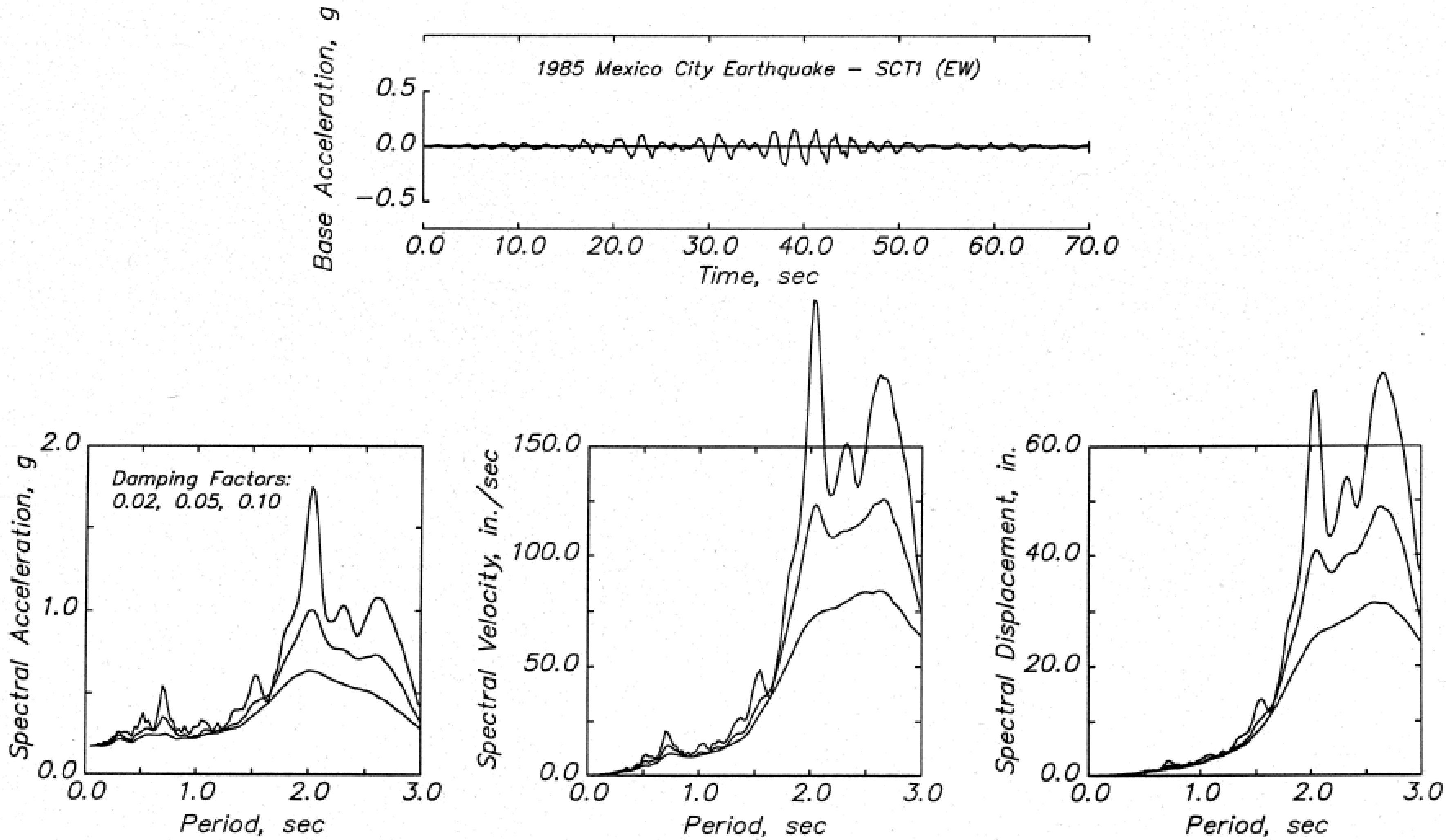


- Frequency content is critical.





• Frequency content is critical.



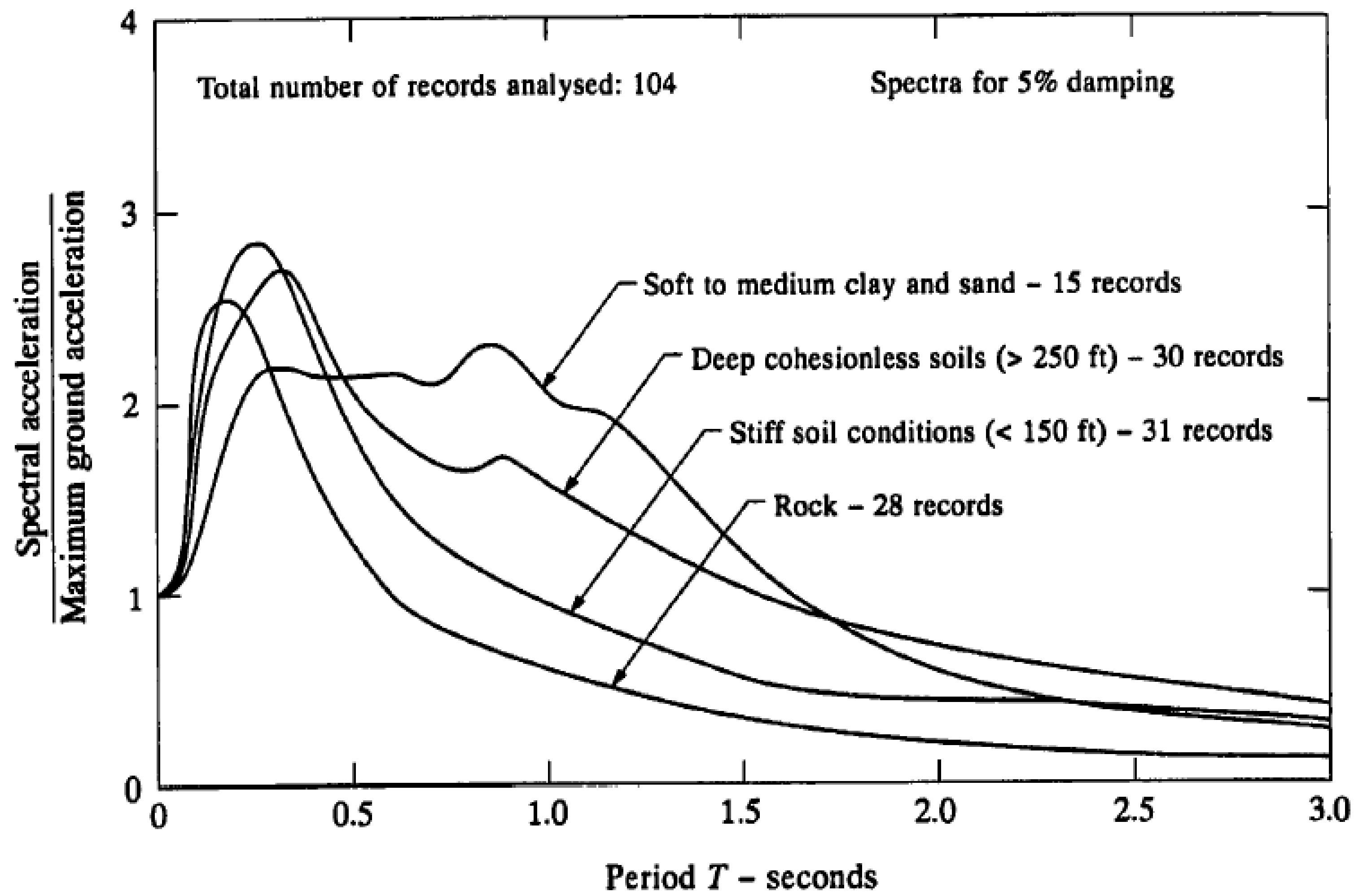


FIGURE 25-5
Average pseudo-acceleration spectra for different site conditions (by Seed et al.).

Response Spectrum Nomenclature

Spectral Displacement $= S_d = |x|_{max}$

Spectral Velocity $= S_v = |\dot{x}|_{max}$

Spectral Acceleration $= S_a = |\ddot{x} + \ddot{x}_g|_{max} = \left|2\xi\omega_n\dot{x} + \omega_n^2 x\right|_{max}$

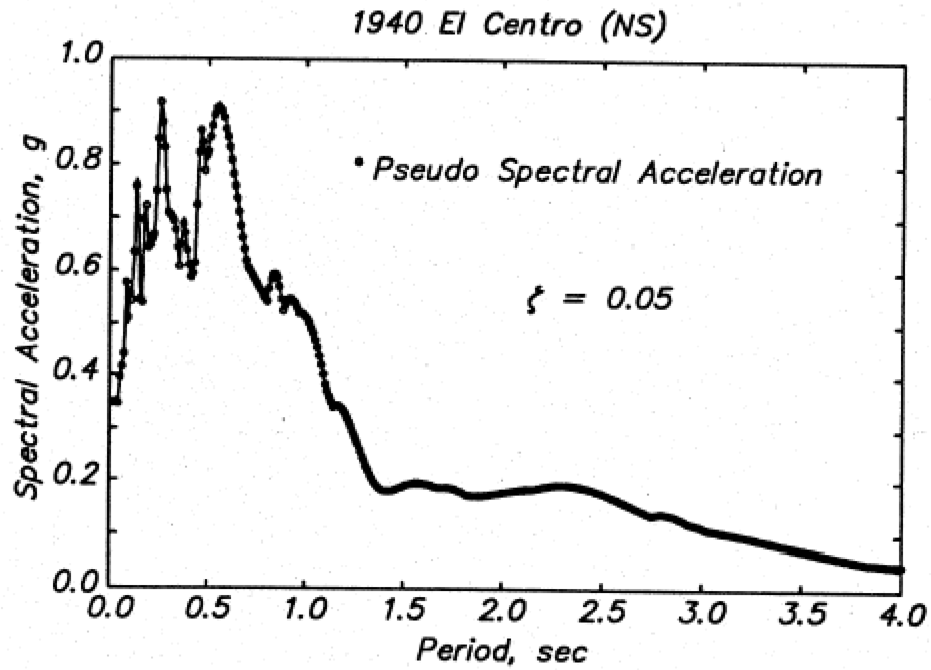
***Pseudo*-spectral velocity** $= PS_v = \omega_n \cdot S_d$

***Pseudo*-spectral acceleration** $= PS_a = \omega_n^2 \cdot S_d$

Define pseudo spectral acceleration:

$$PS_a = \omega^2 S_d$$

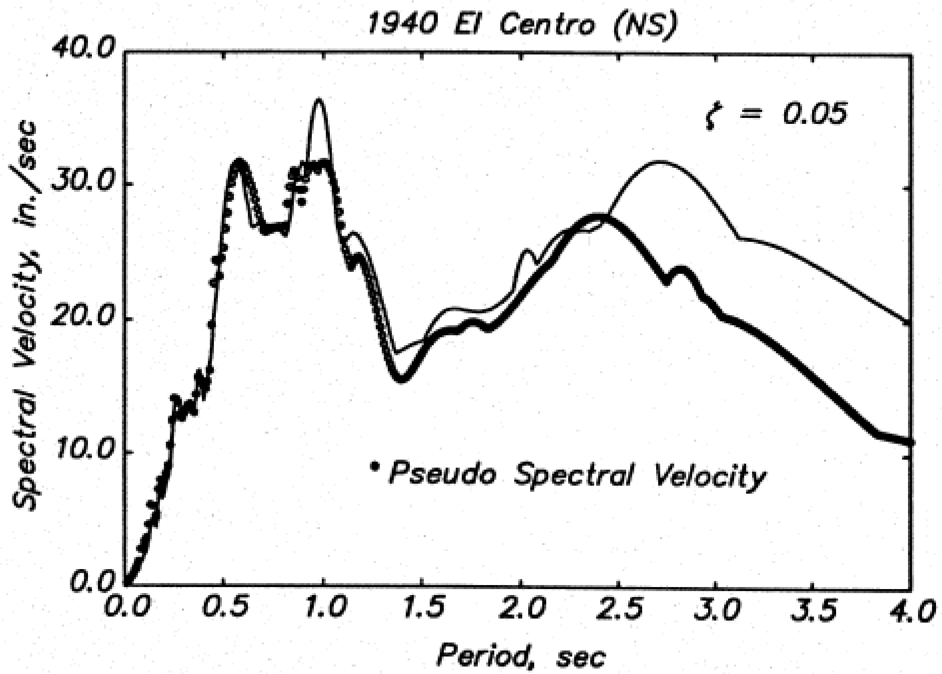
The pseudo spectral acceleration is equal to the natural frequency squared times the spectral displacement. Pseudo spectral acceleration has the same units as spectral acceleration.



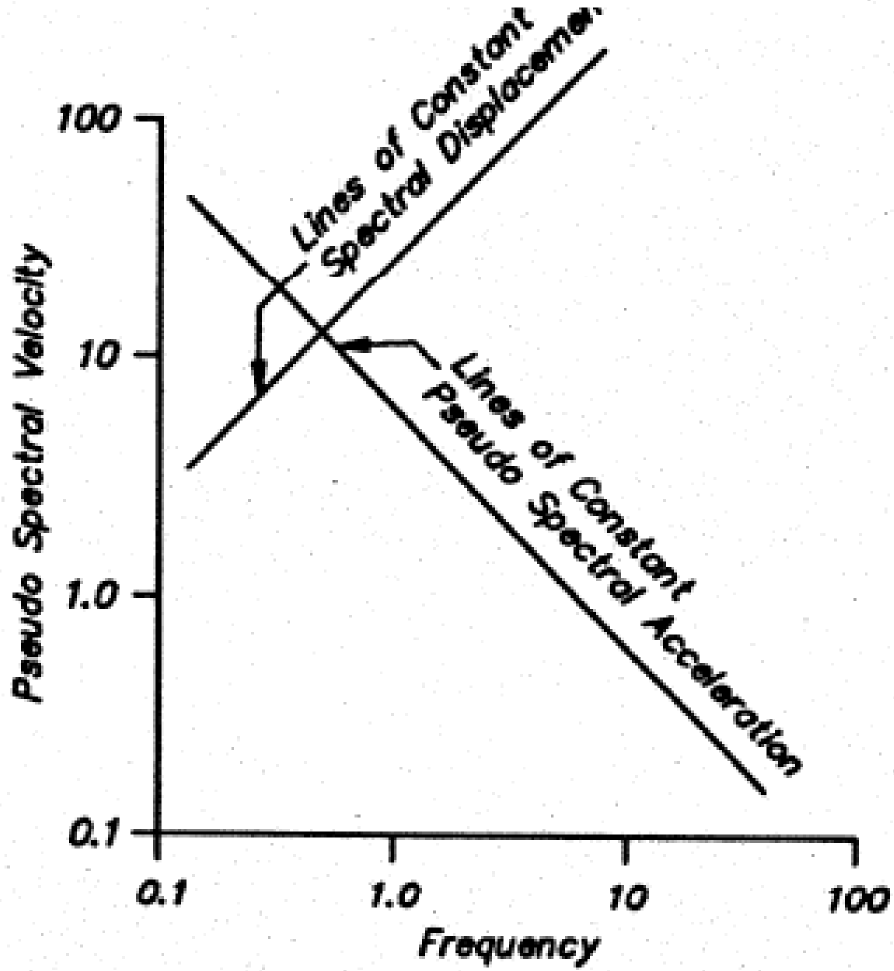
Define pseudo spectral velocity:

$$PS_v = \omega S_d$$

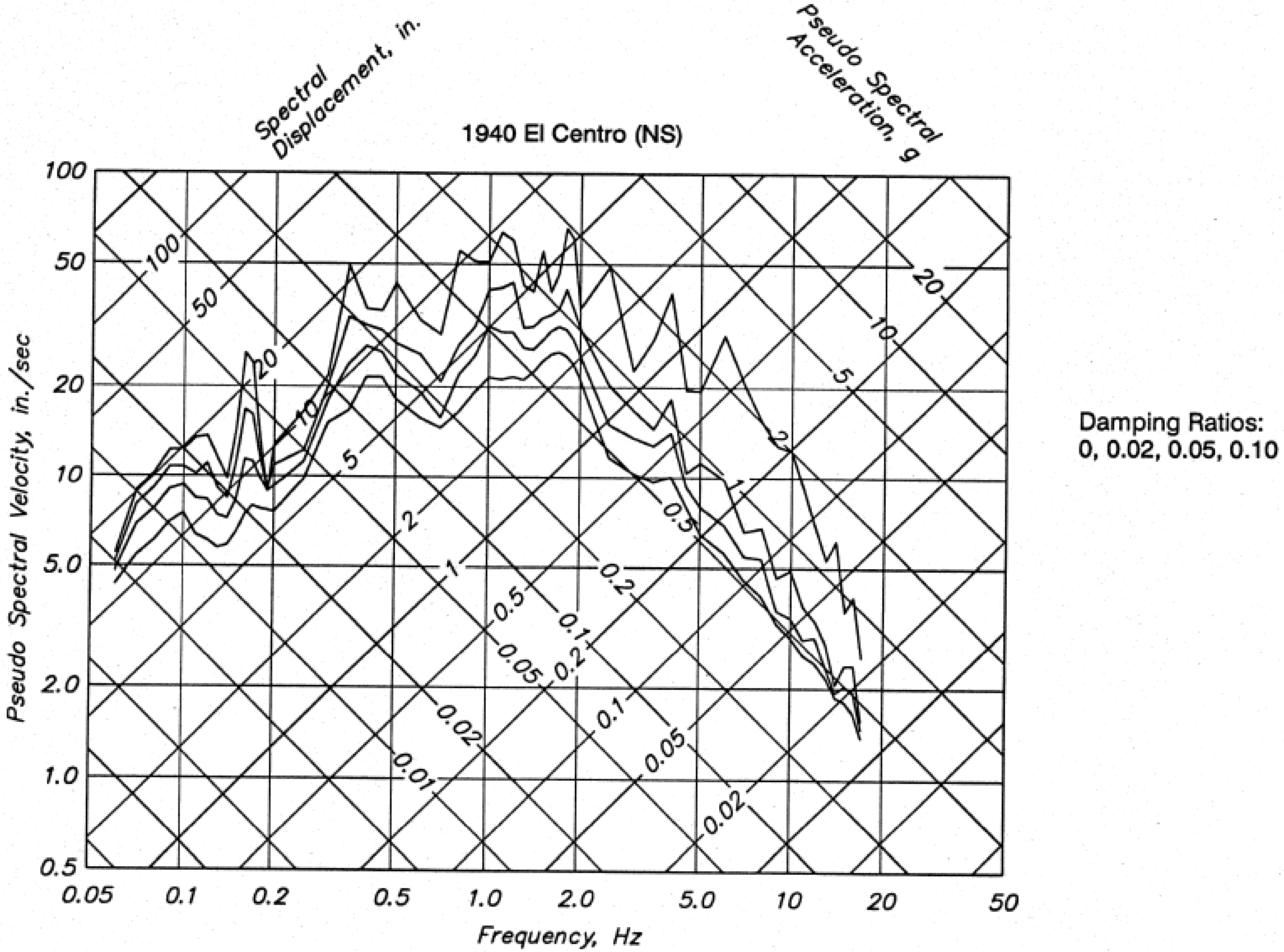
The pseudo spectral velocity is equal to the natural frequency times the spectral displacement. Pseudo spectral velocity has the same units as spectral velocity.



$$\log PS_a(\omega_n,\xi) = \log PS_v(\omega_n,\xi) + \log \omega_n$$
$$\log S_d(\omega_n,\xi) = \log PS_v(\omega_n,\xi) - \log \omega_n$$



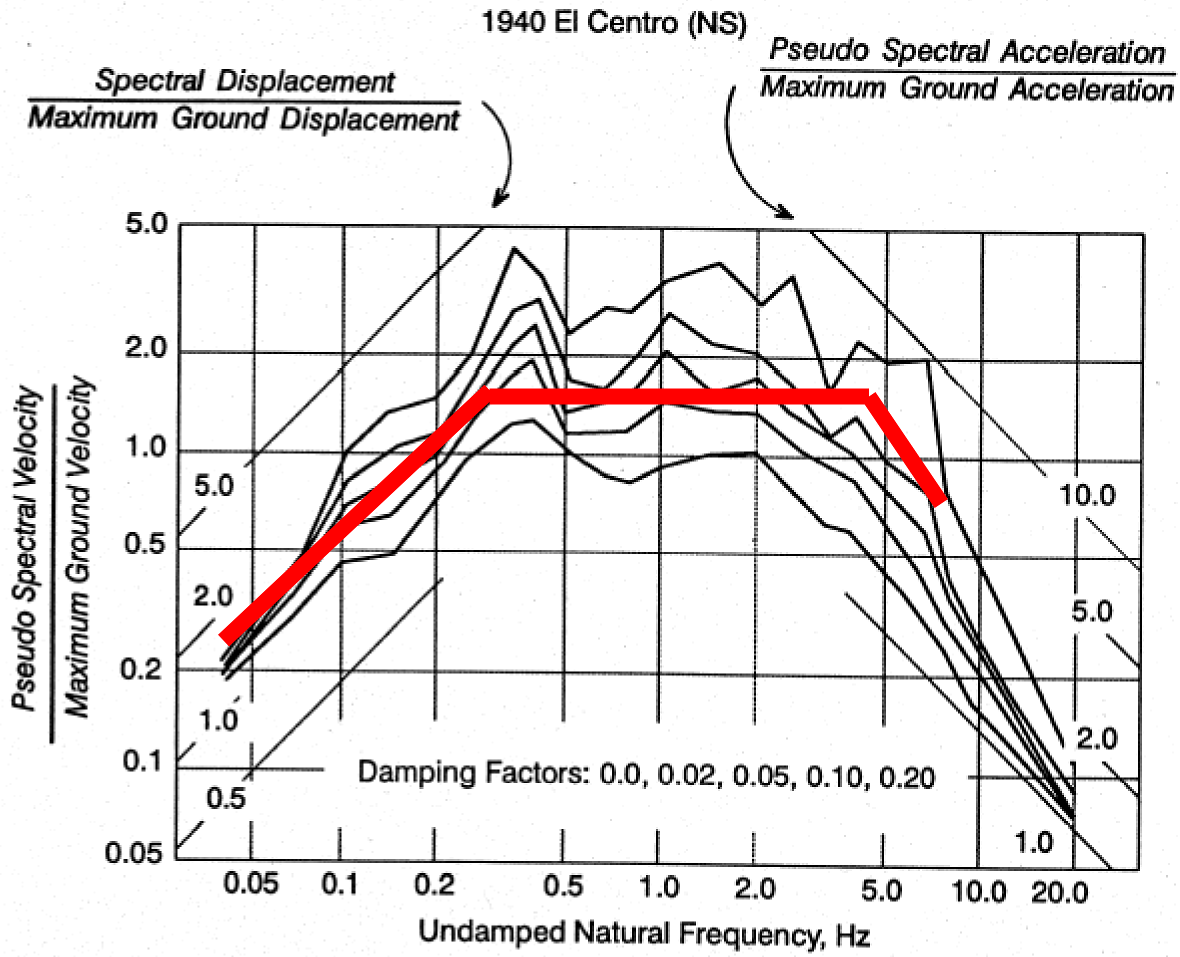
Log-Log plot
(a.k.a. tri-partite response spectrum plot)



PSA, PSV, SD vs. PGD, PGV, PGA

Although the logarithmic response spectra have an irregular shape, the general shape of elastic response spectra may be idealized as having regions of nearly constant spectral displacement, nearly constant pseudo spectral velocity, and nearly constant pseudo spectral acceleration.

Newmark and Hall chose to normalize the elastic response spectra using the maximum ground acceleration, the maximum ground velocity, and the maximum ground displacement.



Values of maximum ground displacement, maximum ground velocity, and maximum ground acceleration may be calculated from the measured ground acceleration records. The ground velocity and ground displacement records are obtained by integrating the measured ground acceleration history numerically.

Newmark and Hall considered a number of earthquake records and found statistical relationships between the amplitude of the spectral quantities and the peak ground response.

$$S_d = D \cdot d_{\max}$$
$$PS_v = V \cdot v_{\max}$$
$$PS_a = A \cdot a_{\max}$$

D, V, and A are the spectral amplification factors.
d_{max}, v_{max}, and a_{max} are the maximum ground displacement, velocity, and acceleration values, respectively.

Spectral Amplification Factors for Horizontal Ground Motion

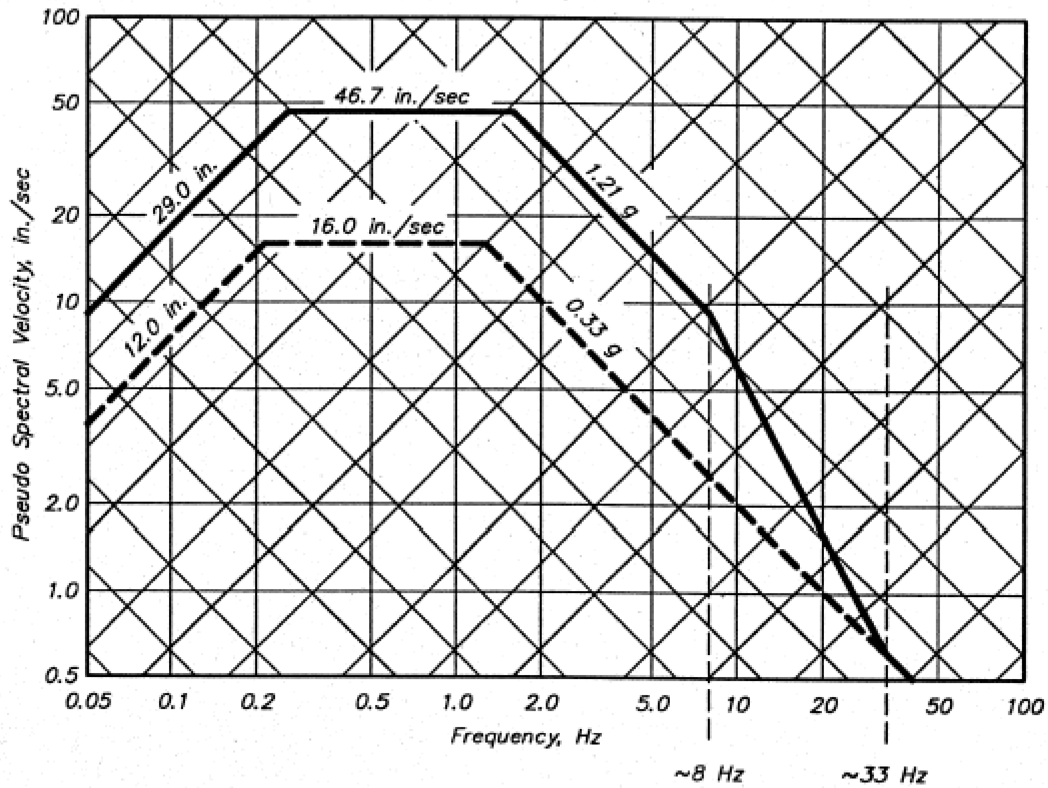
Damping Factor	One Sigma (84.1%)			Median (50%)		
	A	V	D	A	V	D
0.005	5.10	3.84	3.04	3.68	2.59	2.01
0.01	4.38	3.38	2.73	3.21	2.31	1.82
0.02	3.66	2.92	2.42	2.74	2.03	1.63
0.05	2.71	2.30	2.01	2.12	1.65	1.39
0.10	1.99	1.84	1.69	1.64	1.37	1.20
0.20	1.26	1.37	1.38	1.17	1.08	1.01

Example: Develop an elastic response spectrum for the following peak ground parameters. Use a damping factor of 0.02.

a_{max} = 0.33 g $\quad$ v_{max} = 16.0 in./sec $\quad$ d_{max} = 12.0 in.

The statistical data from Newmark and Hall yield the following amplification factors for the median plus one standard deviation:

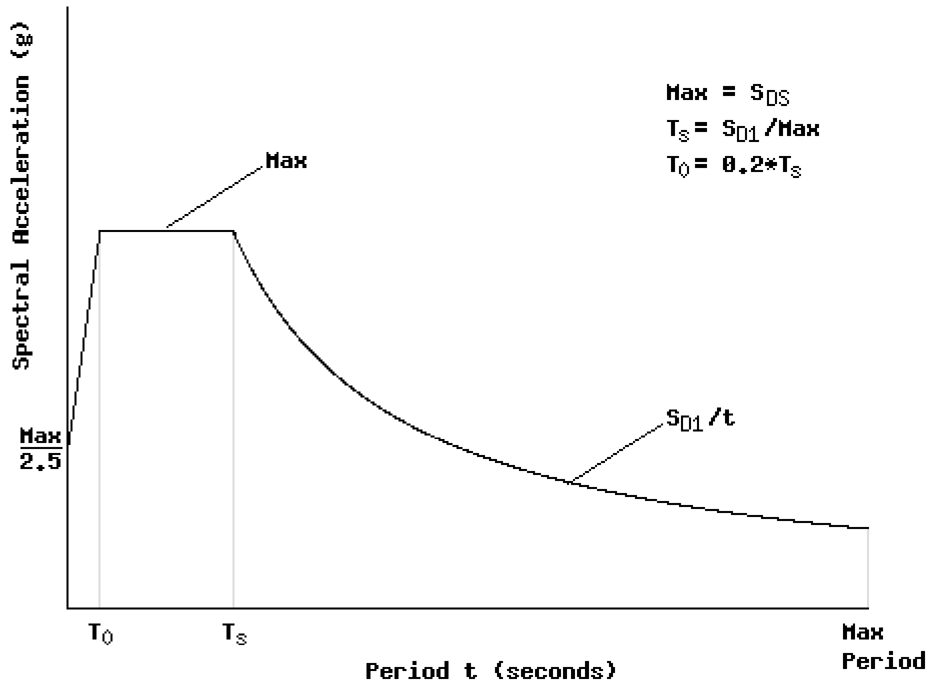
$A = 3.66$	$PS_a = A \cdot a_{max} = 3.66 \cdot 0.33$ g $= 1.21$ g
$V = 2.92$	$PS_v = V \cdot v_{max} = 2.92 \cdot 16.0$ in./sec $= 46.7$ in./sec
$D = 2.42$	$S_d = D \cdot d_{max} = 2.42 \cdot 12.0$ in. $= 29.0$ in.

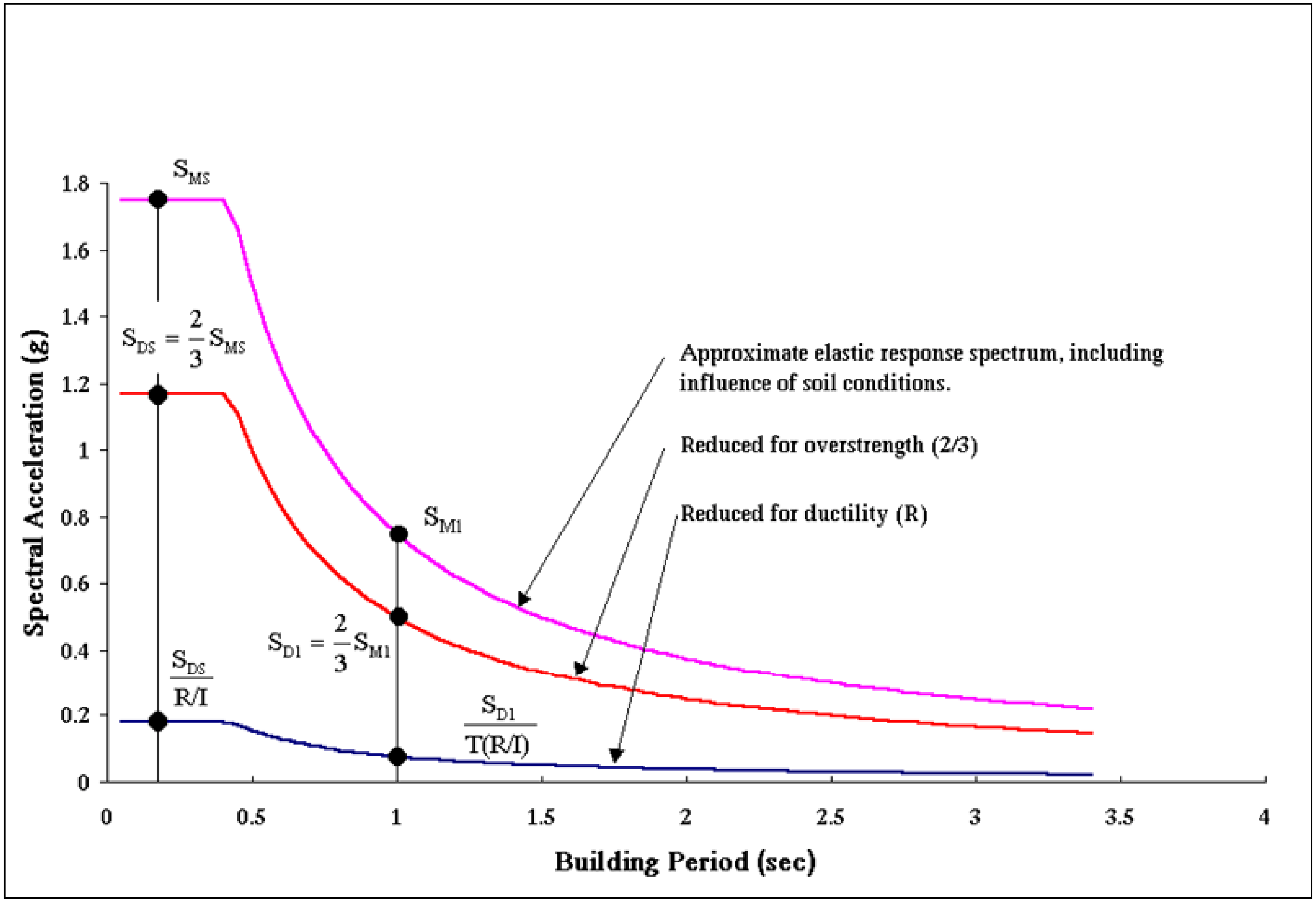


At high frequencies, the spectral acceleration converges to the peak ground acceleration. A linear interpolation is used between 8 and 33 Hz to reproduce this phenomenon.

Code/Design Spectrum

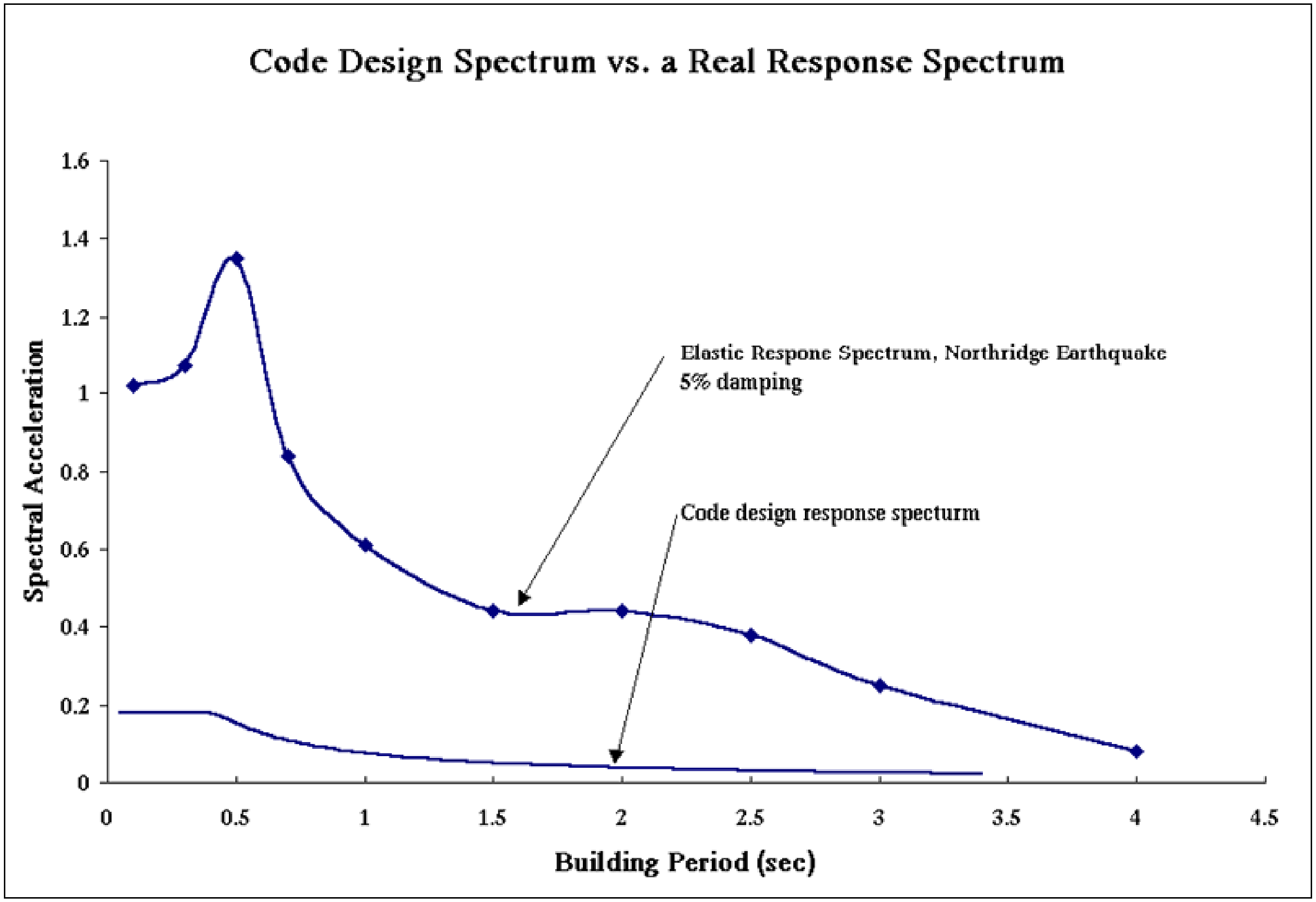
Typical Code Design Spectrum

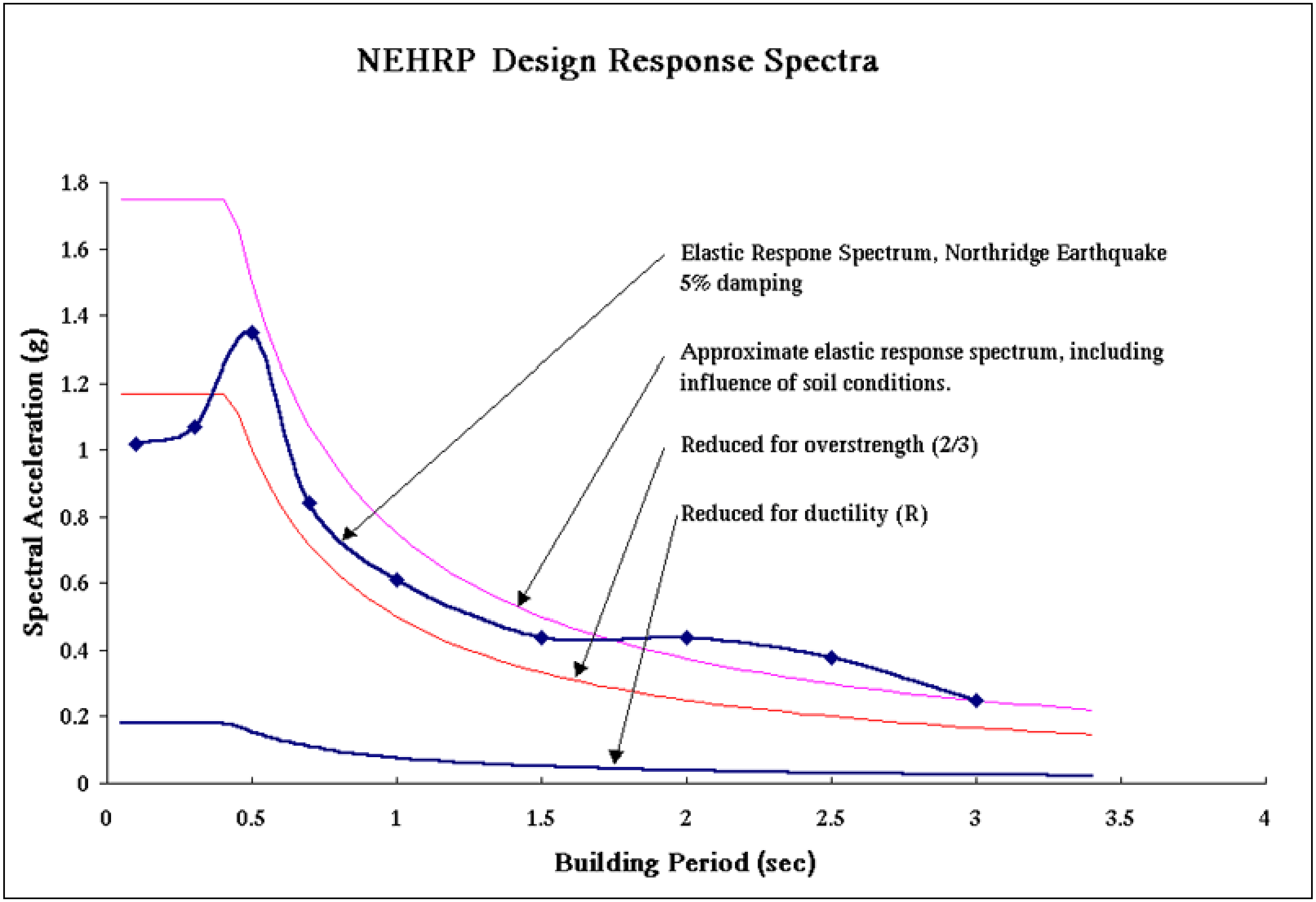




The code spectrum is an approximation of an elastic response spectrum, scaled down by two factors:

- It is reduced by the factor of safety used in allowable stress design to account for the fact to achieve the given yield strength, allowable stress design must aim at a lower strength. (for this case, $F_s = 1.5$)
- It is reduced by the R factor to account for damping and ductility. This reduction creates an inelastic spectrum which accounts for the effect of ductility in limiting force levels. (for this case, R=6.5)


Code Design Spectrum vs. a Real Response Spectrum
Spectral Acceleration
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Building Period (sec)
Elastic Respone Spectrum, Northridge Earthquake
5% damping
Code design response specturm



NEHRP Design Response Spectra
Spectral Acceleration (g)
Building Period (sec)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Elastic Respone Spectrum, Northridge Earthquake 5% damping
Approximate elastic response spectrum, including influence of soil conditions.
Reduced for overstrength (2/3)
Reduced for ductility (R)