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Full Length Research Paper

Engendering earthquake response spectra for Dhaka region usable in dynamic analysis of structures

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Structures are subjected to time varying-forces due to earthquakes which in turn produce time-dependent displacements and stresses within the structures. From a design stance, only the maximum values of displacement and stress are of interest. For survival, the structure must withstand the peak value whenever that may occur. Therefore, knowing the peak values is of utmost important and this information is made available in the form of response spectra. In this study, effort has been made to generate response spectra which may be directly used in the dynamic analysis of structures in Dhaka. As there is a deficiency in apposite earthquake data at Bangladesh especially for Dhaka region, time history of Dhaka Earthquake was at first generated from recently occurred nearby earthquake. Consequently following detailed procedure response spectrum is developed. As response spectrum for a given earthquake is quite irregular and has a number of peaks and valleys, statistical approach has been adopted to construct a smoothed response spectrum to make it suitable for design. The engendered response spectrum has been evaluated with the well-known code specified response spectrum and introduces as acceptable. Therefore, the research reveals a design 'response spectrum' for Dhaka earthquake for the detail dynamic analysis ensuring as competent data for seismic design of structures.

Key words: Peak responses, seismic record, ground excitation, time history, response spectra, natural frequency, spectral acceleration, integral solution, damping ratio.

INTRODUCTION

Although great progress has been made regarding since seismic design was made mandatory by various building codes, it is still not completely understood. So, structural engineers have been giving more and more attention to the design of structures for earthquake resistance. Among various unknowns or less known factors, the conversion of dynamic forces to static forces is one of the areas where additional works may be conducted. Site specific response in earthquake excitation is essentially required to be precisely investigated. Several studies on ground shaking responses have been carried out by a number of researchers (Shahri et al., 2009, 2010; Firat et al., 2009; Kanit et al., 2010, Liu et al., 2010; Mohammed et al., 2010). The dynamic analysis is however a more accurate method than the equivalent static force method in seismic design suggested by the design codes. This type of analysis is carried out in the form of a response spectrum analysis or a time history analysis where an earthquake excitation of the ground is given in the form of response spectrum curve and time history curve. There is a deficiency in suitable earthquake result in Dhaka, Bangladesh (Islam et al., 2010a, 2010b). So for dynamic analysis for seismic design of structures, generation of response spectrum curve is a burning matter. It is also very important for advance seismic force mitigation technique such as base isolation (Islam et al., 2011a, 2011b), pounding control etc. It is possible to generate curve which give peak displacements, velocities and accelerations responses for any structure subjected to a given earthquake. These curves are called response spectra because they give the maximum response of a

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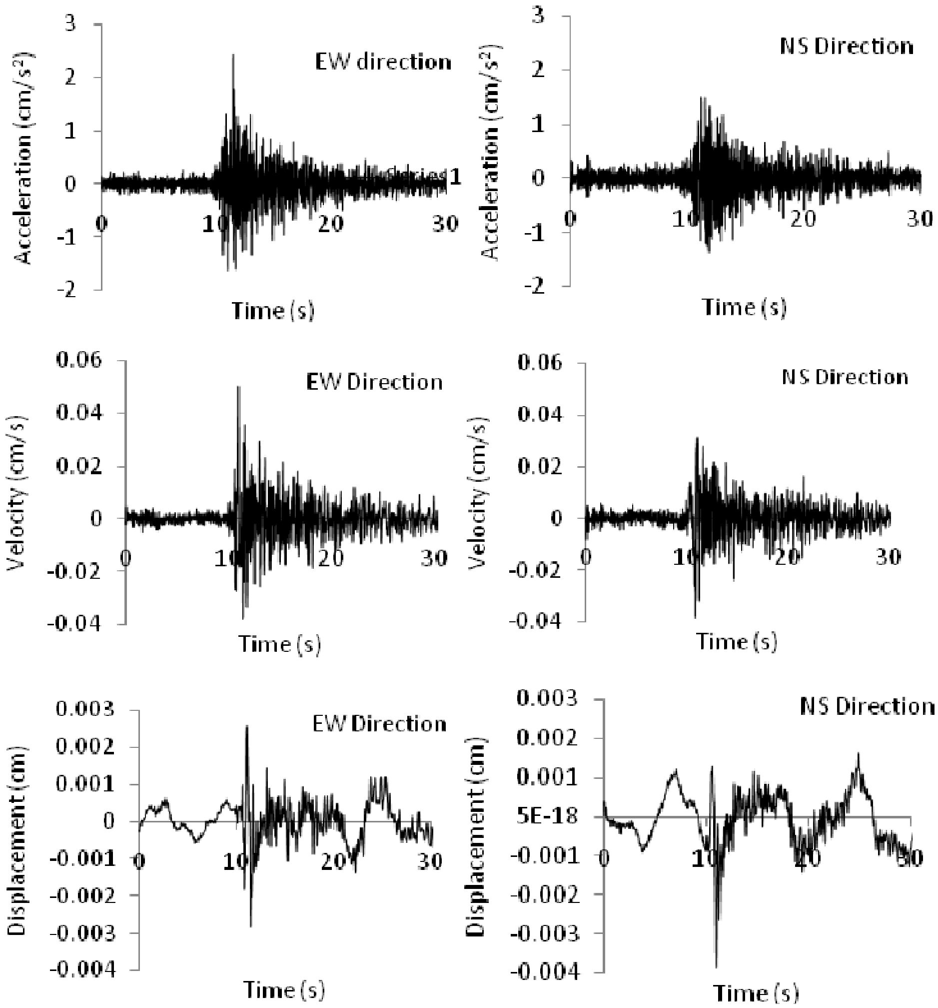

Figure 1. Ground excitation time history records of Natore EQ.

wide spectrum of structures as defined by their frequency (or period) and damping ratio. However, the research of site specific response spectra for Dhaka, Bangladesh vicinity is still young and need to develop precise seismic data in form of response spectra of its own.

The objective of the study is to generate real earthquake response spectra for Dhaka, Bangladesh. To generate spectra of real earthquake time histories, seismic time history is generated first from a recently occurred real earthquake (Islam et al., 2011c, 2011d) and by the course of action maximum values recoded and later plotted against period and damping ratio. Because there is no closed- form solution to the integral equation, each point on each curve in the spectra is computed numerically. Smooth response spectra is successively constructed for Dhaka S_3 soil and then generalized for different seismic zone in Bangladesh. The design response spectra were then evaluated with the spectra proposed in several famous codes. Therefore, target response spectra which can be directly used in the dynamic analysis of structures are duly achieved.

MATERIALS AND METHODS

For generation of time history and response spectrum as well, recent collected data of nearby real earthquake Natore (Ansary, 2009; Islam et al., 2011d) is chosen. The acceleration, velocity and displacement data for recent earthquake at Station ID: ALTUS S/N 2928, 6th January, 2009 16:04:03 (GMT), Place: Natore, Bangladesh is shown in Figure 1. Therefore, acceleration, velocity and displacement time histories for earthquake data for Dhaka was generated first through proper scaling as per peak ground acceleration of Dhaka region according to Bangladesh National Building Code (BNBC, 1993). Then from these time history along with the soil characteristics of S3 soil, site location and seismic coefficients, seismic response coefficient 5% damped response spectrum for Dhaka has been spawned following the stated procedure in the subsequent section.

Mathematical formulation

Complete time varying response of joint displacements and member forces can be produced by basic mode superposition technique which is restricted to linearly elastic analysis. The scheme involves the calculation of only the maximum values of the displacements and member forces in each mode using smooth design spectra. There are computational advantages in using the method for prediction of displacements, velocity and acceleration of ground subjected to structural systems. For this purpose, equations of motion for linear analysis are transformed into the eigenvectors or normal coordinate system. Applying the normal coordinate transformation in accordance with Clough and Penzien (1993), the following decoupled equation of motion for individual modes leads to:

$$M_n\ddot{Y}_n(t)+C_n\dot{Y}_n(t)+K_nY_n(t)=P_n(t) \tag{1}$$

Where the modal coordinate mass, damping, stiffness and load are defined as:

$M_n = \Phi_n^T m\Phi_n$, $C_n = \Phi_n^T c\Phi_n$, $K_n = \Phi_n^T k\Phi_n$ and $P_n = \Phi_n^T p\Phi_n$

For three dimensional seismic motions, the typical modal equation can be rewritten as:

$$\ddot{y}(t)_n + 2\zeta\omega_n\dot{y}(t)_n + \omega_n^{\ 2}y(t)_n = P_{nx}\ddot{u}(t)_{gx} + P_{ny}\ddot{u}(t)_{gy} + P_{nz}\ddot{u}(t)_{gy} \tag{2}$$

Three mode participation factors in Equation 2 are defined by $P_{ni} = -\Phi_n^T M_i$ in which i is equal to x, y or z, ζ is modal damping ratio and ω_n is un-damped natural frequency. Two major problems must be solved in order to obtain an approximate response spectrum solution to this equation. First, for each direction of ground motion, maximum peak forces and displacements must be estimated. Secondly, after the response for the three orthogonal directions is solved, it is necessary to estimate the maximum response due to the three components of earthquake motion acting at the same time. Now the time integration can be carried out individually for each decoupled modal Equation 1. This can be accomplished by numerical evaluation of the Duhamel integral (Clough and Penzien, 1993). For input in one direction only, Equation 1 is written as:

$$\ddot{y}(t)_n + 2\zeta\omega_n\dot{y}(t)_n + \omega_n^{\ 2}y(t)_n = P_{ni}\ddot{u}(t)_g \tag{3}$$

For a specified ground motion $\ddot{u}(t)$ g, damping value and assuming Pni = - 0.10, it is possible to solve Equation 3 at various values of ω and plot a curve of the maximum peak response $y(\omega)_{\max}$. Assigning Pni = -1.0, Equation 4 can be modified to:

$$\ddot{y}(t)_n + 2\zeta\omega_n\dot{y}(t)_n + \omega_n^{\ 2}y(t)_n = -\ddot{u}(t)_g \tag{4}$$

To get the solution of y(t), Duhamel's integral is commonly used (Clough and Penzien, 1975). Here a spreadsheet in excel has been developed for solution through integral calculation described at subsequent section and relative displacement values have been obtained for corresponding time period. This curve is by definition the displacement response spectrum for the earthquake motion. A different curve will exist for each different value of damping. A plot of $\omega y(\omega)$ max is defined as the pseudo-velocity spectrum and a plot of $\omega^2 y(\omega)_{MAX}$ is defined as the pseudo-acceleration spectrum. However, these pseudo- values have minimum physical significance and are not an essential part of a response spectrum analysis. The true values for maximum velocity and acceleration are calculated from the solution of Equation 3. There is a mathematical relationship, however, between the pseudo-acceleration spectrum and the total acceleration spectrum. The total acceleration of the unit mass, single degree-of-freedom system is governed by Equation 3.

$$\ddot{u}(t)_T = \ddot{y}(t) + \ddot{u}(t)_g \tag{5}$$

Equation 3 can be solved for $\ddot{y}(t)$ and substituted into Equation 5 which yields the Equation 6.

$$\ddot{u}(t)_T = -2\zeta\omega\ \dot{y}(t) - \omega^{\ 2}y(t) \tag{6}$$

Therefore, for the special case of zero damping, the total acceleration of the system is equal to $\omega^2 y(t)$. For this reason, the displacement response spectrum curve is normally not plotted as modal displacement $y(\omega)_{MAX}$ versus ω. It is standard to present the curve in terms of S(ω)a versus a period T in seconds. Where:

$$S(\omega)_a = \omega^2 y(\omega)_{MAX} \tag{7}$$

and

$$T = \frac{2\pi}{\omega} \tag{8}$$

The pseudo-acceleration spectrum, S(ω)a, curve has the units of acceleration versus period. It is apparent that all response spectrum curves represent the properties of the earthquake at a specific site and are not a function of the properties of the structural system. After an estimation of the linear viscous damping properties of the structure is made, a specific response spectrum curve is selected.

Integral solution

A sequential procedure is discussed here to solve the equation of motion through complex integration. Duhamel's integral solved in a piecewise exact fashion idealizes the forcing function as a succession of short-impulse being followed by a free vibration response (Ebeling, 1992). Superposition is used to combine each of short duration impulse/free vibration response with the total response for the structural model. For a continuous forcing function, time varying force is divided into a series of duration $d\tau$. The change in velocity of the SDOF system due to the impulsive acceleration $\upsilon(\tau)$ can be determined from Newton's law of motion. As the mass is a directionless quantity, the equation for force is modified for velocity only omitting the mass and the velocity equation comes as the following (Equation 9):

$$\frac{d\dot{y}}{d\tau} = \upsilon(\tau) \tag{9}$$

Or

$$d\dot{y} = \upsilon(\tau)d\tau \tag{10}$$

Where, $\upsilon(\tau)d\tau$ is the impulse and $d\dot{x}$ is the incremental velocity. This incremental velocity may be considered to be initial velocity of the SDOF system at time ζ. The solution to the equation of motion for free vibration is:

$$y(t) = e^{-\zeta\omega t}\left[y_0\cos(\omega_D t) + \frac{\dot{y}_0 + y_0\zeta\omega}{\omega_D}\sin(\omega_D t)\right] \tag{11}$$

Where,

$$\omega_D = \omega\sqrt{1-\zeta^2} \tag{12}$$

Substituting Equation 10 for $\dot{x}_0$ in the second term of Equation 11 and assuming x_0 = 0 results in:

$$dy(t) = e^{-\zeta\omega(t-\tau)} \frac{\upsilon(\tau)d\tau}{\omega_D} \sin \omega_D (t-\tau) \tag{13}$$

The total relative displacement can be determined by summing the differential responses, given by Equation 13 over the entire loading interval:

$$y(t) = \frac{1}{\omega_D} \int_0^t \upsilon(\tau) e^{-\zeta\omega(t-\tau)} \sin \omega_D (t-\tau) d\tau \tag{14}$$

Using the trigonometric identity:

$$\sin \omega(t-\tau) = \sin \omega t \cos \omega\tau - \cos \omega t \sin \omega\tau \tag{15}$$

Equation 14 may be written:

$$y(t) = \frac{e^{-\zeta\omega t}}{\omega_D} \left[A_D(t) \sin(\omega_D t) - B_D(t) \cos(\omega_D t) \right] \tag{16}$$

$$A_D(t) = \int_0^t \upsilon(\tau) e^{\zeta\omega\tau} \cos \omega_D \tau d\tau \tag{17}$$

And

$$B_D(t) = \int_0^t \upsilon(\tau) e^{\zeta\omega\tau} \sin \omega_D \tau d\tau \tag{18}$$

The expressions in Equation 17 can be solved by several techniques. For this study, the loading function $\upsilon(\tau)$ is assumed to be piecewise linear and an exact solution formulated.

$$\upsilon(\tau) = \upsilon(t_{i-1}) + \frac{\Delta\upsilon_i}{\Delta t}(\tau - t_{i-1}) \text{ for } t_{i-1} \le \tau \le t_i \tag{19}$$

Where,

$$\Delta\upsilon_i = \upsilon(t_i) - \upsilon(t_{i-1}) \tag{20}$$

When Equation 19 is substituted into the expressions of Equation 17 and the intermediate variables I_1, I_2, I_3 and I_4 given in Equation 21 are used, Equation 25 represents an exact solution.

$$I_1 = \int_{t_{i-1}}^{t_i} e^{\zeta\omega\tau} \cos \omega_D \tau d\tau = \frac{e^{\zeta\omega\tau}}{(\zeta\omega)^2 + \omega_D{}^2} (\zeta\omega \cos \omega_D \tau + \omega_D \sin \omega_D \tau) \Big|_{t_{i-1}}^{t_i} \tag{21}$$

$$I_2 = \int_{t_{i-1}}^{t_i} e^{\zeta\omega\tau} \sin \omega_D \tau d\tau = \frac{e^{\zeta\omega\tau}}{(\zeta\omega)^2 + \omega_D{}^2} (\zeta\omega \sin \omega_D \tau + \omega_D \cos \omega_D \tau) \Big|_{t_{i-1}}^{t_i} \tag{22}$$

$$I_3 = \int_{t_{i-1}}^{t_i} \tau e^{\zeta\omega\tau} \sin \omega_D \tau d\tau = \left[\tau - \frac{\zeta\omega}{(\zeta\omega)^2 + \omega_D{}^2} \right] \dot{I}_2 + \frac{\zeta\omega}{(\zeta\omega_D)^2 + \omega_D{}^2} \dot{I}_1 \Big|_{t_{i-1}}^{t_i} \tag{23}$$

$$I_4 = \int_{t_{i-1}}^{t_i} \tau e^{\zeta\omega\tau} \cos \omega_D \tau d\tau = \left[\tau - \frac{\zeta\omega}{(\zeta\omega)^2 + \omega_D{}^2} \right] \dot{I}_1 + \frac{\zeta\omega}{(\zeta\omega_D)^2 + \omega_D{}^2} \dot{I}_2 \Big|_{t_{i-1}}^{t_i} \tag{24}$$

Where $\dot{I}_1$ and $\dot{I}_2$ are the integrals for I_1 and I_2 before their evaluation at the limits. By introducing the following relationships:

$$A_D(t_i) = A_D(t_{i-1}) + \left[\upsilon(t_{i-1}) - t_{i-1} \frac{\Delta\upsilon_i}{\Delta t} \right] I_1 + \frac{\Delta\upsilon_i}{\Delta t} I_4 \tag{25}$$

$$B_D(t_i) = B_D(t_{i-1}) + \left[\upsilon(t_{i-1}) - t_{i-1} \frac{\Delta\upsilon_i}{\Delta t} \right] I_2 + \frac{\Delta\upsilon_i}{\Delta t} I_3 \tag{26}$$

The relative displacement, velocity and acceleration may be determined (Green et al., 1997) using Equations 27, 28 and 29, respectively.

$$y_i = \frac{e^{-\zeta\omega t_i}}{\omega_D} \left[A_D(t_i) \sin(\omega_D t_i) - B_D(t_i) \cos(\omega_D t_i) \right] \tag{27}$$

$$\dot{y}_i = \frac{e^{-\zeta\omega t_i}}{\omega_D} \{ [\omega_D B_D(t_i) - \zeta\omega A_D(t_i)] \sin(\omega_D t_i) + [\omega_D A_D(t_i) - \zeta\omega B_D(t_i)] \cos(\omega_D t_i) \} \tag{28}$$

$$\ddot{y}_i = (\upsilon_i - c\dot{y}_i - ky_i) \tag{29}$$

After getting the response spectrum uneven curve, it was then smoothen to make it suitable to use in design. Effort has been made to construct the smooth response spectra for Dhaka S_3 soil. It is then generalized for different seismic zone in Bangladesh. The design response spectra were then compared with the spectra proposed in Uniform Building Code (UBC, 1994), International Building Code (IBC, 2000) and Indian Seismic Code (IS, 2002) corresponding to that of identical soil condition.

RESULTS AND DISCUSSION

Time history for Dhaka earthquake

The time histories for Dhaka are obtained after appropriate scaling. Here the acceleration, velocity and displacement histories of estimated Dhaka earthquake are shown in Figure 2. In the Natore earthquake record, the peak ground acceleration is 2.43 cm/s^2 at 11.425 s but the maximum ground acceleration as per BNBC (1993) for Dhaka is 0.15 g ≈ 147.15 cm/s^2 which is 61.58 ≈ 62 times greater. So, the values have been multiplied by 62 and the following time history curves (Figure 2) are obtained. Maximum ground acceleration value of the

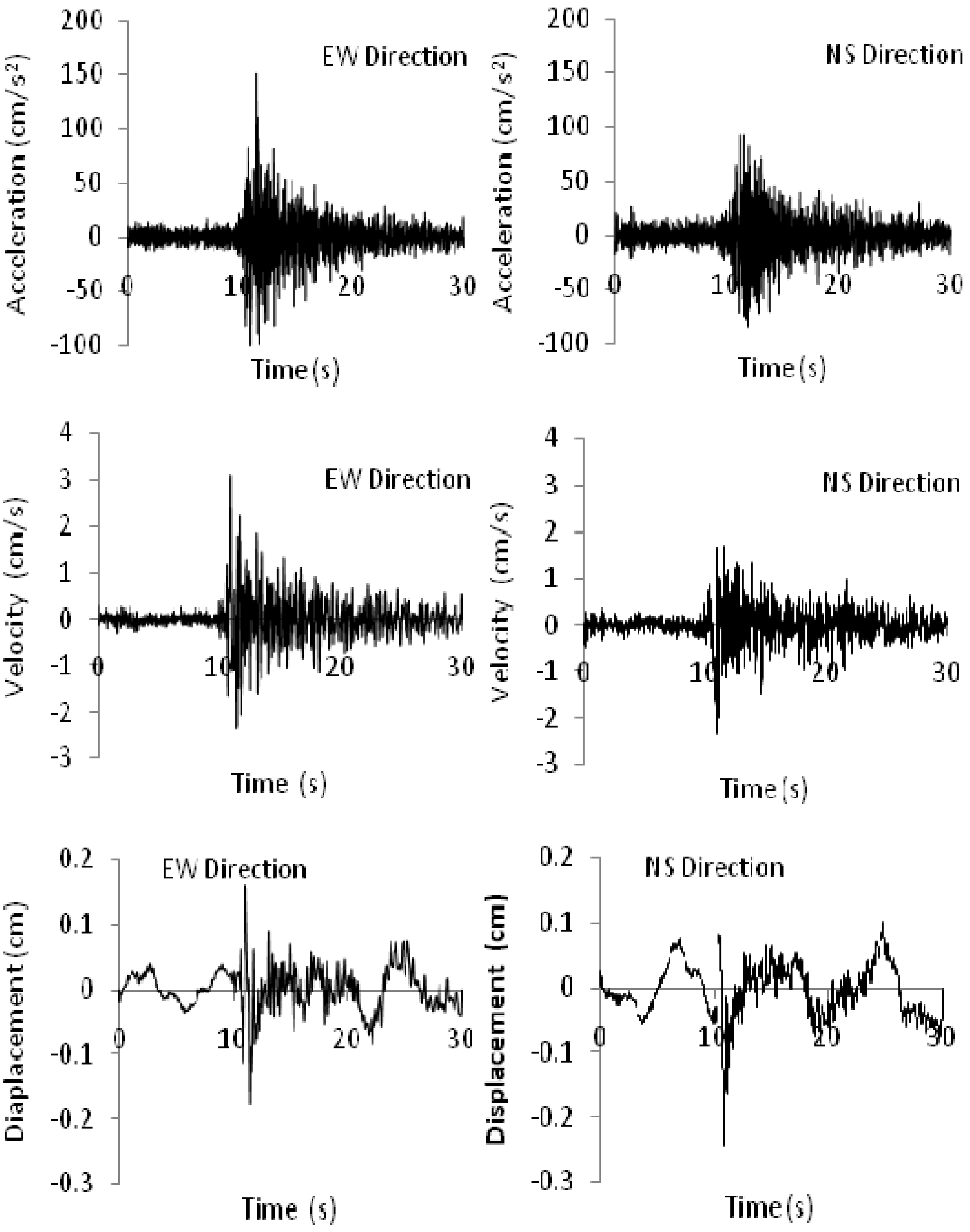

Figure 2. Time history record for earthquake in Dhaka.

earthquake time history satisfies the zone requirement (Z = 0.15) for Dhaka region, that is, 15% of the gravitational acceleration value.

Response spectrum for Dhaka earthquake

Response spectrum for Dhaka city has been generated here from the obtained acceleration, velocity and displacement time history of Dhaka shown in Figure 2. The time history record has been corrected for zero displacement, velocity and acceleration at the beginning and end of the 30 s record. For this earthquake motions, the response spectrum curves for acceleration are summarized. The velocity curves have been intentionally omitted since they are not an essential part of the response spectrum method. Furthermore, it would require considerable space to clearly define terms such as peak ground velocity, pseudo velocity spectrum, relative velocity spectrum and absolute velocity spectrum. For 0, 2, 5 and 10% damping, the plot of pseudo spectral acceleration is shown in Figures 3 and 4. Significant

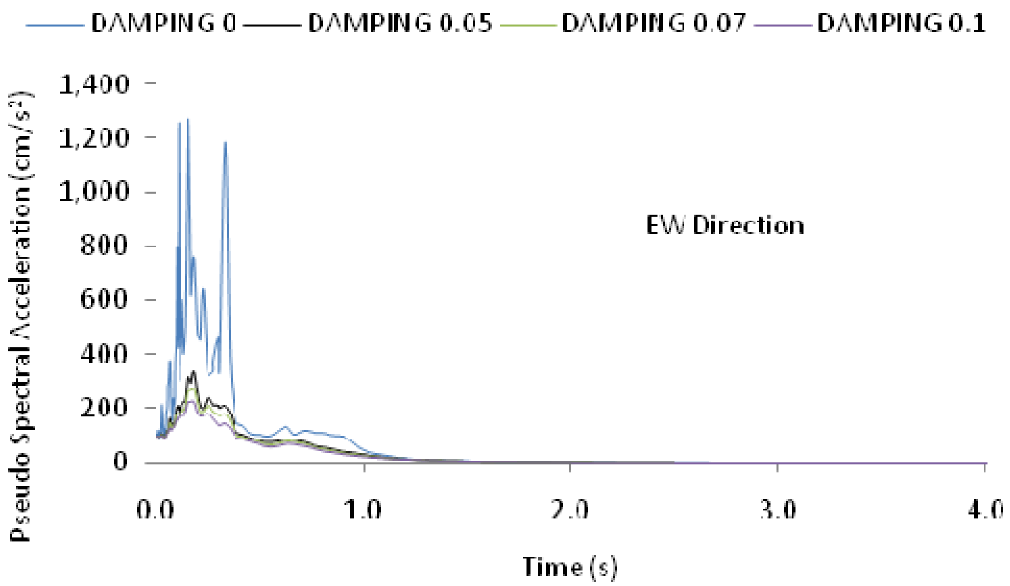

Figure 3. Pseudo acceleration spectra Sa = ω^2 $y(\omega)_{MAX}$ in EW direction for different damping ratio.

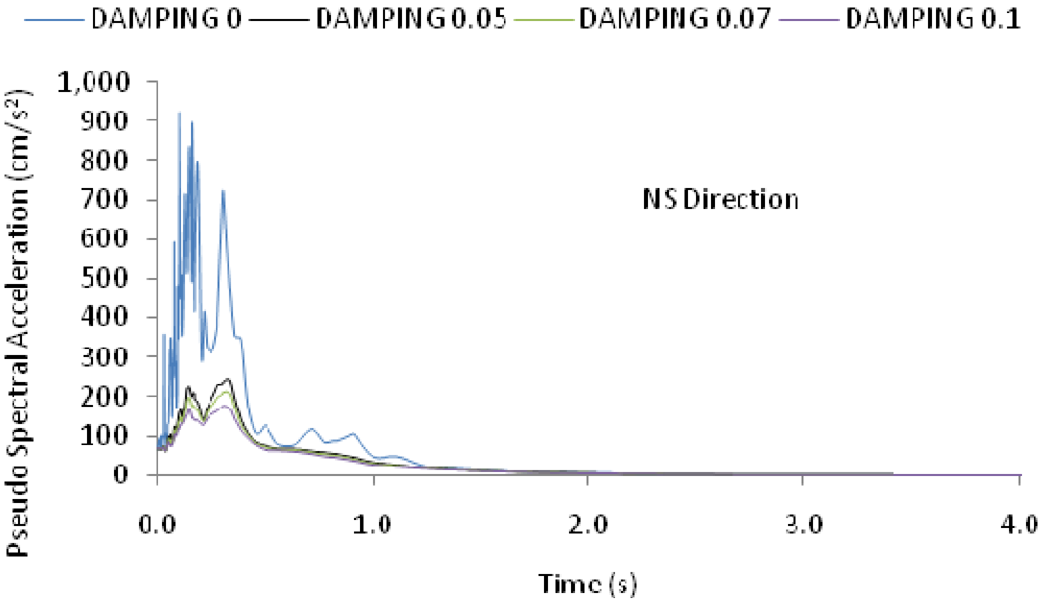

Figure 4 . Pseudo acceleration spectra Sa = ω^2 $y(\omega)_{MAX}$ in NS direction for different damping ratio.

difference between different percent damping for the site is recorded here. Here values of EW direction (Figure 3) indicate maximum values for both spectra. Also, the multiplication by ω^2 tends to completely eliminate the information contained in the long period range. Since most structural failures during recent earthquakes have been associated with soft sites, perhaps we should consider using the relative displacement spectrum as the fundamental form for selecting a design earthquake.

The high frequency, short period, part of the curve is always defined by Equations 30 or 31 where $\ddot{u}_{g_{MAX}}$ is the peak ground acceleration.

$$y(\omega)_{MAX} = \frac{\ddot{u}_{g\,MAX}}{\omega^2} \tag{30}$$

$$y(T)_{MAX} = \frac{\ddot{u}_{g\,MAX} \times T^2}{4\pi^2} \tag{31}$$

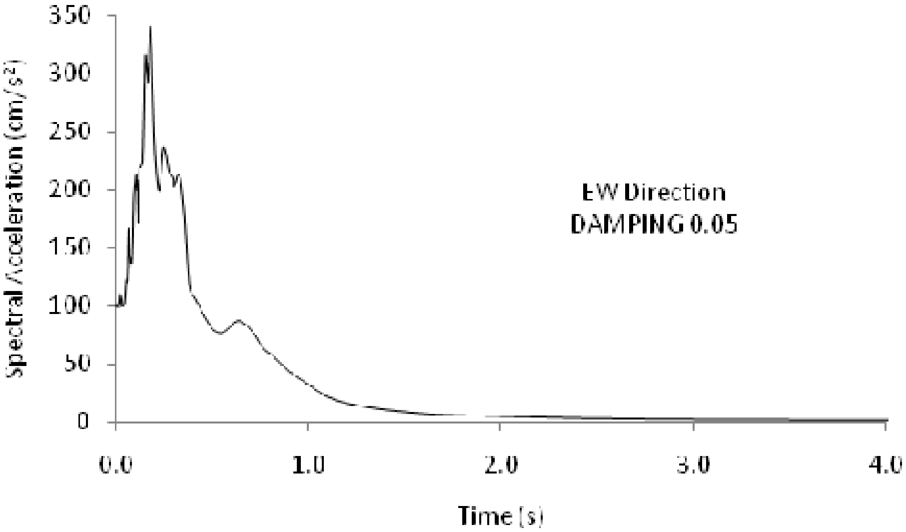

Figure 5. Response spectrum (cm/s^2) for 5% damping in EW direction.

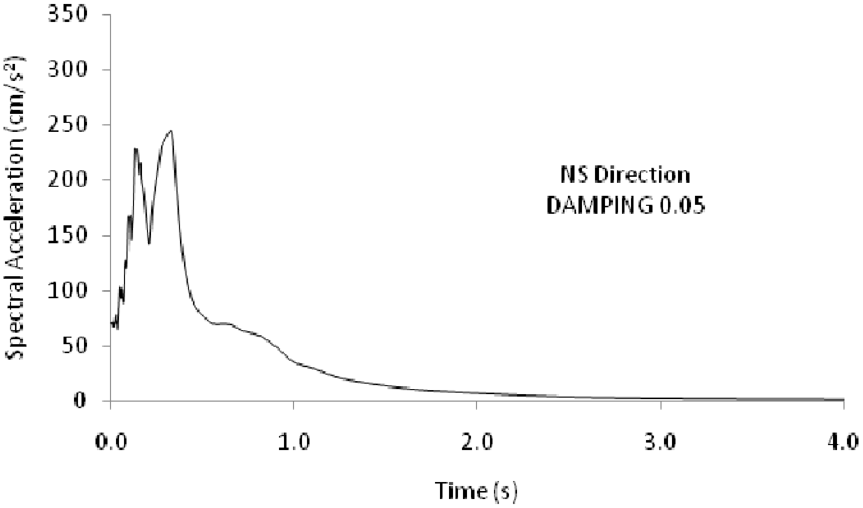

Figure 6. Response spectrum (g) for 5% damping in NS direction.

Construction of smooth response spectra

Response spectrum for a given earthquake record is quite irregular and has a number of peaks and valleys. An earthquake record has a particular frequency content which gives rise to the jagged, saw tooth appearance of peaks and valleys as shown in Figures 3 and 4. This feature is not suitable for design, since for a given period the structure may fall in a valley of the response spectrum resulting in an un-conservative design for an earthquake with slightly different response characteristics. Conversely, for a small change in the period, the structural response might fall on a peak resulting in a very conservative design. To alleviate this problem, the concept of the smoothed response spectrum has been introduced for design. As dynamic analysis, normally 5% damped response spectra are considered so the 5% damped response spectrum in EW and NS direction are presented in Figures 5 and 6, respectively. As discussed earlier, the EW directional responses being governed here, only time varying values of EW direction are used for the construction of response smooth spectrum. It is to mention that for generating the spectral values, natural frequency w_g has been considered as 15 rad/s (for soil type III) (Ansary and Noor, 2000) which indicates natural time period, T = 0.42 s. Design spectra are not of uneven curves and are presented in combination of smooth curves and straight lines (Figure 7). Statistical approach has been adopted here to create a smoothed spectrum to make it suitable

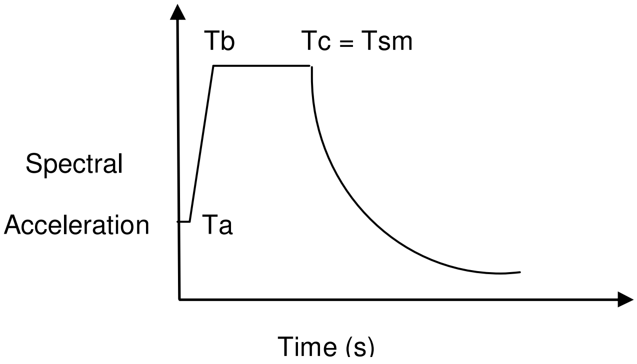

Figure 7. Typical smooth response spectrum.

Table 1. Seismic coefficient C_A.

Soil profile type	Seismic zone coefficient, Z				
	Z = 0.075	**Z = 0.15**	**Z = 0.2**	**Z = 0.3**	**Z = 0.4 (Na)**
S_{1a}	0.06	0.12	0.16	0.24	0.32
S_{1b}	0.08	0.15	0.20	0.30	0.40
S_2	0.09	0.18	0.24	0.33	0.40
S_3	0.12	0.22	0.28	0.36	0.44
S_4	0.19	0.30	0.32	0.36	0.36
Other	Site specific geotechnical investigation and dynamic site response shall be performed to determine seismic coefficients.				

for design. The spectra may be modified to use in the seismic code provisions. In order to achieve this modification for very short period, acceleration has been considered as peak ground acceleration $\ddot{u}_g$(max) and it is assumed to be linearly increased up to beginning period of the maximum constant response ordinate and a minimum period has been chosen below which the spectral ordinates were kept constant to be in the conservative side. These values of time period for different soil conditions have been listed in Table 3.

It is apparent from the table that the natural time period of soil under considerations matched satisfactory with the chosen time period for maximum ordinates. It can be said that resonance can occur when structural time period coincides with the natural time period of the soil beneath. After this time period, the spectrum curve is smoothened following the formula in Equation 34 as per the coefficients obtained from soil conditions according to Table 4. Figure 7 shows selection of the points along with smooth lines of different portions. For very short period (up to Ta = 1/33 s), acceleration has been considered as peak ground acceleration $\ddot{u}_g$(max) and it is assumed to be linearly increased up to beginning period of the maximum constant response ordinate T_b expressed in Equation 32. This constant ordinate has been continued till the time period (Naeim and Paz, 1995) reached to T_c as in Equation 33.

$$T_b = 0.2T_{sm} \tag{32}$$

$$T_c = T_{sm} = \frac{C_v}{2.5C_a} \tag{33}$$

Seismic coefficients are intended to define the minimum spectral ordinates to be used in design. The terms C_A and C_V correspond to constant-acceleration and constant-velocity regions of the response spectrum respectively. The seismic coefficient value (UBC, 1994) of C_A is illustrated in Table 1 and C_V at Table 2 as well. The value of C_A (from Table 1 for Z = 0.15 and soil profile type S_3) is found as 0.22 and the value of C_V (from Table 2 for Z =0.15 and soil Profile Type S_3) is found as 0.32. So, Ta = 1/33 = 0.03 s, Tc = 0.58 s as per Equation 32 and Tb = 0.11 s as per Equation 33. Taking the values for these points from the uneven curve and free hand smoothing, acceleration response spectrum has been found which is shown in Figure 8.

For smooth design response spectra, the afore-mentioned curve is modified properly. After a short period Tb, S bears a constant value for T<Tc. When T>Tc, the

Table 2. Seismic coefficient Cv.

Soil profile type	Seismic zone coefficient, Z				
	Z = 0.075	Z = 0.15	Z = 0.2	Z = 0.3	Z = 0.4 (Nv)
S_{1a}	0.06	0.12	0.16	0.24	0.32
S_{1b}	0.08	0.15	0.20	0.30	0.40
S_2	0.13	0.25	0.32	0.45	0.56
S_3	0.18	0.32	0.40	0.54	0.64
S_4	0.26	0.50	0.62	0.84	0.96
Other	Site specific geotechnical investigation and dynamic site response shall be performed to determine seismic coefficients.				

Table 3. Classification of ground conditions for earthquake stations.

Site category	Natural time period
Soil type I (rock)	T<0.2
Soil type II (hard soil)	0.2< = T<0.4
Soil type III (medium soil)	0.4< = T<0.6
Soil type IV (soft soil)	T>0.6

Table 4. Values of coefficient a and b for modification of response spectra.

Site category	Coefficient a	Coefficient b
I	0.74	-0.90
II	0.95	-0.93
III	1.48	-0.98
IV	3.74	-1.07

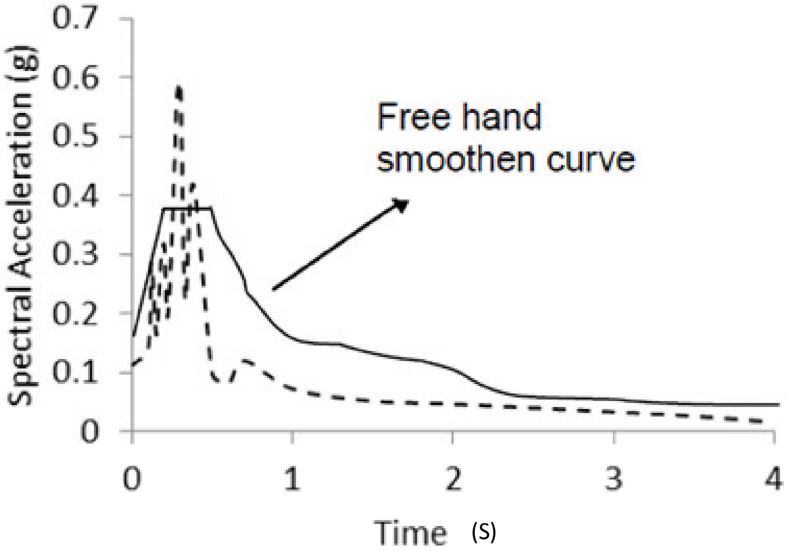

Figure 8. Optimal response spectrum (g) for 5% damping and its free hand smoothing.

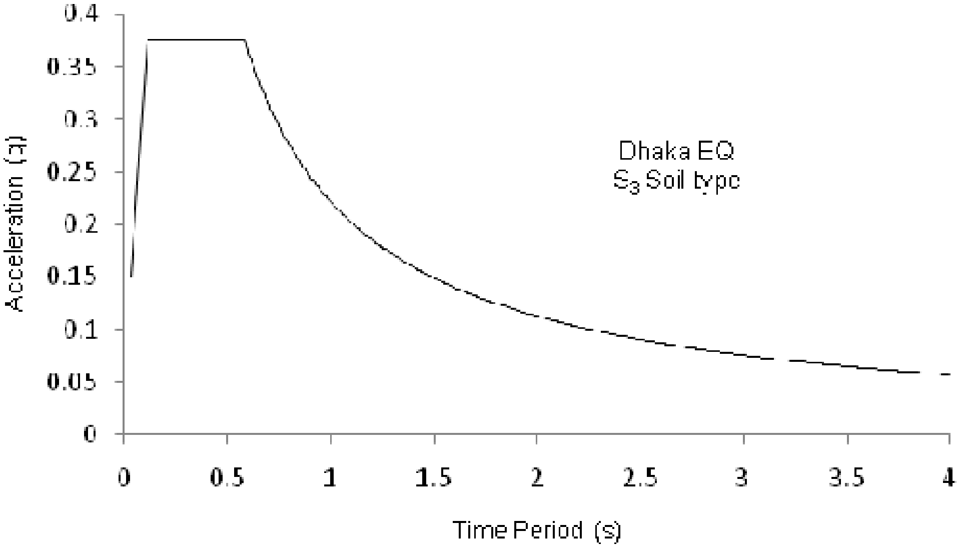

Figure 9. Acceleration response spectrum for S_3 soil in Dhaka.

value of S has been derived by using the formula (Ansary and Noor, 2000) in Equation 34.

$$S = aT^b \tag{34}$$

Here S is the spectral ordinate, a and b are constants, T is the time period. To get the values a and b, natural time period has been checked along with soil type (Ansary and Noor, 2000) through Table 3.

Now for soil type III, the values of a and b (Table 4) can be obtained 1.48 and -0.98 respectively (Ansary and Noor, 2000). From the Equation 34, for Tc = Tsm = 0.58, Sa = 2.503. This value resembles to the generated spectral value corresponding to same time period 0.58. As for Tb up to Tsm, spectral ordinate is constant so Sa = 2.503 for also Tb = 0.11 s. Selected periods for changing spectral values also mostly resemble to the period selection described as Ta = 1/33, Tb = 1/8, Tc = 1/2 s (Lee and Kanamori, 2002) and Tb = 0.10 and Tc = 0.60 s (Kappos, 2002) and accordingly maximum value of response spectrum is well similar to 2.5* üg. The initial value of spectral acceleration has been taken as 1.0*$ü_g$ (where $ü_g$ = peak ground acceleration) at T_0. For T>Tc, Sa has been derived from Equation 32 (Ansary and Noor, 2000). Figure 9 shows the detail figure of the smooth response spectra.

Proposed design response spectra

Derived design 'response spectrum, for dynamic analysis of Dhaka earthquake history can then be represented as follows (Figure 9). The response spectrum for soil type S_3 can be generalized for another seismic zoning condition so that for other regions of Bangladesh, it can be used. Here the normalized response spectrum is shown in Figure 10.

Evaluation of proposed design response spectra with different codes

Proposed response spectrum is very close to the suggested response spectra by UBC94 and IBC2000 except slightly greater than those in exponential zone. But it shows much greater values than IS 1893:2002 suggested response spectrum in exponential zone. Initial time period of velocity constant zone is slightly greater than proposed curve at UBC94. All the curves are identical in velocity constant zone. Apart from this, the developed response spectrum curve is on the whole identical with the free hand smoothen curve presented in Figure 8. The comparative description of the proposed design response spectrum curve is illustrated in Figure 11 to introduce it as acceptable solution for Dhaka (S_3 soil) figuring the code specified response spectrum in case of the same soil condition.

Conclusion

In fact, Bangladesh lacks heavily on seismic instruments and we have not enough data of earthquake records particularly of Dhaka; so natural earthquake record has been considered performing proper scaling to disembark at site specific response spectra suitable for dynamic analysis of structures. The generated response spectra and time history may be used in dynamic analysis of structures in Dhaka. For other regions of Bangladesh, the generated response spectrum may be used adjusting the

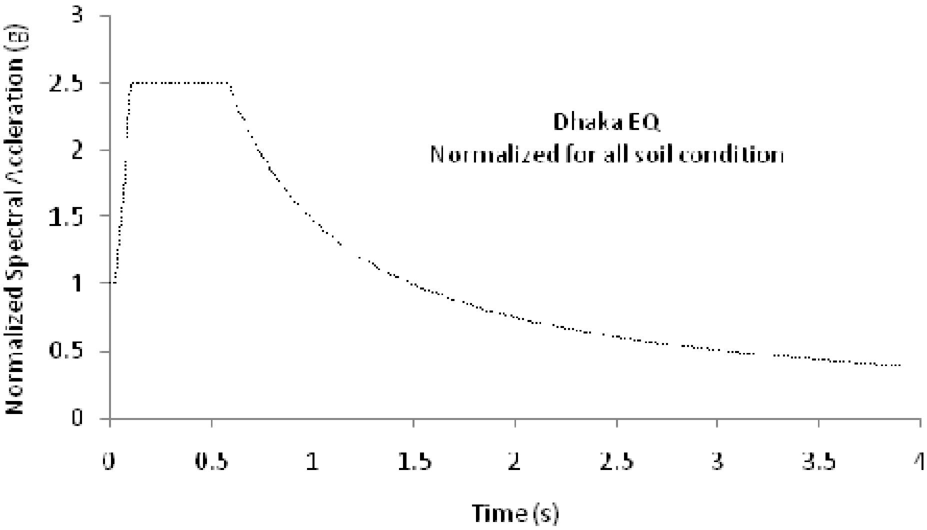

Figure 10. Normalized 5% damped response spectra (g) for Dhaka.

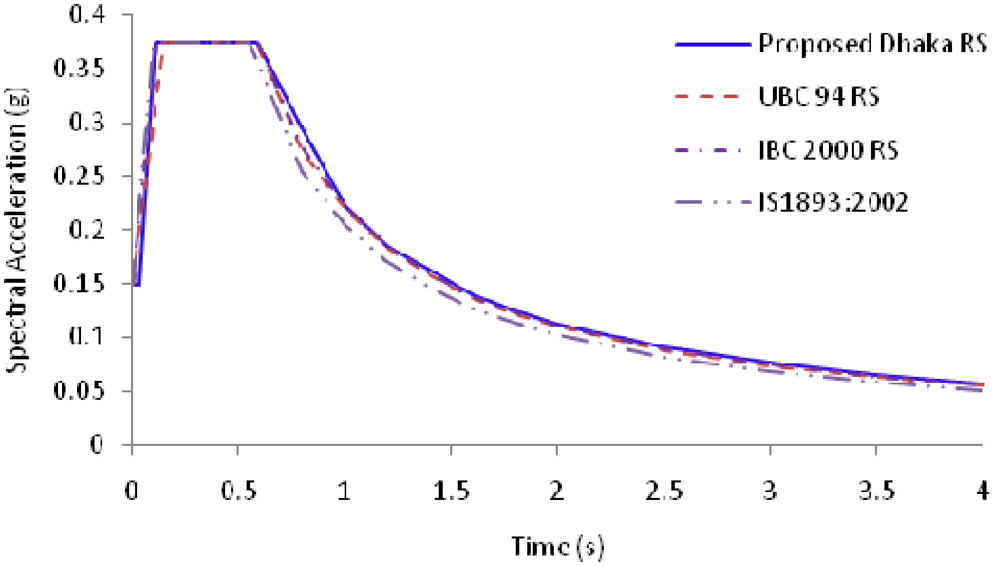

Figure 11. Comparison of proposed response spectrum for Dhaka (S_3 soil) with different codes.

zoning condition. It is imperative to install suitable number of seismic stations so that in future, spectra based on site specific real earthquake records for allover Bangladesh can be developed.

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NOMENCLATURE

C_A, seismic coefficient correspond to the constant-acceleration region; **C_V,** seismic coefficient correspond to the constant-velocity region; **g,** acceleration due to gravity; **Na,** near source factor at constant acceleration; **Nv,** near source factor at constant velocity; **S(ω)a,** Pseudo acceleration spectrum = ω^2 $y(\omega)_{MAX}$; **T,** time period; **Tsm,** time period corresponding to the maximum response; **Üg,** peak ground acceleration; **ü(t)g,** specified ground motion; **$\ddot{u}(t)_T$,** total acceleration of the unit mass, single degree-of-freedom system; $\upsilon(\tau)$, impulsive acceleration; **$\omega y(\omega)_{MAX}$,** Pseudo-velocity spectrum; **ω,** natural frequency; **ω_D,** damped natural frequency; **ω_n,** un-damped natural frequency; **ζ,** modal damping ratio.

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