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Ground Motion Modelling in Bangladesh Using Stochastic Method

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***Abstract*---**Geological and tectonic framework indicates that Bangladesh is one of the most seismically active regions in the world. The Bengal Basin is at the junction of three major interacting plates: the Indian, Eurasian, and Burma Plates. Besides there are many active faults within the region, e.g. the large Dauki fault in the north. The country has experienced a number of destructive earthquakes due to the movement of these active faults. Current seismic provisions of Bangladesh are mostly based on earthquake data prior to the 1990. Given the record of earthquakes post 1990, there is a need to revisit the design provisions of the code. This paper compares the base shear demand of three major cities in Bangladesh: Dhaka (the capital city), Sylhet, and Chittagong for earthquake scenarios of magnitudes $7.0M_W$, $7.5M_W$, $8.0M_W$, and $8.5M_W$ using a stochastic model. In particular, the stochastic model allows the flexibility to input region specific parameters such as shear wave velocity profile (that were developed from Global Crustal Model CRUST2.0) and include the effects of attenuation as individual components. Effects of soil amplification were analysed using the Extended Component Attenuation Model (ECAM). Results show that the estimated base shear demand is higher in comparison with code provisions leading to the suggestion of additional seismic design consideration in the study regions.

***Keywords*---**Attenuation, earthquake, ground motion, stochastic, seismic hazard.

I.INTRODUCTION

BANGLADESH is one of the most densely populated countries in the world. A large number of these populations are living in cities like Dhaka, Sylhet, and Chittagong. The infrastructure in most of these big cities has not been designed and built to standard practice and hence are vulnerable to natural disasters. Dhaka the capital city has a total population of over 13 million with an average of 45,000 people per square kilometer which makes it particularly vulnerable to earthquake hazard. Given these cities proximity to seismic sources a proper seismic hazard assessment is essential. This assertion is further compounded by the fact that the seismic provisions in the code are based on data prior to the 1990's. Post the 1990's there has been a major improvement in the earthquake data collection worldwide. Accordingly there has been major earthquakes of magnitudes >7 in the recent history.

In the absence of major broadband ground motion recording stations, the use of semi-empirical or stochastic model is quoted as a viable alternative procedure [1]-[3]. In this paper, the authors have resorted to a component stochastic modelling approach "GENQKE" [1], [2] as it offers the flexibility to include region specific geological and seismological parameters.

II.GEOLOGY AND SEISMICITY OF BANGLADESH

Geologically, Bangladesh and most of west Bengal of India are occupied by the Bengal basin. Bengal Basin is surrounded by Indian Shield to the west and north, and the Indo-Burman Ranges to the east of Bangladesh (Fig. 1). Therefore, this basin is in close proximity to two subduction zones created by India and Eurasia plates. Continental collision between India and Eurasia plates at the region of Himalayas makes it one of the most seismic hazard areas on earth. The Indian plate is thrusting beneath Eurasian plates, converging at a relative rate of 40-50 mm/yr [4]. The tremors can be felt as far as Bangladesh which is in excess of 1000 km. The recent earthquake on 25th April, 2015 (7.8 Mw) in Nepal and the subsequent aftershocks were felt in Dhaka and many other cities in Bangladesh although no major structural damaged has been reported. Therefore, the country is surrounded by the Himalayan Arc, the Shillong Plateau and the Dauki fault system in the north; the Burmese Arc and Arakan Yoma anticlinorium in the east; the Naga DisangHaflong thrust zone in the northeast; and the recently activated inner fault in Haluaghat of Mymenshingh makes a compelling case for review of seismic hazard assessments. Bangladesh had experienced a number of large magnitudes in these regions e.g. Great Indian earthquake (1897) magnitude (Richter) of 8.7, Assam earthquake (1950) magnitude (Richter) of 8.5. Previous researchers, e.g. [5], identified five major tectonic blocks that can produce damaging earthquakes in the future. These blocks are (Fig 1):

1) Bogra fault Zone,
2) Tripura fault zone,
3) Assam fault zone,
4) Shillong plateau, and
5) Dhubri fault zone.

Of all these blocks, 1and 2 are less active and 3, 5 are far away from the major cities listed in the study. This leaves the Shillong plateau as the nearest site source for stochastic modelling.

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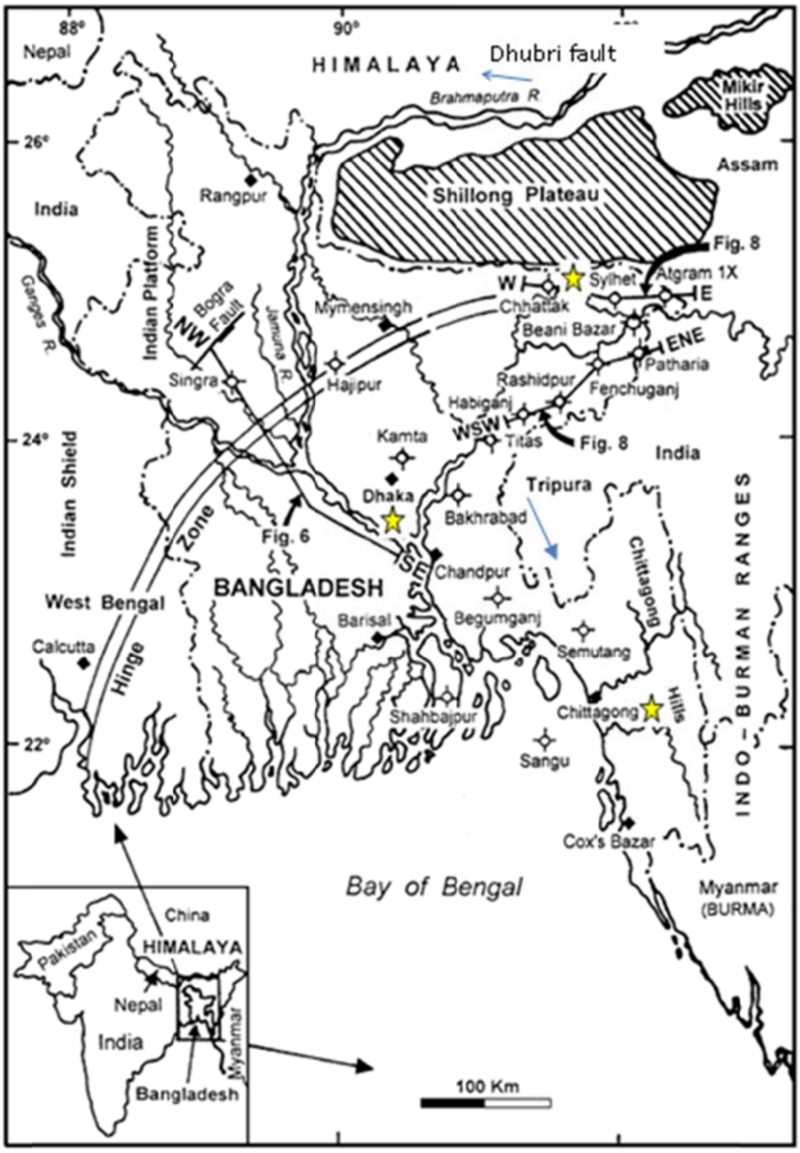


Fig. 1 Major tectonic features surrounding the Bengal Basin [6]

III.Seismological Model and Parameters

The Fourier amplitude spectrum of earthquake waves reaching an outcrop can be defined as $A_X(f)$ with factors as shown in (1):

$$A_X(f) = S(f)\times G\times An(f)\times P(f)\times V(f) \tag{1}$$

where, $S(f)$ is the Source Factor, G is the Geometric Attenuation Factor, $An(f)$ is the Anelastic Whole Path Attenuation Factor, $P(f)$ is the Upper Crustal Attenuation Factor, $V(f)$ is the Upper Crustal Amplification Factor.

A. Source Factor S(f)

Source factor defines the frequency content of body waves radiating from the source of the earthquake which was developed by [7] and [8]. Atkinson [7] suggested two corner frequencies (f_A and f_B) for the Fourier displacement amplitude model as:

$$S(f) = CM_O\left[\frac{(1-\varepsilon)}{1+(\frac{f}{f_A})^2}+\frac{\varepsilon}{1+(\frac{f}{f_B})^2}\right] \tag{2}$$

where, C is the Scaling factor, M_O is the seismic moment and ε is the relative weighting parameter.

$$C=\frac{R_P FV}{4\pi\rho\beta^3} \tag{3}$$

where, R_P is the wave radiation factor, F the free surface amplification factor, V the factor partitioning energy in the two orthogonal directions, $\rho$is the rock density at the rupture depth (Kg/m^3) and β is the shear wave velocity of the rock at the rupture depth Km/s. The product of $R_P FV$ can be taken as 0.78. The lower corner frequency f_A, lower corner frequency f_B and relative weighting parameter ε can be determined using (4), (5), and (6), respectively:

$$\log f_A = 2.41 - 0.533M \tag{4}$$

$$\log f_B = 1.43 - 0.188\ M \tag{5}$$

$$\log \varepsilon = 2.52 - 0.637M \tag{6}$$

CRUST2.0 is a reliable database of oceanic and continental crust structure with a grid of 2°×2° cells and presents the physical properties of the crust and the uppermost mantle. The density of the rock ($\rho = 2800$ kg/m^3) and SWV at mid crust ($\beta = 3400\ m/s$) for the subject region are obtained by averaging data from CRUST2.0. Fig. 2 shows the crustal geological structures of Bangladesh and Fig. 3 shows the SWV profile of Bangladesh developed using guidelines from [9].

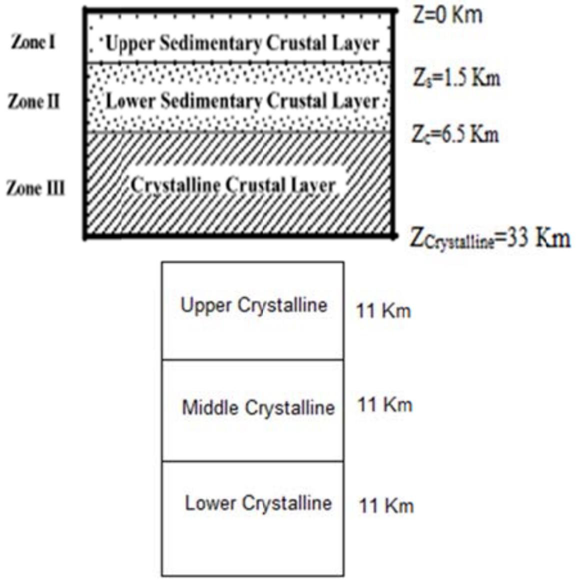


Fig. 2 Crustal geological structures of Bangladesh

B. Geometric Attenuation Factor, G

Geometric Attenuation Factor can be expressed as function of crustal thickness as:

$$G = \frac{R_0}{R} \quad \text{when } R<1.5D \tag{7}$$

$$G = \frac{R_0}{1.5D} \quad \text{when } 1.5D<R<2.5D \tag{8}$$

$$G = \frac{R_0}{1.5D}\sqrt{\frac{2.5\,D}{R}} \text{when } 2.5D<R \tag{9}$$

where, R_0 is the reference distance (and is typically assumed to be 1 km), D is the crustal thickness in the subject region(from Fig. 2). The site-source distances (R) have been taken as 210,60 and 320 Km for Dhaka, Sylhet and Chittagong respectively.

C. Anelastic Whole Path Attenuation Factor, An(f)

Anelastic Whole Path Attenuation Factor represents the attenuation as a result of energy loss due to geometric spreading and anelastic attenuation. This factor can be estimated using (10) developed by [10]:

$$An(f) = e^{-\pi f R/Q\beta} \tag{10}$$

where Q is the wave transmission quality factor, R is the length of the wave travel path and β is the shear wave velocity. Wave transmission quality factor can be expressed as:

$$Q = Q_0 f^{\eta} \tag{11}$$

Q_0 is the wave transmission quality factor at 1 Hz frequency and f is the wave frequency.

There are many well established methods of determining Q_0 for seismically active regions (such as California, ENA, WNA, etc.). For Bangladesh, this is yet to be measured and values estimated for Singapore [11] have been used in this study (i.e. Q_0= 150 and η=0.56). This assumption is also supported by (12) [12] to measure Q_0. Using (12) Q_0 value works out to 148 using SWV at 30m depth as 0.7Km/s.

$$Q_0 = 60+320(V_{s,0.03}-0.05)^{0.8} where,\ 0.5\frac{Km}{s} < V_{s\ 0.03} < 3.0\frac{Km}{s} \tag{12}$$

D. Upper Crustal Attenuation Factor, P(f)

The attenuation at the upper part of the crustal is defined Upper Crustal Attenuation Factor and can be measured suing (13)

$$P(f) = e^{-\pi f \kappa} \tag{13}$$

where κ (Kappa) operator can be measured using (14) developed by [12].

$$\kappa = \frac{0.057}{V_{s\ 0.03}^{0.8}} - 0.02;\ where,\ 0.5\frac{Km}{s} < V_{s\ 0.03} < 3.0\frac{Km}{s} \tag{14}$$

For Bangladesh, κ value has estimated about 0.056 using SWV at 30m depth as 0.7Km/s.

E. Upper Crustal Amplification Factor, V(f)

Shear wave velocity is amplified when propagating through upper part of the earth's crust where there is relatively young rocks called as soft rock or stiff soil [13]. Boore and Joyner [14] have suggested a methodology to estimate frequency-dependent crustal amplification factors for generic California rock sites as shown in (15):

$$V(f) = \sqrt{\frac{\rho_A \beta_A}{\rho_B \beta_B}} \tag{15}$$

where, ρ_A and β_A is the density and shear wave velocity of rock at the depth of the source, and ρ_B and β_B is the density and shear wave velocity over a specific depth that the values are averaged, measured from the top of the crust. Shear wave velocity of Bangladesh is modeled by using power law relationships developed by [15]. For this purpose, Bangladesh is considered as non- glaciated with deep sediments. The modelling parameters are as following:

1. Sediment thickness, Z_s= 1.5 km
2. Depth of the top of crystalline crust, Z_c=6.5 km
3. S-wave velocity within the sediment, $V_{s,0.03}$=0.7 km/s

4. S-wave velocity within the crust, $V_{s,15}$=3.40 km/s

Fig. 3 shows the modeled SWV profile for Bangladesh associated with SWV for Generic Rock (GR), and proposed SWV for ENA and WNA [15] for comparison which shows that modeled SWV profile for Bangladesh is consistence with the other profiles.

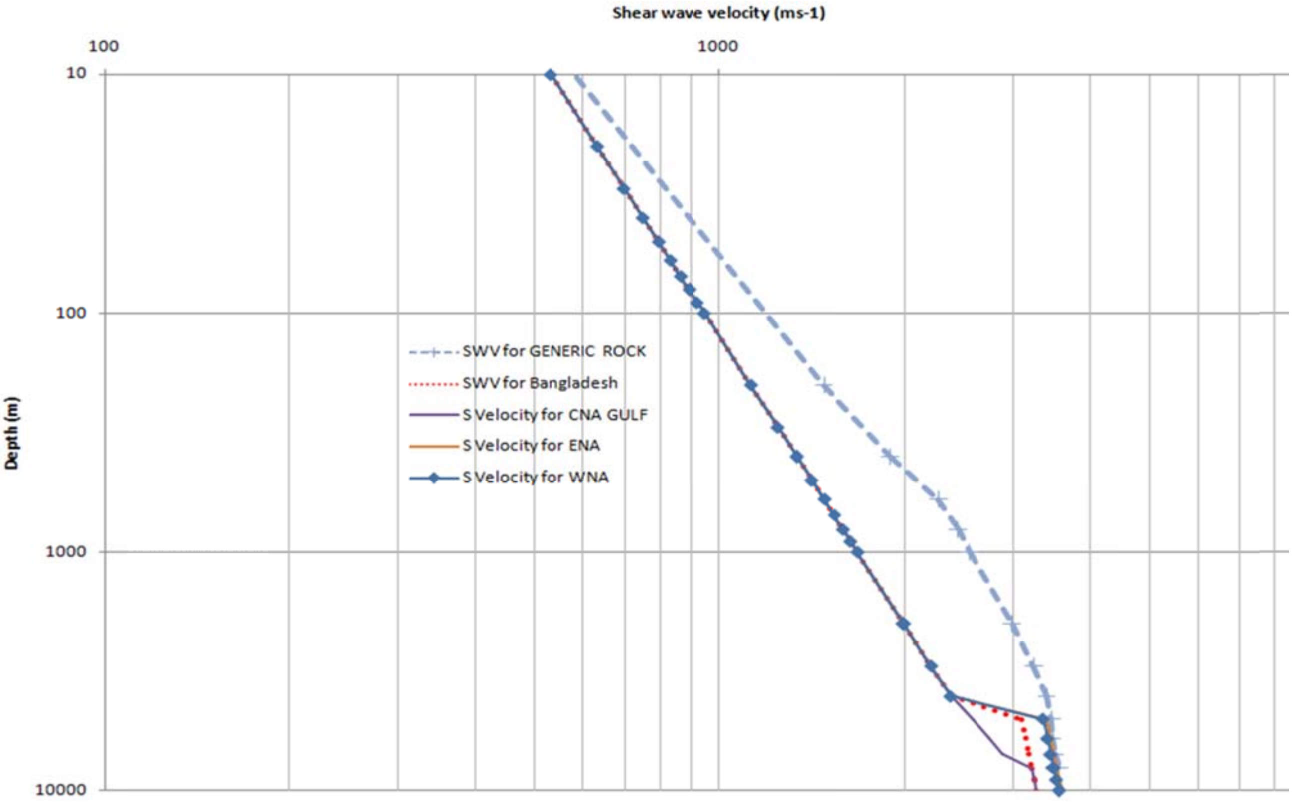


Fig. 3 SWV profile of Bangladesh

IV. Synthetic Accelerogram

The aforementioned seismological model of the Fourier amplitude spectrum has been reviewed by [16] and combined with randomly selected phase angles in a stochastic procedure to simulate seismograms to fit with the frequency contents. This synthetic accelerograms were produced using program, “GENQKE”, which was developed at the University of Melbourne [17]. For this study, seismograms were produced for the design earthquake scenarios with magnitudes of $7.0M_W$, $7.5M_W$, $8.0M_W$ and $8.5M_W$ for Dhaka, Sylhet and Chittagong. Table I shows PGAs (Peak Ground Accelerations) and PGVs (Peak Ground Velocities) for the design earthquake scenarios. Fig. 4 shows examples of simulated accelerograms for design earthquake scenario at Dhaka and Sylhet.

V. Drift Demand at Rock Sites

The ensemble average response spectrum (5% critical damping) simulated for each of the projected scenarios is shown in Fig. 5. The response spectrum of Fig. 5 can be used for calculating the elastic drift demand (Δ) on single-degree-of-freedom lumped-mass systems of 5% critical damping.

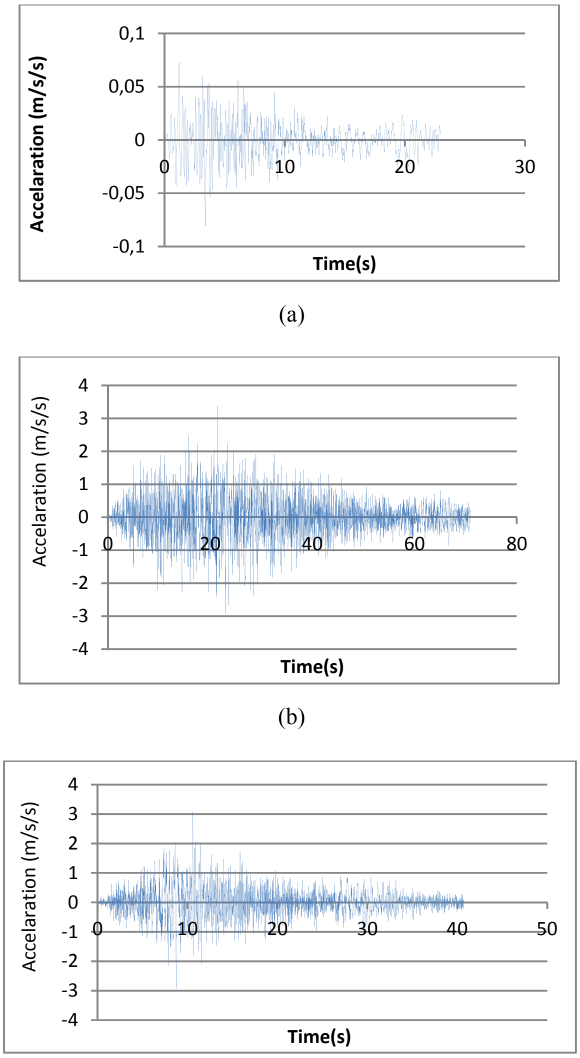
$$\Delta = A \times \left(\frac{T}{2\pi}\right)^2 \tag{16}$$

A= Pseudo-spectral acceleration, T= Fundamental period.

The upper limit of response spectrum for Dhaka for period range of 0.05s to 0.4s and 0.45 to 1.6s approximated as constant 0.46g acceleration and 1200 mm/s as constant velocity (Fig. 5 (a)). Equation (16) gives Δ value as around 0.3 to 18 mm for above period range, where base shear demand is very high (about 50% of seismic weight).

TABLE I
Results (Ground Motion Parameters) of Simulated Design Earthquakes

M_w	PGV(mms^{-1}) at Dhaka	PGA (g) at Dhaka	PGV(mms^{-1}) at Sylhet	PGA (g) at Sylhet	PGV(mms^{-1}) at Chittagong	PGA (g) at Chittagong
7.0	230	0.111	108	1.674	10	.032
8.0	43	0.198	134	2.054	22	.071
8.5	57	0.316	248	3.077	53	.104
9.0	132	0.462	329	3.385	65	.175



(a)

(b)

(c)

Fig. 4 Examples of simulated accelerograms for (a) M7R210 for Dhaka, (b) M8.5R60 for Sylhet, (c) M8.0R60 for Sylhet

The upper limit estimate of response spectrum values of Sylhet for period range of 0.04 to 0.22s and 0.3 to 1s can be approximated as 0.22g constant acceleration and 8250mm/s as constant velocity (Fig. 5 (b)). Result shows higher “effective drift” values of about 394 to 1313 mm. From Table I, it is clear that PGA for Sylhet exceeded 3g in some of the simulations (compare large M with short R); the shape of the response spectrum clearly brings out the frequency contents in the acceleration and velocity controlled regions. Thus, the region has a higher risk from large earthquakes.

For Chittagong, period range of 0.12 to 0.92s and 1.1 to 3s approximated as 0.22g constant acceleration and 380mm/s as constant velocity (Fig. 5 (c)). This part of the country also shows higher “effective drift” values of about 67 to 181 mm respectively. It is noted that these drift values are for rock sites only.

VI. DRIFT DEMAND AT SOIL SITES

A simple model developed by [18], called Extended Component Attenuation Model (ECAM) have been adopted to estimate soil amplification effects. Table II shows Site Amplification Factors (SAFs) calculated for subject regions. It is clear that using the amplification factors from Table II will accentuate the demand on buildings founded on soil sites. These values easily exceed the code provisions of seismic base shear demand.

TABLE II
SAFS CALCULATED BY USING ECAM

M_W	SAFs for Dhaka	SAFs for Sylhet	SAFs for Chittagong
7.0	8.11	7.86	7.62
7.5	7.37	7.13	6.88
8.0	6.76	6.39	6.14
8.5	6.02	5.65	5.41

VII. CONCLUDING REMARKS

- According to the stochastic model adopted in the study the base shear demand due to seismic actions can be well above the design limits suggested in the current design practice in Bangladesh.
- The shape of the response spectra obtained from stochastic simulations depicts large frequency contents in both the acceleration and velocity controlled regions. Although further verification is required with recorded simulations, these shape effects might warrant changes in the design procedure of structures.

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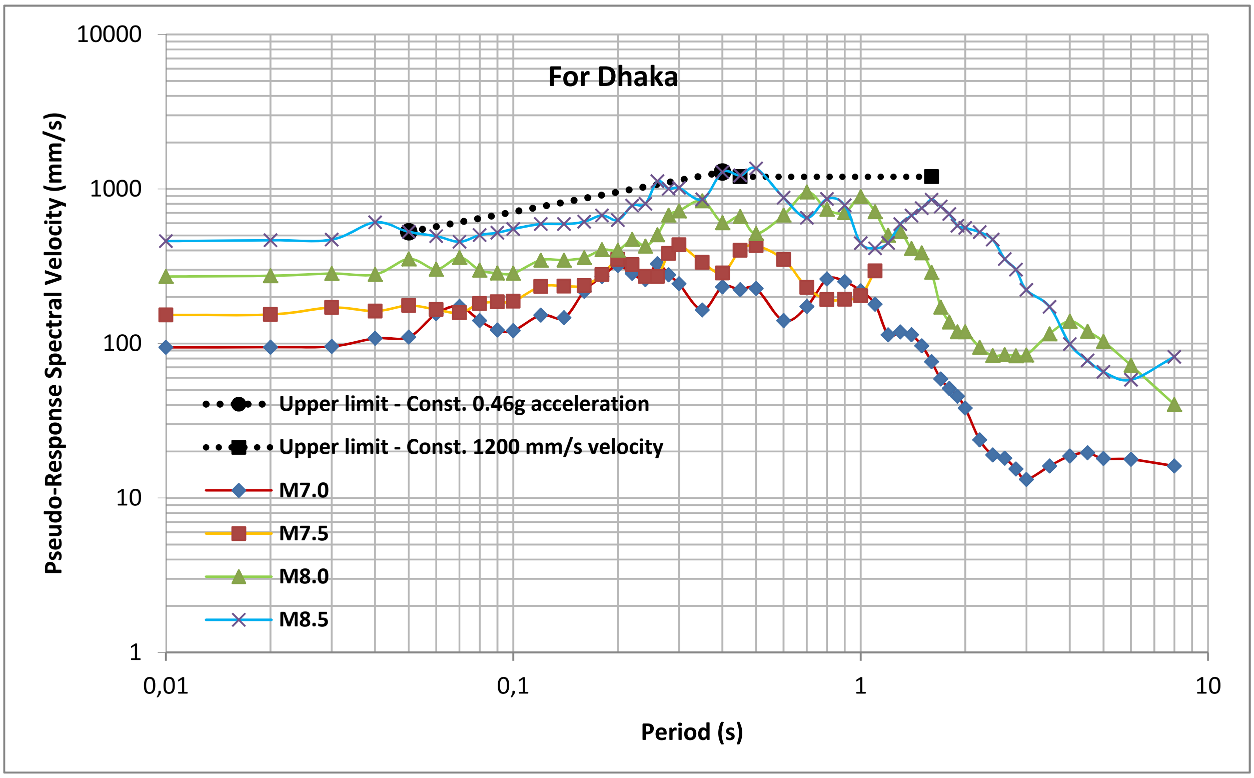
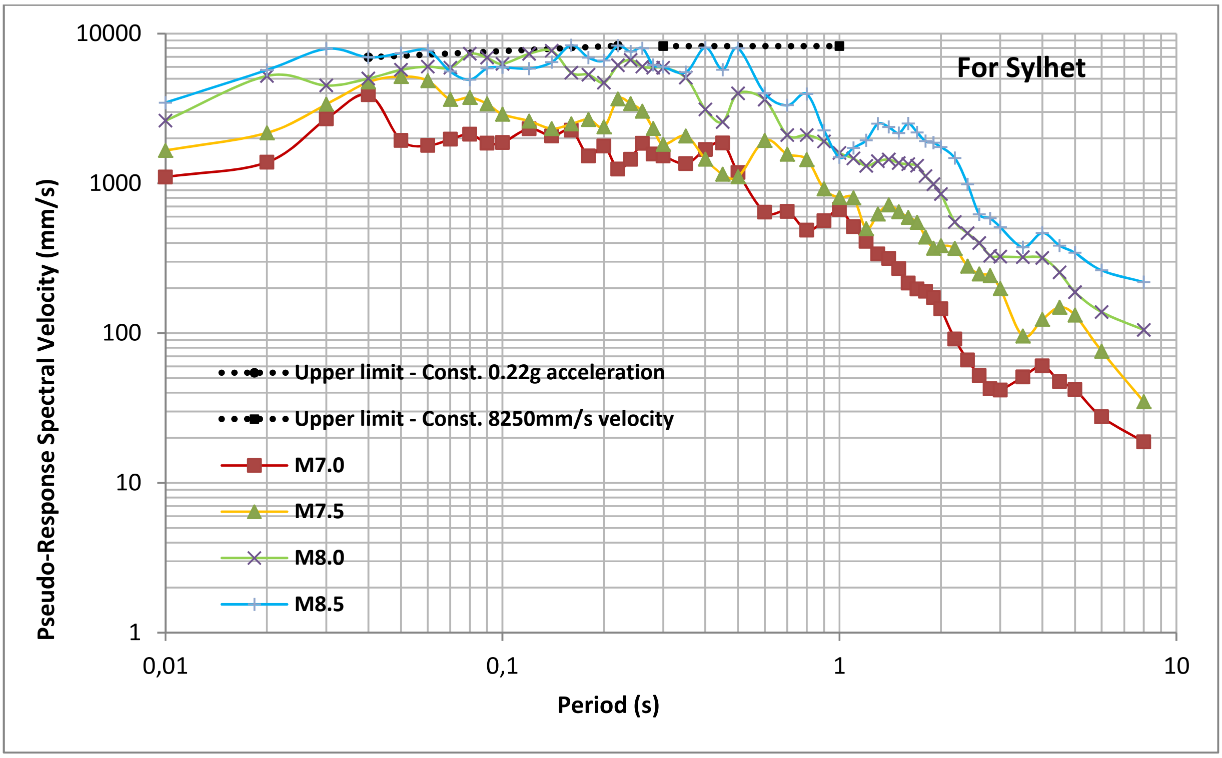


(a)



(b)

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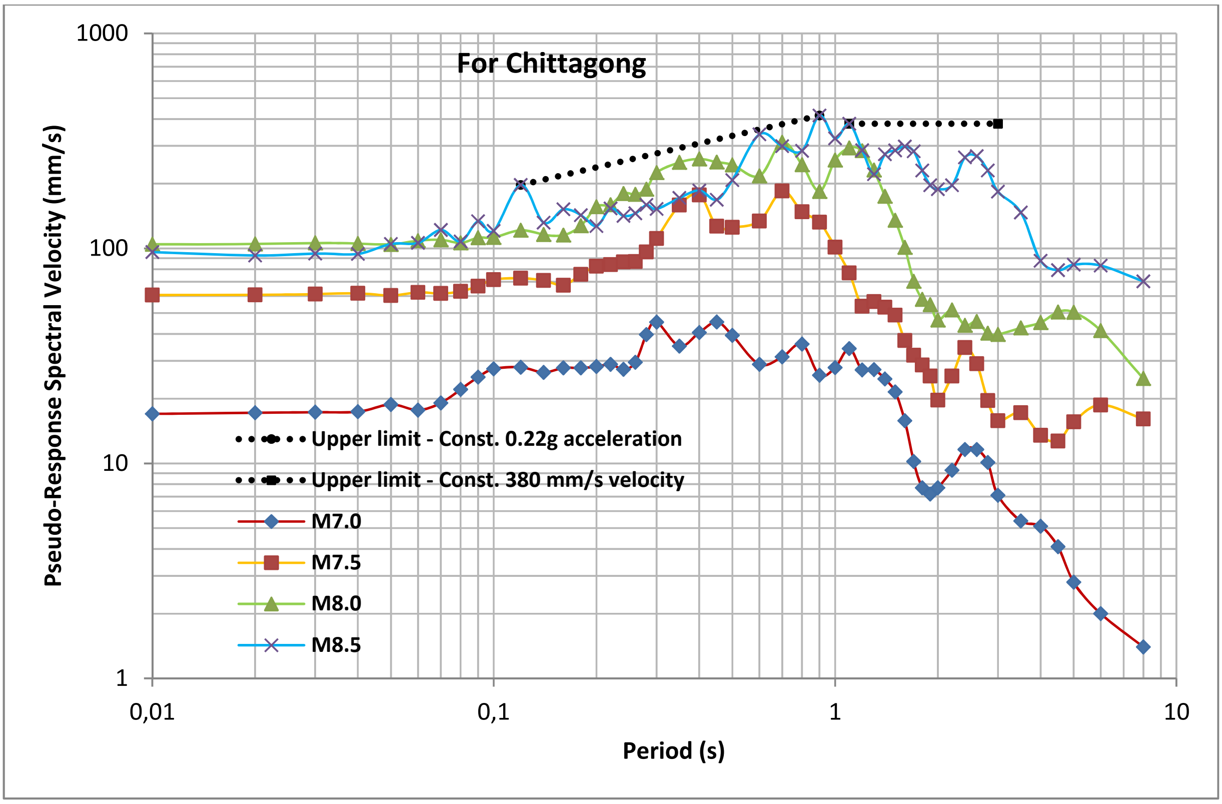

(c)

Fig. 5 RSV diagrams for 5% critical damping for (a) Dhaka, (b) Sylhet and (c) Chittagong

REFERENCES

[1] Albidah, A., Altheeb, A., & Lam, N. (2011). Stochastic Attenuation Modelling: Saudi Arabian Case Study. Australian Earthquake Engineering Society Conference, 18-20 Nov 2011. Novotel Barossa Valley, South Australia.

[2] Gamage, P., Venkatesan, S., & Dissanayake, R. (2011). Seismic drift demand on multi-storey buildings in Sri Lanka due to long-distant earthquakes. Kandy, Sri Lanka: Proceedings of the International Conference on Structural Engineering, Construction and Management (ICSECM 2011).

[3] Boore, D. (2003). Simulation of Ground Motion Using the Stochastic Method. Pure and Applied Geophysics, Pp635–676.

[4] U.S. geological survey. Website:www.usgs.gov

[5] Hossain M.A. (1998). Earthquake Database and Seismic Zoning of Bangladesh. Department of Civil Engineering, BUET, Dhaka, Bangladesh.

[6] Alam, M., Alam, M. M., Curray, J.R., Chowdhury, L. M., Gani, R.M., (2002).An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history. Journal of Sedimentary Geology 155: 179–208

[7] Atkinson, G (1993), ‘Earthquake source spectra in eastern North America ’, Bull. Seism. Soc.Am. vol. 83, pp.1778 –1789.

[8] Atkinson, G. M. & Boore, D. M. (1998), ‘Evaluation of models for earthquake source spectra in eastern North America’, Bull. Seism. Soc. Am. vol. 88, pp. 917-934.

[9] Chandler, A., Lam, N., & Tsang, H. (2005). Shear wave velocity modelling in crustal rock for seismic hazard analysis. 25(2), Pp167-185.

[10] Boore, D.M & Atkinson, G (1987), ‘Stochastic Prediction of ground motion and spectral response parameters at hard-rock sites in eastern North America ’, Bull. Seism. Soc. Am. vol. 73, pp. 1865 –1894.

[11] Lam, N., Wilson, J.L., Balendra, T., Venkatesan, S. (2009), Seismic load estimates of distant subduction earthquakes affecting Singapore, Engineering Structures, Vol. 31, no. 5 (May 2009), pp. 1230-1240

[12] Chandler, A. M. (2006). "Near-surface attenuation modelling based on rock shear-wave velocity profile.". Soil Dynamics and Earthquake Engineering 26, Pp 1004-1014.

[13] Atkinson, G. M. (2000). Stochastic Modelling of California Ground Motions. Bulletin of the Seismological Society of America,90(2), Pp255–274.

[14] Boore, D. M. and W. B. Joyner (1997). "Site amplifications for generic rock sites." Bulletin - Seismological Society of America 87(2): 327-341.

[15] Chandler, A. M., N. T. K. Lam, et al. (2005). "Shear wave velocity modelling in crustal rock for seismic hazard analysis." Soil Dynamics and Earthquake Engineering 25(2): 167-185.

[16] Lam, N., J. Wilson, et al. (2000). Generation of synthetic earthquake accelerograms using seismological modelling: A review. Journal of Earthquake Engineering 4(3): 321-354.

[17] Lam, N. T. K. (1999). Program "GENQKE" User's Guide-Program for generating synthetic earthquake accelerograms based on stochastic simulations of seismological models, Department of Civil and Environmental Engineering, The University of Melbourne, Australia.

[18] Venkatesan, S. (2006). A soil amplification model for intra-plate seismic regions, PhD Thesis. Department of Civil & Environmental Engineering, University of Melbourne, Australia.