



The influence of ground motion characteristics on site response coefficients

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ABSTRACT: Site response coefficients are used by many building codes to relate rock motions to corresponding motions for site conditions other than rock. The site response coefficients in the latest edition of the *NEHRP* Provisions were derived from observed earthquake motions, largely supplemented by data from numerical site response analyses. The input motions used in the site response analyses were wide ranging in characteristics, with the derived site amplification coefficients specified universally across the US. However, the amplification of seismic waves varies as a function of the motions' frequency content relative to the *elastic* dynamic characteristics of the soil profile, in addition to factors such as impedance ratio and soil non-linearity. Given the difference in the frequency characteristics of the ground motions observed in the various tectonic regimes across the US, it should not be expected that similar soil profiles located across the US will amplify motions similarly, if subjected to regionally-characteristic earthquakes, irrespective of soil non-linearity. Examined herein is the influence of the frequency characteristics of ground motion on the ratio of the computed soil surface *pga* to the corresponding rock outcrop *pga*, with a clear trend being identified, providing credence for the development of region specific site response coefficients.

1 INTRODUCTION

The amplification of seismic waves propagated up through a soil column is a function of the dynamic response characteristics of the soil profile, the characteristics of the base rock motions (or the corresponding rock outcrop motions), and the impedance contrast between the soil profile and underlying base rock. One way to quantify the influence of site conditions on motions experienced at the surface of a profile is by the ratio of the 5% damped response spectra (*RRS*) of profile surface motions to the corresponding motions on a reference site condition (e.g., "firm" rock outcrop). This approach forms the basis of the site response coefficients used in many building codes, and alleviates the need to generate multiple sets of seismic hazard maps for each of the various site classifications. Corresponding design spectra for different site classes can be determined using seismic hazard maps for the reference site condition in conjunction with the appropriate site response coefficients.

The preliminary results of a study examining the influence of the frequency content of the ground motion on site response coefficients are presented herein. These results are used to outline a new approach that explicitly incorporates the natural period of the soil profile relative to the frequency characteristics of the rock motion. Primary attention in the preliminary phase of this work is given to the amplification of short period motions by soft soil profiles (i.e., site class *E*, *NEHRP* 2001). For the profiles analysed, a clear trend is identified between the characteristic period of the ground motion and the amplification of short period motions, thus providing credence for the development of site response coefficients specific to the characteristics of motions in the various tectonic regimes, rather than the universal coefficients currently specified in the *NEHRP* Provisions.

2 BACKGROUND

The large amplification of seismic motions in soft soil profiles experienced during the 1985 Mexico City and 1989 Loma Prieta earthquakes was the impetus for the dramatic increases in the site response coefficients for soft soil sites that appeared in the 1994 Edition of the *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (NEHRP Provisions) (Rinne 1994). The essence of these changes was retained in the 1997 and 2000 Editions, with the latter being the latest version published. The 2000 Edition of the *NEHRP Provisions* (NEHRP 2001) specifies two amplitude-dependent site response coefficients: F_a for short periods (0.2sec) and F_v for long periods (1.0sec) (Dobry et al. 2000). In addition to recorded earthquake data, the currently codified values for F_a and F_v were derived from numerical site response analyses, with the derived values specified for universal use across the US. The input motions used in these site response analyses were wide ranging in characteristics (e.g., frequency content, duration, peak amplitude), representing motions that could potentially be experienced in the various tectonic regimes in the US (Dobry et al. 1994).

As mentioned previously, the current values for F_a and F_v are based on quantifying the influence of site conditions on ground motions by *RRS*. It is important to understand that a given soil profile does not have a unique *RRS*, irrespective of the effects of soil non-linearity. This is in contrast to the transfer function, which is unique for a linear (i.e., non-degrading) profile. Wherein, the transfer function is defined as the ratio of the Fourier amplitude spectrum (*FAS*) of surface motions for a given site condition to the *FAS* of the corresponding motions on a reference site condition (e.g., firm rock outcrop). Figure 1 illustrates the general relationship between the transfer function and *RRS* of two free-field, rock outcrop motions recorded during the 1989 Loma Prieta earthquake at different distances from the fault rupture (i.e., g01090: 11.2km and rin090: 79.7km). Both the transfer function and the *RRS* were computed using a modified version of SHAKE91 (Idriss and Sun 1992). The motions were propagated up through the Redwood Shores soil profile (Dobry 1991), with the soil properties held at their small strain values (i.e., no soil non-linearity). The Redwood Shores soil profile has a small strain fundamental period (T_n) of approximately 2 seconds and was one of the profiles used in developing the currently codified site response coefficients for site class *E* profiles. As may be seen in Figure 1, the motion recorded near the source (i.e., g01090) generally showed less amplification (i.e., smaller *RRS* values) at shorter periods, relative to the motion recorded at a longer site-to-source distance. Because the soil properties were not allowed to degrade from their small strain values, this trend is independent of the amplitude of the input motions and is a function of the elastic dynamic response characteristics of the soil profile and the frequency content of the input motions. The motion recorded closer to the source was relatively rich in high frequencies, as compared to the motion recorded at a greater site-to-source distance. Similar trends in *RRS* as a function of frequency content of the motion was noted for other motions and soft soil profiles analysed.

For all intents and purposes, the spectral acceleration at 0.01sec is equal to peak ground acceleration (*pga*). Accordingly, the *RRS* at 0.01sec represents the ratio of the *pga* of motions at the surface of the soil profile and the corresponding rock outcrop motions. Figure 2a shows the relationship between the *pga* for soft soil profiles and corresponding rock outcrop motions observed during the 1985 Mexico City and 1989 Loma Prieta earthquakes, supplemented with data from numerical site response analyses (Idriss 1990). As may be seen in this figure, the peak ground accelerations (*pga*) at soft soil sites are significantly larger than those experienced on nearby rock sites, for rock accelerations below 0.4g. The de-amplification of soil surface accelerations, as compared to rock accelerations above 0.4g, has been attributed to soil non-linearity (e.g., Dobry et al. 2000, Borchardt 2002).

Employing an analogous definition to effective peak acceleration (*EPA*) given in ATC 3-06 (ATC 1978), the relationship between the *pga* for soft soil profiles and corresponding rock outcrop motions shown in Figure 2a can be related to the currently codified values for F_a for site class *E* profiles. This relationship is illustrated in Figure 2b, wherein *EPA* is defined as the spectral acceleration at 0.2sec divided by 2.5. As may be seen in this figure, there is good agreement between the soft soil curve proposed by Idriss (1990) and the F_a values for site class *E*. However, also shown in Figure 2b is the relationship between *pga* for soft soil profiles and corresponding rock outcrop motions observed

during the 1999 Chi-Chi (Taiwan) earthquake (Idriss and Abrahamson 2000). As may be seen in this figure, the curve for the Chi-Chi earthquake is considerably lower than the other two curves. Referring back to Figure 1, the authors hypothesise that one reason for the dichotomy between the curves shown in Figure 2b may be the frequency content of the rock motion, relative to the fundamental period of the soil profiles.

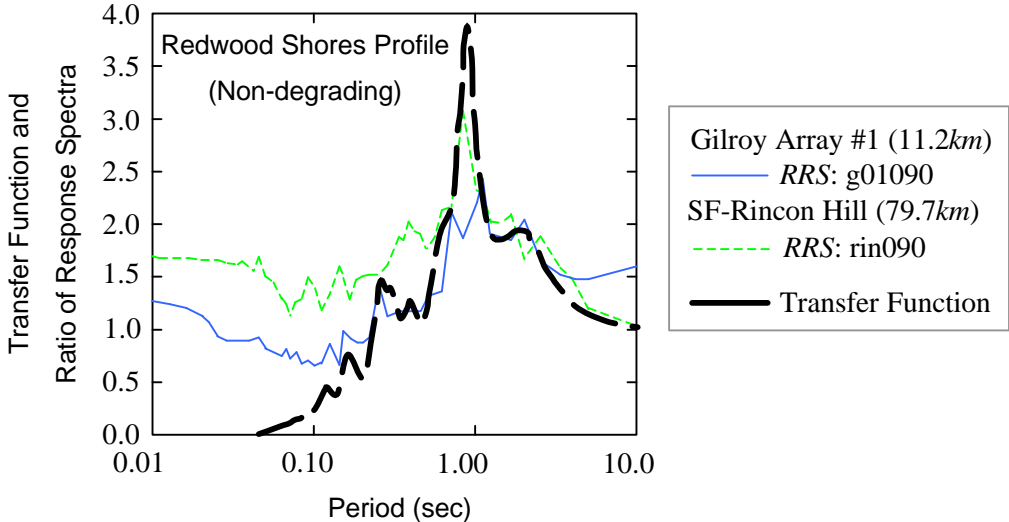


Figure 1. Transfer function and RSS for the Redwood Shores soft soil profile computed using a modified version of SHAKE91, wherein the soil properties were not allowed to degrade from their small strain values.

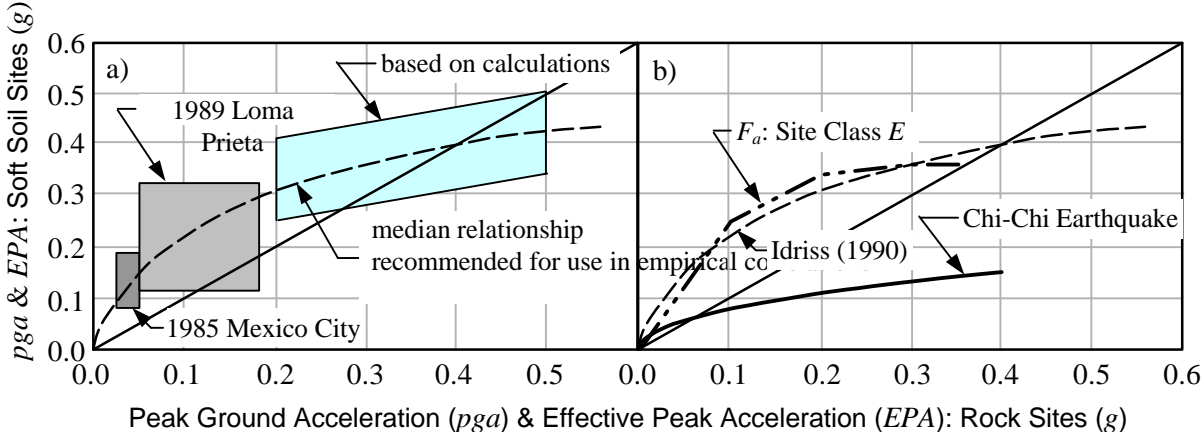


Figure 2. Correlations relating corresponding soft soil surface and rock outcrop *pga*'s (or analogously *EPA*'s). a) Correlation proposed by Idriss (1990) derived from observed data from the 1985 Mexico City and 1989 Loma Prieta earthquakes, supplemented by data from numerical site response analyses. b) Comparison of the soft soil curve proposed by Idriss (1990), the Site Class *E* curve derived from the *NEHRP* Provisions' F_a values, and observed data from the Chi-Chi earthquake.

3 CHARACTERISING THE FREQUENCY CONTENT OF GROUND MOTIONS

To further explore the influence of frequency content of ground motions on site amplification, a procedure for quantifying the characteristic period of the ground motion was needed. In this vein, various approaches proposed in literature were reviewed: Gutenberg and Richter (1956), Figueroa (1960), Seed et al. (1969), and Rathje et al. (1998), with the most recent and extensive study being that by Rathje et al. (1998). In their study, Rathje et al. explored three approaches to quantifying the characteristic period of the ground motion: mean period (T_m), predominant period (T_p), and smoothed spectral predominant period (T_o). Length restrictions prohibit a detailed discussion of these three

approaches in this paper, and therefore, the reader is referred to Rathje et al. (1998) for additional details.

Although all the correlations developed by Rathje et al. relating T_m , T_p , and T_o to earthquake magnitude (M) and site-to-source distance (R) have considerable scatter, Rathje et al. concluded that the correlations for T_m and T_o have considerably less scatter than the correlation for T_p . However, neither T_m nor T_o are easily related to the *NEHRP* Provisions' design spectrum. As an alternative, T_{VA} is proposed for use in quantifying the characteristic period of the ground motion. T_{VA} is the period corresponding to the intersection of the constant spectral acceleration and velocity regions of a 5% damped Newmark-Hall type spectrum constructed using the actual pga and pgv values of a given ground motion. T_{VA} is computed by:

$$T_{VA} = \frac{pgv}{pga} \cdot 2p \cdot \frac{\alpha_v(\xi = 5\%)}{\alpha_A(\xi = 5\%)} \quad (1)$$

where pgv = peak ground velocity. $\alpha_v(\xi = 5\%)$ and $\alpha_A(\xi = 5\%)$ are the median spectrum amplification factors for horizontal motion proposed by Newmark and Hall (1982) for the constant velocity and constant acceleration regions of 5% damped response spectra, respectively. $\alpha_v(\xi = 5\%) = 1.65$ and $\alpha_A(\xi = 5\%) = 2.12$.

The use of T_{VA} to characterise the frequency content of ground motions has precedence. Shimazaki and Sozen (1984) used T_{VA} as the characteristic period of ground motions, noticing that T_{VA} was in close agreement with the characteristic period defined in relation to the energy spectra, per Akiyama (1985). Figure 3 shows a comparison of computed values of T_m , T_p , T_o , and T_{VA} for acceleration time history pjh045, a free-field, rock outcrop motion recorded during the 1989 Loma Prieta earthquake. The use of T_{VA} to quantify the characteristic period of ground motion has several advantages over those measures reviewed by Rathje et al. (1998):

- 1) T_{VA} is relatively easy to compute from time histories of ground motions.
- 2) As may be observed from Figure 3b, T_{VA} is easily related to the *NEHRP* design spectra (i.e., T_{VA} for a Newmark-Hall type spectrum is synonymous to T_S for a *NEHRP* Provisions' design spectrum).
- 3) Existing attenuation relations for pga and pgv may be used in conjunction with Equation (1) to predict T_{VA} as a function of M and R .
- 4) As shown in the next section, the use of T_{VA} results in good correlations relating to the amplification of ground motions.

4 SITE RESPONSE ANALYSES

A series of site response analyses were performed propagating sixteen rock motions up through two soil profiles. The analyses were performed using a modified version of SHAKE91, with the soil properties being allowed to degrade from their small strain values. The records used in the site response analyses were rock outcrop motions recorded during the 1989 Loma Prieta and 1994 Northridge earthquakes and are listed in Table 1. The two soil profiles analysed were the Redwood Shores profile (Dobry 1991), discussed previously, and the San Francisco Airport profile (Idriss 1993). Per the *NEHRP* Provisions, both profiles are site class *E*, but $T_n \approx 2sec$ for the Redwood Shores profile, while $T_n \approx 1sec$ for the San Francisco Airport profile.

The results of the analyses are presented in Figure 4. As may be seen in Figure 4a, the relationships between the rock outcrop and soil surface pga 's are distinctly different for the two profiles, even though both are site class *E*. The San Francisco Airport profile amplified the rock outcrop pga 's, irrespective of the magnitude of the pga . On the contrary, the Redwood Shores profile amplified the rock outcrop pga 's less than about 0.15g, and de-amplified larger pga 's. The soft soil curve proposed by Idriss (1990) is also shown in Figure 4a and represents a reasonable average of the results from the site response analyses for the two profiles. Additionally, observed data for three soft soil sites recorded

during the 1985 Mexico City earthquake are plotted in this figure. The three sites were located in the ancient Texcoco Lake bed, with the following station designations: SCT1, CDAF, and CDAO (Anderson et al. 1986). In Figure 4a, the pga 's for these soft soil sites were plotted against the average pga of horizontal motions recorded by two stations located on a nearby rock outcrop, having station designations: CUIP and CUMV (Anderson et al. 1986).

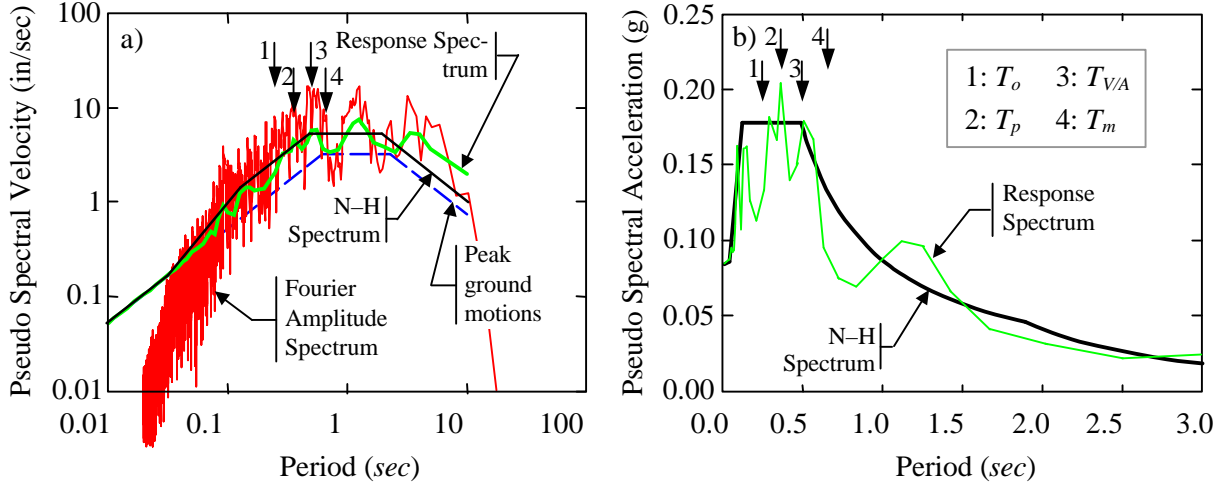


Figure 3. Comparison of various measures used to quantify the "characteristic" period of a free-field, rock outcrop motion recorded during the 1989 Loma Prieta earthquake (Station: 58338 Piedmont Jr High; pjh045). Design and response spectra are for 5% damping. a) log-log plot of pseudo spectral velocity versus oscillator period; and b) linear-linear plot of pseudo spectral acceleration versus oscillator period.

An alternate presentation of the data from the site response analyses is shown in Figure 4b. In this figure, the ratios of the computed soil surface pga 's to the corresponding rock outcrop pga 's are plotted as functions of the corresponding ratios of T_{VA} and T_n (i.e., $pga_{\text{soft soil}} / pga_{\text{firm rock}}$ versus T_{VA} / T_n). As may be seen in this figure, the results from both profiles follow the same trend: the ratio $pga_{\text{soft soil}} / pga_{\text{firm rock}}$ increases as the ratio T_{VA} / T_n increases. The following quadratic expression was fit to the data.

$$R_{pga} = -1.664 \cdot R_T^2 + 4.763 \cdot R_T + 0.39 \quad (2)$$

where $R_{pga} = pga_{\text{soft soil}} / pga_{\text{firm rock}}$ and $R_T = T_{VA} / T_n$.

If the soil profiles were treated as damped single-degree-of-freedom (SDOF) oscillators, the observed trend shown in Figure 4b is somewhat predictable, in that as the ratio T_{VA} / T_n approaches 1 (i.e., resonance), the dynamic response of the profiles increases. Accordingly, extrapolating beyond the data shown in Figure 4b, the ratio $pga_{\text{soft soil}} / pga_{\text{firm rock}}$ would be expected to decrease as T_{VA} / T_n increases greater than 1 (i.e., moving away from resonance). Although the SDOF analogy is an over simplification of the dynamic response of the soil profiles, particularly because the oscillator damping would not be constant, but rather would increase as a result of increased dynamic response, it provides a reasonable explanation for trend shown in Figure 4b.

The observed data from the three Mexico City soft soil sites are also plotted in Figure 4b. The small strain periods for the sites were computed from soil profiles given in Seed et al. (1988), with $T_{n \text{ SCT1}} \approx 1.9 \text{ sec}$, $T_{n \text{ CDAF}} \approx 2.4 \text{ sec}$, and $T_{n \text{ CDAO}} \approx 3.1 \text{ sec}$. As may be seen in Figure 4b, the Mexico City data agrees remarkably well with the observed trend in the data from the site response analyses, with the exception one of the horizontal components for SCT1 site, which plots higher than the observed trend. A more in depth review of the SCT1 site and ground motions is required to determine possible reasons for this apparent anomaly.

Finally, it should be noted that plots similar to Figure 4b were made in which the characteristic periods

of the ground motions were quantified as T_m , T_o , and T_p , in place of T_{VA} . However, none of the resulting plots showed nearly the clear trend shown in Figure 4b.

Table 1. Acceleration time histories used in the site response analyses.

Earthquake	Station	Record	pga (g)	pgv (cm/sec)	T_{VA} (sec)
Loma Prieta, M_w 6.9 1989/10/18 00:05	Gilroy Array #1 47379 (11.2km)*	g01000	0.41	31.6	0.384
		g01090	0.47	33.9	0.357
	Piedmont Jr High 58338 (78.3km)	pjh045	0.08	8.2	0.487
		pjh315	0.07	9.1	0.639
	Rincon Hill 58151 (79.7km)	rin000	0.08	6.7	0.428
		rin090	0.09	10.4	0.563
	Point Bonita 58043 (88.6km)	ptb207	0.07	11.4	0.800
		ptb297	0.07	12.9	0.893
	SF Sierra Pt 58539 (68.2km)	ssf115	0.06	7.1	0.632
		ssf205	0.11	8.8	0.418
Yerba Buena Is 58163 (80.6km)	ybi000	0.03	4.2	0.722	
	ybi090	0.07	13.4	0.982	
Northridge, M_w 6.7 1994/01/17 12:31	Mt. Wilson 24399 (36.1km)	mtw000	0.23	7.4	0.158
		mtw090	0.13	5.8	0.216
	Lake Hughes #9 127 (26.8km)	lo9000	0.17	8.4	0.254
		lo9090	0.22	10.1	0.232

* Closest distance to fault rupture

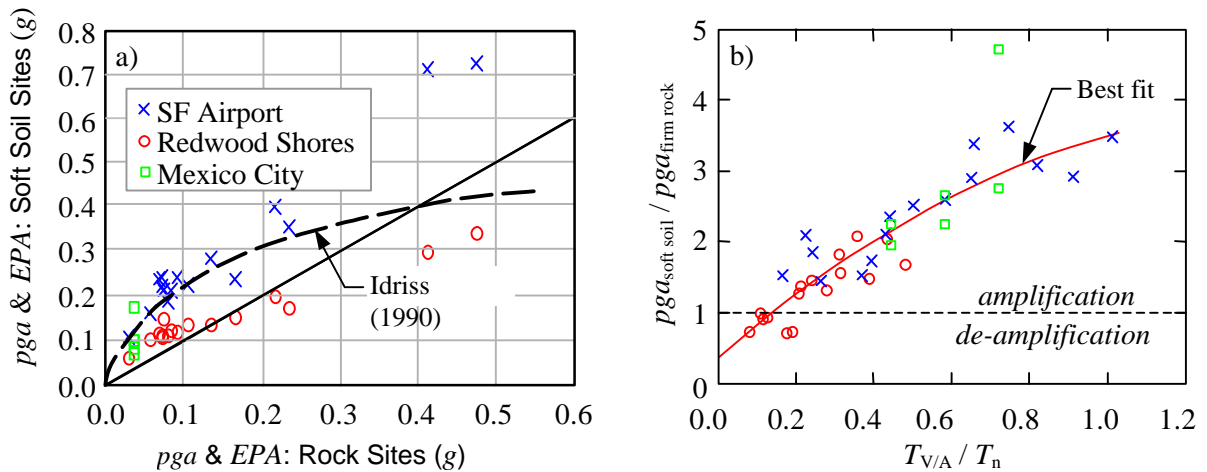


Figure 4. Results from site response analyses. a) Data from the site response analyses in comparison with the soft soil curve proposed by Idriss (1990). Also shown are observed data from the 1985 Mexico City earthquake. b) Alternate presentation of the same data shown in (a).

The seismic hazard maps that accompany the *NEHRP* Provisions were used to compute the characteristic period for rock motions for several cities across the US. Although constructed differently, the design spectrum for the *NEHRP* Provisions has essentially the same shape as the

Newmark-Hall spectrum. This is particularly evident when both are plotted using linear-linear scales. Based on the similarity of the spectral shapes, T_{VA} for the Newmark-Hall spectra is synonymous to T_S for the *NEHRP* Provisions' design spectra. This may be seen by comparing the relative location of T_{VA} in Figures 3b to the relative locations of T_S in Figure 5a. Values for T_S for five cities located in the central/eastern US (CEUS) and five cities located in the western US (WUS) are shown in Figure 5b. The ten cities selected were those used by Algermissen and Leyendecker (1992) in developing the design spectral shape for the *NEHRP* Provisions. As may be seen in Figure 5b, T_S values in the WUS are characteristically larger than those in the CEUS. Accordingly, given the preliminary trend identified in Figure 4b, a soft soil profile located in the WUS would tend to amplify motions more than a similar soil profile located in CEUS, at least in the short period range (i.e., T_S/T_n for the WUS would be larger than T_S/T_n for the CEUS, therefore $pga_{\text{soft soil}} / pga_{\text{firm rock}}$ for the WUS would be greater than that for the CEUS).

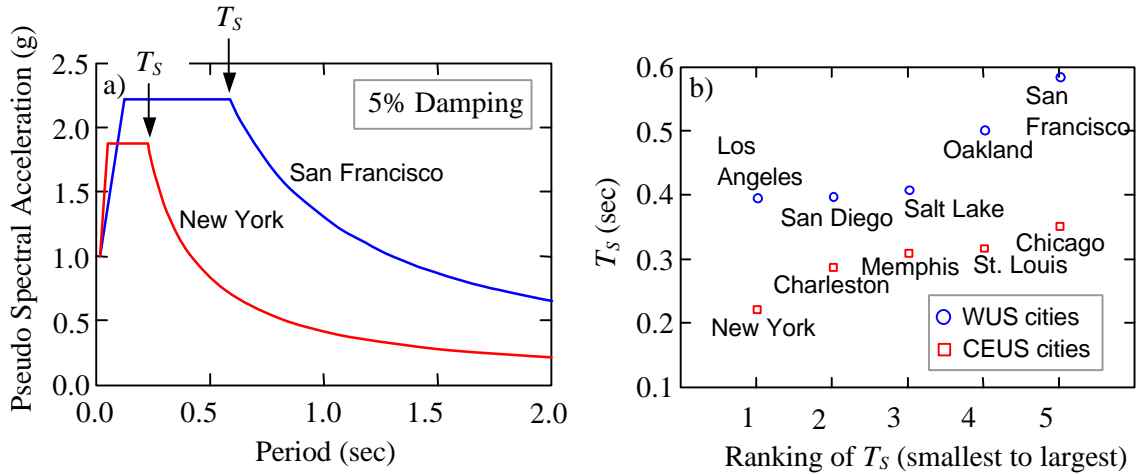


Figure 5. Characteristic periods of ground motions as determined from the *NEHRP* Provisions' design spectra. a) Examples of T_S determined from the design spectra for New York and San Francisco. b) Comparison of T_S for five CEUS and five WUS cities.

5 CONCLUSIONS AND FUTURE WORK

Although the results presented in this paper are preliminary, a clear correlation is identified between the amplification of short period motions and the ratio of the characteristic period of the rock motions (T_{VA}) to the fundamental periods of the soil profiles (T_n). Analogous to damped *SDOF* oscillators, as the ratio T_{VA}/T_n approaches 1 (i.e., resonance), the dynamic response of the profiles increase, resulting in an increase in the ratio $pga_{\text{soft soil}} / pga_{\text{firm rock}}$.

One advantage of quantifying the characteristic period of rock motions by T_{VA} is that it is synonymous to T_S for the *NEHRP* Provisions' design spectrum. Using the seismic hazard maps that accompany the *NEHRP* Provisions, a comparison is made between typical T_S values for the CEUS and WUS, with T_S for the WUS being larger than for the CEUS. Accordingly, if similar soft soil profiles (i.e., profiles having the same T_n) were subjected to regionally-characteristic earthquake motions, the profile located in the WUS would tend to amplify short period motions more than the profile located in CEUS. This can be understood by the identified trends in the ratio $pga_{\text{soft soil}} / pga_{\text{firm rock}}$ as a function of the ratio T_S/T_n .

The preliminary results presented above highlights the need to develop site response coefficients specific to the characteristics of motions in the various tectonic regimes, rather than the universal coefficients currently specified in the *NEHRP* Provisions. Additional issues such as the influence of impedance contrast between the base rock and soil profile and the influence of the frequency content of ground motions on the long period site response coefficient are currently being examined by the authors.

REFERENCES:

- Akiyama, H. 1985. Earthquake-Resistant Limit-State Design for Building. University of Tokyo Press. 372pp.
- Algermissen, S.T. and E.V. Leyendecker (1992). A Technique for Uniform Hazard Spectra Estimation in the US, Proceedings: Tenth World Conference on Earthquake Engineering, Balkema, Rotterdam. 391-397.
- Anderson, J.G., J.N. Brune, J. Prince, E. Mena, P. Bodin, M. Onate, R. Quaas, S.K. Singh. 1986. Aspects of Strong Motion, Proceedings: The Mexico Earthquakes-1985, Factors Involved and Lessons Learned (M.A. Cassaro and E.M. Romero, eds), Sept. 19-21, 1986. 33-54.
- Applied Technical Council. 1978. Tentative Provisions for the Development of Seismic Regulations for Buildings, ATC 3-06 Report, Redwood City, CA.
- Borcherdt, R.D. 2002. Empirical Evidence for Acceleration-Dependent Amplification Factors, Bulletin of the Seismological Society of America, 92(2). 761-782.
- Dobry, R. 1991. Soil Properties and Earthquake Ground Response, Volume 4, Proceedings of the Tenth European Conference on Soil Mechanics and Foundation Engineering, Florence, Italy, May 26-30, 1991. 1171-1187.
- Dobry, R., G.R. Martin, E. Parra, and A. Bhattacharyya. 1994. Development of Site-Dependent Ratios of Elastic Response Spectra (RSS), Proceedings: NCEER/SEAOC/BSSC Workshop on Site Response During Earthquakes and Seismic Code Provisions (G.R. Martin, ed.), November 18-20, 1992, University of Southern California.
- Dobry, R., R.D. Borcherdt, C.B. Crouse, I.M. Idriss, W.B. Joyner, G.R. Martin, M.S. Power, E.E. Rinne, and R.B. Seed. 2000. New Site Coefficients and Site Classification Systems Used in Recent Building Code Provisions, EERI Earthquake Spectra. 16(1). 41-67.
- Figuroa, A. 1960. Some Consideration about the Effect of Mexican Earthquakes, Volume III, Proceedings: Second World Conference on Earthquake Engineering. 1553-1561.
- Gutenberg, B. and C.F. Richter. 1956. Earthquake Magnitude, Intensity, Energy, and Acceleration (Second Paper), Bulletin of the Seismological Society of America. 46(2). 105-145.
- Idriss, I.M. 1990. Response of Soft Soil Sites During Earthquakes, Volume 2, Proceedings: H. Bolton Seed Memorial Symposium, (J.M. Duncan, ed.), University of California, Berkeley, May 1990. 273-289.
- Idriss, I.M. 1993. Assessment of Site Response Analysis Procedures, report to the Structures Division, Building and Fire Research Laboratory, National Institute of Standards and Technology, July 1993.
- Idriss, I.M. and N.A. Abrahamson 2000. Geotechnical Aspects of the Earthquake Ground Motions Recorded During the 1999 Chi-Chi Earthquake. Invited Paper, Keynote Session C, International Workshop on the Annual Commemoration of the Chi-Chi Earthquake, Sept. 18-20, 2000, Taipei, Taiwan.
- Idriss, I.M. and J.I. Sun (1992). SHAKE91: a computer program for conducting equivalent linear seismic response analyses of horizontally layered soil deposits, University of California, Davis.
- NEHRP 2001. NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Part 1- Provisions: FEMA 368, Part 2-Commentary FEMA 369, Federal Emergency Management Agency, Washington DC.
- Newmark, N.M. and W.J. Hall (1982). Earthquake Spectra and Design, Earthquake Engineering Research Center, Oakland, CA, 103pp.
- Rathje, E.M., N.A. Abrahamson, and J.D. Bray. 1998. Simplified Frequency Content Estimates of Earthquake Ground Motions, Journal of Geotechnical and Geoenvironmental Engineering. 124(2). 150-159.
- Rinne, E.E. 1994. Development of New Site Coefficients for Building Codes, Volume III, Proceedings: Fifth US National Conference on Earthquake Engineering, July 1-14, 1994, Chicago, IL. 69-78.
- Seed, H.B., I.M. Idriss, and F.W. Kiefer. 1969. Characteristics of Rock Motions During Earthquakes, ASCE Journal of the Soil Mechanics and Foundation Division. 95(5). 1199-1218.
- Seed, H.B., M.P. Romo, J.I. Sun, A. Jaime, and J. Lysmer. 1988. The Mexico Earthquake of September 19, 1985 – Relationships Between Soil Conditions and Earthquake Ground Motions, Earthquake Spectra, 4(4). 687-729.
- Shimazaki, K. and M.A. Sozen. 1984. Seismic Drift of Reinforced Concrete Structures. Special Research Paper (Draft). Hazama Corp.