NTUA – SCHOOL OF CIVIL ENGINEERING **16/3/2012**

CB22. ENGINEERING SEISMOLOGY

EXERCISE No 3

Calculate the Boore-Atkinson acceleration response spectrum for a 6.3 moment magnitude earthquake, on a normal fault, at a Joyner-Boore distance of 1 km and a soil deposit with V_{S30} = 360 m/sec. Afterwards, calculate the amplified spectrum in order to incorporate the directivity effect at the examined site.

THE DISTANCE AND MAGNITUDE FUNCTIONS

The distance function is given by:

$$F_D(R_{JB},\mathbf{M}) = [c_1 + c_2(\mathbf{M} - \mathbf{M}_{ref})]\ln(R/R_{ref}) + c_3(R - R_{ref}), \quad (3)$$

where

$$R = \sqrt{R_{JB}^2 + h^2} \quad (4)$$

and c_1, c_2, c_3, $\mathbf{M}_{ref}$, R_{ref}, and h are the coefficients to be determined in the analysis.

The magnitude scaling is given by:

a) $\mathbf{M} \leq \mathbf{M}_h$

$$F_M(\mathbf{M}) = e_1 U + e_2 SS + e_3 NS + e_4 RS + e_5(\mathbf{M} - \mathbf{M}_h) + e_6(\mathbf{M} - \mathbf{M}_h)^2, \quad (5a)$$

b) $\mathbf{M} > \mathbf{M}_h$

$$F_M(\mathbf{M}) = e_1 U + e_2 SS + e_3 NS + e_4 RS + e_7(\mathbf{M} - \mathbf{M}_h), \quad (5b)$$

where U, SS, NS, and RS are dummy variables used to denote unspecified, strike-slip, normal-slip, and reverse-slip fault type, respectively, as given by the values in Table 2, and $\mathbf{M}_h$, the "hinge magnitude" for the shape of the magnitude scaling, is a coefficient to be set during the analysis.

SITE AMPLIFICATION FUNCTION

The site amplification equation is given by:

$$F_S = F_{LIN} + F_{NL}, \quad (6)$$

where F_{LIN} and F_{NL} are the linear and nonlinear terms, respectively.

The linear term is given by:

$$F_{LIN} = b_{lin} \ln(V_{S30}/V_{ref}), \quad (7)$$

where b_{lin} is a period-dependent coefficient, and V_{ref} is the specified reference velocity (=760 m/s), corresponding to NEHRP B/C boundary site conditions; these coefficients

were prescribed based on the work of Choi and Stewart (2005; hereafter "CS05"); they are empirically based but were not determined by the regression analysis in our study.

The nonlinear term is given by:

a) $pga4nl \leq a_1$:

$$F_{NL} = b_{nl} \ln(pga\_low/0.1) \quad (8a)$$

b) $a_1 < pga4nl \leq a_2$:

$$F_{NL} = b_{nl} \ln(pga\_low/0.1) + c[\ln(pga4nl/a_1)]^2 + d[\ln(pga4nl/a_1)]^3 \quad (8b)$$

c) $a_2 < pga4nl$:

$$F_{NL} = b_{nl} \ln(pga4nl/0.1) \quad (8c)$$

where a_1 (=0.03 g) and a_2 (=0.09 g) are assigned threshold levels for linear and non-linear amplification, respectively, pga_low (=0.06 g) is a variable assigned to transition between linear and nonlinear behaviors, and $pga4nl$ is the predicted PGA in g for V_{ref} =760 m/s, as given by Equation 1 with F_S=0 and ε=0. The three equations for the non-linear portion of the soil response (Equation 8a–8c) are required for two reasons: 1) to prevent the nonlinear amplification from increasing indefinitely as $pga4nl$ decreases and

2) to smooth the transition from linear to non-linear behavior. The coefficients c and d in Equation 8b are given by

$$c = (3\Delta y - b_{nl}\Delta x)/\Delta x^2 \tag{9}$$

and

$$d = -(2\Delta y - b_{nl}\Delta x)/\Delta x^3, \tag{10}$$

where

$$\Delta x = \ln(a_2/a_1) \tag{11}$$

and

$$\Delta y = b_{nl}\ln(a_2/pga\_low). \tag{12}$$

The nonlinear slope b_{nl} is a function of both period and V_{S30} as given by:

a) $V_{S30} \leq V_1$:

$$b_{nl} = b_1. \tag{13a}$$

b) $V_1 < V_{S30} \leq V_2$:

$$b_{nl} = (b_1 - b_2)\ln(V_{S30}/V_2)/\ln(V_1/V_2) + b_2. \tag{13b}$$

c) $V_2 < V_{S30} < V_{ref}$:

$$b_{nl} = b_2 \ln(V_{S30}/V_{ref})/\ln(V_2/V_{ref}). \tag{13c}$$

d) $V_{ref} \leq V_{S30}$:

$$b_{nl} = 0.0. \tag{13d}$$

where $V_1 = 180$ m/s, $V_2 = 300$ m/s, and b_1 and b_2 are period-dependent coefficients (and consequently, b_{nl} is a function of period as well as V_{S30}). These equations are a simplified version of those used by CS05.

Table 6. Distance-scaling coefficients ($\mathbf{M}_{ref}$=4.5 and R_{ref}=1.0 km for all periods, except R_{ref}=5.0 km for $pga4nl$)

Period	c_1	c_2	c_3	h
PGV	−0.87370	0.10060	−0.00334	2.54
PGA	−0.66050	0.11970	−0.01151	1.35
0.010	−0.66220	0.12000	−0.01151	1.35
0.020	−0.66600	0.12280	−0.01151	1.35
0.030	−0.69010	0.12830	−0.01151	1.35
0.050	−0.71700	0.13170	−0.01151	1.35
0.075	−0.72050	0.12370	−0.01151	1.55
0.100	−0.70810	0.11170	−0.01151	1.68
0.150	−0.69610	0.09884	−0.01113	1.86
0.200	−0.58300	0.04273	−0.00952	1.98
0.250	−0.57260	0.02977	−0.00837	2.07
0.300	−0.55430	0.01955	−0.00750	2.14
0.400	−0.64430	0.04394	−0.00626	2.24
0.500	−0.69140	0.06080	−0.00540	2.32
0.750	−0.74080	0.07518	−0.00409	2.46
1.000	−0.81830	0.10270	−0.00334	2.54
1.500	−0.83030	0.09793	−0.00255	2.66
2.000	−0.82850	0.09432	−0.00217	2.73
3.000	−0.78440	0.07282	−0.00191	2.83
4.000	−0.68540	0.03758	−0.00191	2.89
5.000	−0.50960	−0.02391	−0.00191	2.93
7.500	−0.37240	−0.06568	−0.00191	3.00
10.000	−0.09824	−0.13800	−0.00191	3.04

Table 2. Values of dummy variables for different fault types

Fault Type	U	SS	NS	RS
Unspecified	1	0	0	0
Strike-slip	0	1	0	0
Normal	0	0	1	0
Thrust/reverse	0	0	0	1

Table 7. Magnitude-scaling coefficients

Period	e_1	e_2	e_3	e_4	e_5	e_6	e_7	$\mathbf{M}_h$
PGV	5.00121	5.04727	4.63188	5.08210	0.18322	−0.12736	0.00000	8.50
PGA	−0.53804	−0.50350	−0.75472	−0.50970	0.28805	−0.10164	0.00000	6.75
0.010	−0.52883	−0.49429	−0.74551	−0.49966	0.28897	−0.10019	0.00000	6.75
0.020	−0.52192	−0.48508	−0.73906	−0.48895	0.25144	−0.11006	0.00000	6.75
0.030	−0.45285	−0.41831	−0.66722	−0.42229	0.17976	−0.12858	0.00000	6.75
0.050	−0.28476	−0.25022	−0.48462	−0.26092	0.06369	−0.15752	0.00000	6.75
0.075	0.00767	0.04912	−0.20578	0.02706	0.01170	−0.17051	0.00000	6.75
0.100	0.20109	0.23102	0.03058	0.22193	0.04697	−0.15948	0.00000	6.75
0.150	0.46128	0.48661	0.30185	0.49328	0.17990	−0.14539	0.00000	6.75
0.200	0.57180	0.59253	0.40860	0.61472	0.52729	−0.12964	0.00102	6.75
0.250	0.51884	0.53496	0.33880	0.57747	0.60880	−0.13843	0.08607	6.75
0.300	0.43825	0.44516	0.25356	0.51990	0.64472	−0.15694	0.10601	6.75
0.400	0.39220	0.40602	0.21398	0.46080	0.78610	−0.07843	0.02262	6.75
0.500	0.18957	0.19878	0.00967	0.26337	0.76837	−0.09054	0.00000	6.75
0.750	−0.21338	−0.19496	−0.49176	−0.10813	0.75179	−0.14053	0.10302	6.75
1.000	−0.46896	−0.43443	−0.78465	−0.39330	0.67880	−0.18257	0.05393	6.75
1.500	−0.86271	−0.79593	−1.20902	−0.88085	0.70689	−0.25950	0.19082	6.75
2.000	−1.22652	−1.15514	−1.57697	−1.27669	0.77989	−0.29657	0.29888	6.75
3.000	−1.82979	−1.74690	−2.22584	−1.91814	0.77966	−0.45384	0.67466	6.75
4.000	−2.24656	−2.15906	−2.58228	−2.38168	1.24961	−0.35874	0.79508	6.75
5.000	−1.28408	−1.21270	−1.50904	−1.41093	0.14271	−0.39006	0.00000	8.50
7.500	−1.43145	−1.31632	−1.81022	−1.59217	0.52407	−0.37578	0.00000	8.50
10.000	−2.15446	−2.16137	−2.53323	−2.14635	0.40387	−0.48492	0.00000	8.50

Table 4. Period-independent site-amplification coefficients

Coefficient	Value
a_1	0.03 g
pga_low	0.06 g
a_2	0.09 g
V_1	180 m/s
V_2	300 m/s
V_{ref}	760 m/s

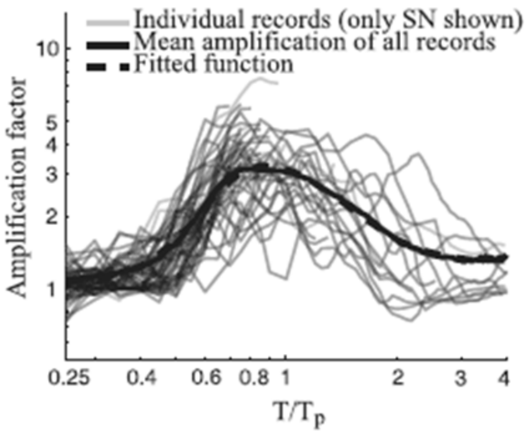
Table 3. Period-dependent site-amplification coefficients

Period	b_{lin}	b_1	b_2
PGV	−0.600	−0.500	−0.06
PGA	−0.360	−0.640	−0.14
0.010	−0.360	−0.640	−0.14
0.020	−0.340	−0.630	−0.12
0.030	−0.330	−0.620	−0.11
0.050	−0.290	−0.640	−0.11
0.075	−0.230	−0.640	−0.11
0.100	−0.250	−0.600	−0.13
0.150	−0.280	−0.530	−0.18
0.200	−0.310	−0.520	−0.19
0.250	−0.390	−0.520	−0.16
0.300	−0.440	−0.520	−0.14
0.400	−0.500	−0.510	−0.10
0.500	−0.600	−0.500	−0.06
0.750	−0.690	−0.470	0.00
1.000	−0.700	−0.440	0.00
1.500	−0.720	−0.400	0.00
2.000	−0.730	−0.380	0.00
3.000	−0.740	−0.340	0.00
4.000	−0.750	−0.310	0.00
5.000	−0.750	−0.291	0.00
7.500	−0.692	−0.247	0.00
10.000	−0.650	−0.215	0.00

Period-magnitude relationship

$$\log\ T_P = -2.9 + 0.5M_w$$

BELL SHAPED AMPLIFICATION AROUND Tp



$$\ln Af = \begin{cases} 1.131 \cdot \exp(-3.11 \cdot [\ln(T/T_p) + 0.127]^2) + 0.058 & \text{για } T \leq 0.88 \cdot T_p \\ 0.896 \cdot \exp(-2.11 \cdot [\ln(T/T_p) + 0.127]^2) + 0.255 & \text{για } T > 0.88 \cdot T_p \end{cases}$$