Proposed Changes to the Geotechnical Earthquake Engineering Provisions of the Bangladesh National Building Code

Tahmeed M. Al-Hussaini[1], Tahsin R. Hossain[1] and M. Nayeem Al-Noman[1]
[1]*Department of Civil Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh*
E-mail: htahmeed@yahoo.com

ABSTRACT: The Bangladesh National Building Code (BNBC) has not been updated since its inception in 1993. Earthquake design provisions are important, since Bangladesh is located in a seismically active region not far from the boundary of the Indian Plate and Eurasian Plate. Many advances in earthquake engineering research have taken place over the last two decades. In 2010, a project has been taken up for upgradation of the building code to incorporate current knowledge and developments. Significant changes have been proposed in the seismic design provisions of the updated version of the building code. This paper describes the salient features of the proposed changes to geotechnical earthquake engineering provisions affecting computation of the seismic loads. Major changes have taken place with regard to the seismic zoning map, soil classification system, site-dependent response spectrum, and in defining seismic design category.

1. INTRODUCTION

Bangladesh lies in a moderately seismic-prone region and historical evidence points to major earthquakes within or close to the country. The collision of the Indian plate, moving northeast, with the Eurasian plate is the cause of frequent earthquakes in the region comprising Bangladesh, North-East India, Nepal and Myanmar. Historically Bangladesh has been affected by five earthquakes of large magnitude (M) greater than 7.0 (Richter) within the last 150 years. Of them, the 1897 Great Indian earthquake (M=8.1 re-estimated by Ambraseys and Bilham, 2003) had an epicentral distance of only 230 km north of Dhaka, the capital. That earthquake caused extensive damages to masonry buildings in many parts of Bangladesh. The 1885 Bengal earthquake (M=7.0) and 1918 Srimongal earthquake (M=7.6) had their epicentres within Bangladesh, they caused considerable damage locally. The 1762 Chittagong earthquake, also a local earthquake with estimated magnitude M=7.5, although not well documented, is reported to have caused major landmass changes in the coastline. In recent years, small to moderate earthquakes are regularly occurring (Al-Hussaini, 2005) with epicenters in neighbouring India and Burma (some within the country) which are being felt in many parts of the country, particularly in the southeast Chittagong region. Some of these earthquakes have caused some damage.

Bangladesh National Building Code (BNBC-1993) was first prepared in 1993, under directives issued by the Ministry of Works. On behalf of the House Building Research Institute (HBRI), the consulting firm Development Design Consultants (DDC) engaged Bangladesh University of Engineering and Technology (BUET) to take the leading role in developing the first building code of the country. BNBC-1993 (DDC, 1993) contains seismic design provisions which were based on the knowledge of the time when it had been developed. Since then, major progress has been made in worldwide research in earthquake engineering and different building codes have been upgraded accordingly. Significant amount of research have also been carried out in Bangladesh. In recent years, HBRI has taken up an initiative to upgrade the existing building code (BNBC-1993) to incorporate the advances in knowledge and experience over almost two decades. A group of Consultants, principally consisting of faculty members from BUET along with some external consultants, have been entrusted by HBRI to prepare an updated building code. Several editorial board members from within and outside BUET, have been engaged as reviewers of the updated code. The first and second authors have been responsible for updating the seismic design provisions of BNBC. Draft seismic design provisions of the building code have been submitted in December 2010.

This paper presents briefly the basic philosophy for estimation of seismic load as per existing seismic design provisions of BNBC-1993. This is followed by some research findings and finally description of proposed changes in seismic design provisions that have been proposed in the updated code particularly in defining the ground motion.

2. BNBC-1993

2.1 Format Seismic Zoning Map

The 1993 Bangladesh national building code has adopted a seismic zoning map (Ali and Choudhury, 1994) consisting of three seismic zones, with zone coefficients of 0.25 (Zone 3 in the north and north-east), 0.15 (Zone 2 in the middle, north-west and south-east) and 0.075 (Zone 1 in the south west), as shown in Fig.1. This zoning map is based on peak ground accelerations estimated by Hattori (1979) for a return period of 200 years.

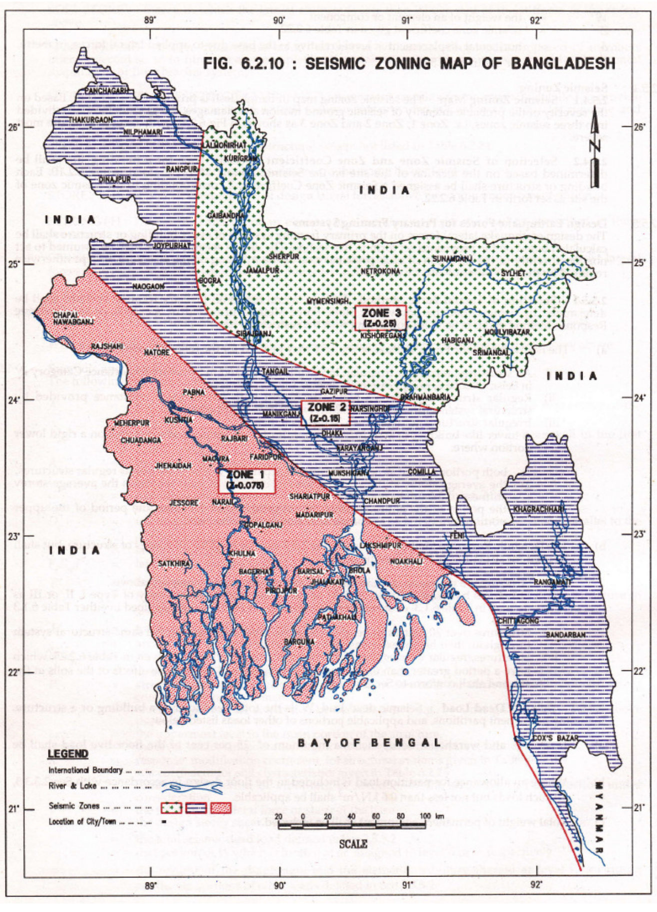

Figure 1 Seismic Zoning Map in BNBC-1993
The zone coefficient (Z) represents the peak ground acceleration (PGA) in units of g (acceleration due to gravity).

2.1 Seismic Base Shear

The seismic base shear may be calculated as:

$$V = \frac{ZICW}{R} \tag{1}$$

where,
Z= zone coefficient, I=importance factor
W= seismic weight of building
R= reduction factor representing energy dissipation in structure,
C= $1.25ST^{1.5}$
S= soil factor (Table 1), T=fundamental period of building (sec)

Once base shear is calculated, seismic shear forces in other stories can be calculated.

Site effect is characterized by soil factor S and response spectrum shape described later. The soil is classified into four classes S1, S2, S3 and S4 as described in Table 1. Soil type S4 produces largest seismic forces.

Table 1 Soil Classification in BNBC-1993

Soil classification	Site soil characteristics	Soil factor
S1	Rock-like material characterized by a shear wave velocity > 762 m/sec, or Stiff or dense soil conditions where soil depth<61 m	1.0
S2	Soil profile with dense or stiff soil conditions, where soil depth > 61 m.	1.2
S3	Soil profile 21 m. or more in depth and containing more than 6 m. of soft to medium stiff clay but not more than 12 m. of soft clay.	1.5
S4	Soil profile containing more than 12 m. of soft clay characterized by shear wave velocity < 152 m/sec	2.0

2.3 Response Spectrum

For buildings requiring dynamic analysis, response spectrum analysis or time history analysis may be necessary. Response spectrum analysis employs characteristic response spectrum depending on soil type. Figure 2 shows normalized response spectrum for soil class S1, S2 and S3. The ordinate represents spectral acceleration (S_a) normalized with respect to gZ. For soil class S4, site specific spectrum need to be determined.

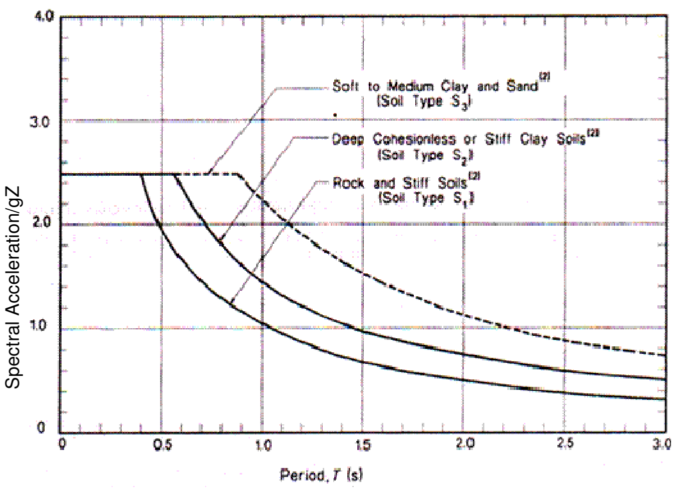

Figure 2 Response Spectrum for Soil Types S1, S2, S3 in BNBC-1993

3. RESEARCH STUDIES

3.1 Seismic Hazard Assessment

Studies based on earthquake catalogues and historical data have revealed the significant seismic risk befalling this country. Hattori's (1979) seismic hazard assessment results for a return period of 200 years have been used in establishing the seismic zoning map of Bangladesh used in BNBC-1993. Ansary and Sharfuddin (2002) formed a homogeneous earthquake catalogue and performed probabilistic seismic hazard assessment using attenuation law by Duggal (1989). Based on results for 200 year return period, they proposed modified seismic zoning map with same zone coefficients but with larger areas for Zone 3 and Zone 2, in other words increased seismic hazard in some areas. Their seismic hazard estimation methodology is based on the assumption that the PGA at a site maintains a recurrence frequency relationship similar to the Gutenberg-Richter magnitude-frequency relationship. The authors are of the opinion that this assumption is not generally justified for two reasons. The PGA at a site depends not only on the earthquake magnitude but also on the epicentral distance from the site, in addition different earthquake sources are most likely to possess different frequency characteristics.

More recently, standard probabilistic seismic hazard assessment method using multiple source zones has been applied for determining the PGA values for various return periods ranging from 475 years to 2475 years. Al-Hussaini and Al-Noman (2010) presented preliminary results from this analysis. The earthquake catalogue has been formed using various sources and including historical earthquakes. Main shock data is extracted from the earthquake catalogue after removing repeated data and by removing aftershocks using magnitude dependent time-window and space-window. Earthquakes are grouped into five magnitude classes (M = 4, 5, 6, 7, 8), each class represents a magnitude range M-0.5 to M+0.4. The period of completeness for different magnitude classes is determined by studying the cumulative earthquake occurrence during the entire period. Seismic source zones have been delineated considering Bolt's (1987) source zones in addition to fault locations and cluster of major (M>5) earthquake epicentres affecting Bangladesh. A total of seven seismic source zones have been designated. Four seismic source zone models with some changes in source boundaries have been tried to take into account uncertainties in source boundaries. For each seismic source zone, the following Gutenberg-Richter relationship (Gutenberg and Richter, 1956) is assumed to be valid:

$$\log \nu = a - bM \tag{2}$$

where ν is the cumulative annual frequency for earthquakes with magnitude M and a, b are regression constants. The period of completeness is used to obtain the cumulative annual earthquake occurrence rate (ν) for each magnitude class for each source zone.

In the probabilistic seismic hazard assessment (PSHA) method, the ground motion at a site is estimated for a specified probability of being exceeded in a given time period. The computational scheme involves: delineation of seismic source zones, characterization of the source zones, selection of appropriate attenuation laws with source-site distance, and a predictive model of seismic hazard. A key element is the variability of ground motion at a given site for a given earthquake scenario. The largest ground motions are controlled by the number of standard deviations above the median ground motion. Given the magnitude, distance and number of standard deviations for the ground motion, the ground motion is computed for each earthquake scenario using an attenuation law which represents the decay of ground motion with distance from source.

The computer program CRISIS (UNAM 1999) is used to perform probabilistic seismic hazard assessment (PSHA) studies for Bangladesh. In the absence of reliable attenuation laws for Bangladesh, recent well-established attenuation relations (one standard deviation above median) developed by various researchers for different regions (Western USA, Eastern USA, Iran, Europe and India) of the world have been used in the study. In addition a new attenuation relationship for Bangladesh originally developed by Islam et al. (2010), and later corrected for site effect, has been used. This local attenuation law is not based on ground motion measurements but is based on intensity based isoseismals of historical and recent earthquakes, and therefore employs intensity-PGA (peak ground acceleration) relationship as well. This law is found to be close to the attenuation law for Western USA developed by Abrahamson and Silva (1997). Also in Bolt's (1987) report, he stated that the attenuation in Bangladesh is expected to be similar to that in the Western USA. Results of this probabilistic hazard analysis for the attenuation law of Abrahamson and Silva (1997) are presented here.

Typically building codes specify the design earthquake to have a 10% probability of exceeding in 50 years (design life of building). This is equivalent to a return period of 475 years for earthquakes which are assumed to follow the Poissonian distribution. However, recently some codes are considering larger return periods to account for large earthquakes with long recurrence periods. The International Building code (ICA, 2006) considers the Maximum Credible Earthquake (MCE) to correspond to a return period of 2475 years which is equivalent to 2% probability of exceedance in 50 years. The Indian Code (BIS, 2005) is also using MCE motion in its seismic zoning map.

Figure 3 shows results of PSHA studies for a return period of 2475 years for seismic source zone model no.2 and using the attenuation law of Abrahamson and Silva (1997). It is observed that the maximum PGA value is in the north-east (Sylhet/Mymensingh) amounting to 0.39g, while the PGA value in the port city of Chittagong in the south-east is 0.29g, the PGA value in the capital city of Dhaka in the centre is around 0.19g. These PGA values are for rock or firm soil and does not include local site effect.

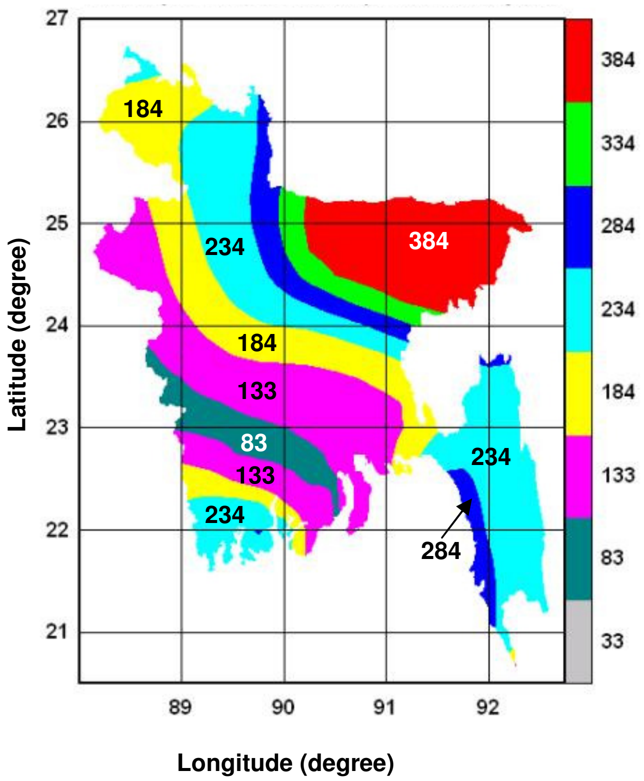

Figure 3 Predicted PGA values (in cm/sec^2) for return period of 2475 years for source zone model-2 and attenuation law of Abrahamson and Silva, 1997.

3.2 Site Effect

A recent study by Al-Hussaini et al. (2007) addresses local site effects in Dhaka city which has a Z value of 0.15. Numerical simulations of ground motion amplification are studied for several sites in Dhaka city for a variety of ground motions using a modified version 'SHAKE91' (Idriss and Sun, 1992) of the original one-dimensional wave propagation program 'SHAKE' (Schnabel et al., 1972). The spectral acceleration (S_a) values obtained for different sites for 5% damping ratio are normalized with respect to the gZ (PGA_{rock}) value and then compared with the design response spectra curves (Figure 2) of existing building code. Figure 4 presents mean normalized spectral acceleration for 10 sites consisting of S3 type soil. Comparing with BNBC 1993 provision for Soil S3, it is observed that the normalized spectral acceleration values of the mean curves, in general, significantly exceed the corresponding values of the BNBC curve in the period range of 0.2 to 0.5 sec. These curves suggest that the peak Sa/gZ value should be increased to around 3.5 instead of existing 2.5 value for the early period range for S3 type soils.

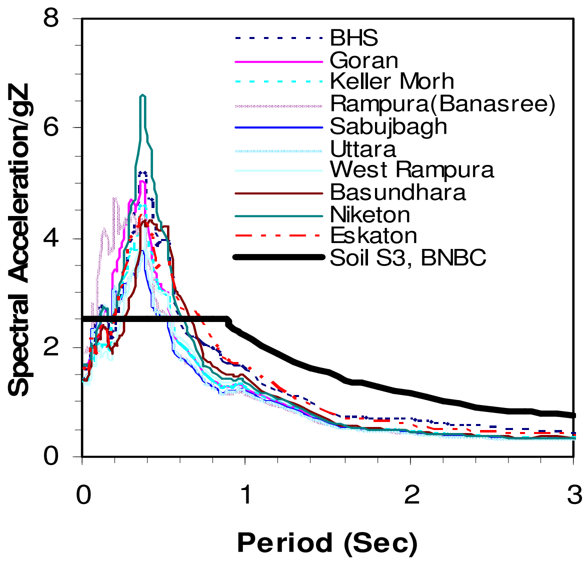

Figure 4 Mean value of normalized spectral acceleration for 10 sites with S3 type soil and comparison with BNBC-1993

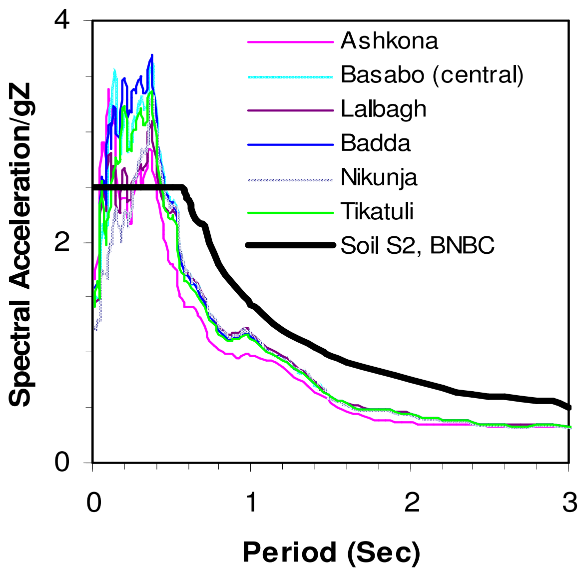

Figure 5 Mean value of normalized spectral acceleration for 6 sites with S2 type soil and comparison with BNBC-1993

Figure 5 presents mean normalized spectral acceleration for 6 sites of Dhaka city consisting of S2 type soils. Comparing with BNBC 1993 provisions for Soil S2, these curves suggest that the maximum Sa/gZ value should be increased to around 2.75 to 3 instead of existing 2.5 value.

4. PROPOSED CHANGES IN UPDATED BNBC

This section deals with the proposed major changes in the seismic design provisions of the updated Bangladesh National Building Code which define the design ground motion and seismic shear forces in the building, as described by Al-Hussaini and Hossain (2010).

4.1 Seismic Zoning Map

The concept of Maximum Credible Earthquake (MCE) with a return period of 2475 years has been introduced in the updated building code. The concept of MCE has been adopted in the latest versions of International Building Code and Indian Building Code. Figure 5 presents the proposed seismic zoning map for Bangladesh based on PGA values for a return period of 2475 years. The country is divided into four seismic zones with zone coefficient Z equal to 0.12 (Zone 1), 0.2 (Zone 2), 0.28 (Zone 3) and 0.36 (Zone 4). The zone coefficient represents the PGA value on rock or very stiff soil site.

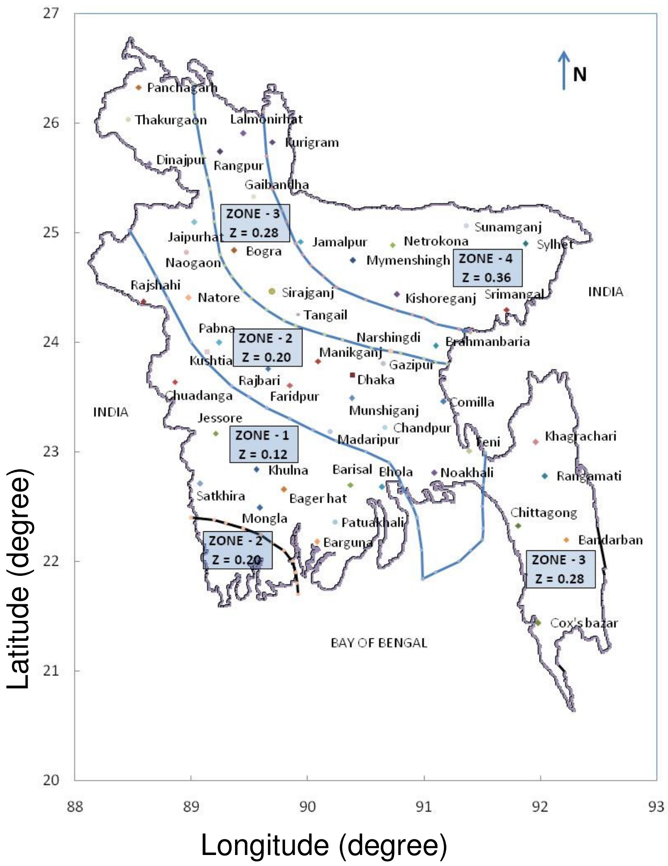

Figure 5 Proposed seismic zoning map for Bangladesh based on a return period of 2475 years

The design basis earthquake (DBE) ground motion is selected at a ground shaking level that is 2/3 of the maximum considered earthquake (MCE) ground motion. Comparison of the PGA values between BNBC-1993 and Proposed BNBC is presented in Table 2 for some important cities and towns of Bangladesh. Due to introduction of four zones, the change of PGA between zones is more gradual than before. It is noted that there is almost no change for Sylhet, Mymensingh, Rajshahi, Khulna. However for Chittagong, Tangail there is significant change, the PGA increases from 0.15 to 0.19. Also for towns such as Pabna and Madaripur, the PGA increases from 0.075 to 0.13. For Dhaka, the PGA value is slightly reduced. For Bogra which is located very close to zone boundary in 1993 zoning map, the PGA is reduced significantly.

Table 2 Comparison of PGA Values in BNBC-1993 and Proposed BNBC for selected towns

City/Town	Proposed BNBC		BNBC 1993
	MCE	DBE	
Dhaka, Dinajpur	0.2	0.13	0.15
Chittagong, Tangail	0.28	0.19	0.15
Bogra	0.28	0.19	0.25
Sylhet, Mymensingh, Kurigram, Kishoreganj	0.36	0.24	0.25
Khulna, Rajshahi	0.12	0.08	0.075
Natore, Pabna, Madaripur	0.2	0.13	0.075

4.2 Soil Classification

Site will be classified as type SA, SB, SC, SD, SE, S_1 and S_2 adopting a similar system as in Euro-Code. Classification will be done in accordance with Table 3 based on the soil properties of upper 30 meters of the site profile.

Table 3 Site Classification based on properties of top soil

Site Class	Description of soil profile up to 30 meters depth	Average Soil Properties in top 30 meters		
		Shear wave velocity $\bar{V}_s$ (m/s)	Standard Penetration Value, $\bar{N}$ (blows/30cm)	Undrained shear strength, $\bar{S}_u$ (kPa)
SA	Rock or other rock-like geological formation, including 5 m of weaker material on top.	> 800	--	--
SB	Very dense sand, gravel, or very stiff clay	360 – 800	> 50	> 250
SC	Dense or medium dense sand, gravel or stiff clay	180 – 360	15 - 50	70 - 250
SD	Loose-to-medium dense cohesionless soil or predominantly soft-to-medium stiff cohesive	< 180	< 15	< 70
SE	Surface alluvium layer with V_s values of type SC or SD with thickness of 5 to 20 m, underlain by stiffer material with	--	--	--
S_1	Deposits containing a layer at least 10 m thick, of soft clays/silts with high plasticity index (> 40) and high water	< 100 (indicative)	--	10 - 20
S_2	Liquefiable soils, or sensitive clays, or any other soil profile not included in SA to SE or	--	--	--

Let n be number of soil layers in upper 30 m; d_i, V_{si}, N_i represent thickness, shear wave velocity and Field (uncorrected) Standard Penetration Test (N) value respectively of layer i. Let also k be number of cohesive soil layers in upper 30 m and d_{ci}, S_{ui} represent thickness and undrained shear strength respectively of cohesive layer i. Then, average soil properties will be determined as given in the following equations:

$$\bar{V}_s = \sum_{i=1}^{n} d_i \bigg/ \sum_{i=1}^{n} \frac{d_i}{V_{si}} \tag{3}$$

$$\bar{N} = \sum_{i=1}^{n} d_i \bigg/ \sum_{i=1}^{n} \frac{d_i}{N_i} \tag{4}$$

$$\bar{S}_u = \sum_{i=1}^{k} d_{ci} \bigg/ \sum_{i=1}^{k} \frac{d_{ci}}{S_{ui}} \tag{5}$$

The site classification will preferably be done using average Vs, otherwise average N may be used.

4.3 Design Response Spectrum

The earthquake ground motion for which the building has to be designed is represented by the design response spectrum. Both static and dynamic analysis methods are based on this response spectrum. This spectrum represents the spectral acceleration for which the building has to be designed as a function of the building period, taking into account the ground motion intensity. The spectrum is based on elastic analysis but in order to account for energy dissipation due to inelastic deformation and benefits of structural redundancy, the spectral accelerations are reduced by the response reduction factor R. For important structures, the spectral accelerations are increased by the importance factor I (Table 4).

Table 4 Structure Importance Factor

Importance Class	**Type of Buildings**	**Importance factor I**
I	Ordinary buildings not belonging to other categories.	1.0
II	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, important government buildings etc.	1.25
III	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, telephone exchange, police stations, designated emergency shelters, etc.	1.5
IV	Monumental structures with cultural heritage.	1.5

NOTES:
1. For buildings housing hazardous materials, higher importance factor may be established considering consequences in the event of serious damage or collapse.
2. The designer may choose values of importance factor greater than those listed in this table.

The spectral acceleration for the design basis earthquake (DBE) is given by the following equation:

$$S_a = \frac{2}{3}\frac{ZI}{R}C_s \tag{6}$$

where,
S_a = Design spectral acceleration (in units of g)

β = Coefficient used to provide lower bound (2/3*ZI*β) for S_a. Eurocode recommended value for β is 0.2
Z = Seismic zone coefficient (Figure 5)
I = Structure importance factor (Table 4)
R= Response reduction factor which depends on the type of structural system. The ratio I/R cannot be greater than one. Values of R for different structural systems have been listed by Al-Hussaini and Hossain (2010)
C_s= Normalized acceleration response spectrum, which is a function of structure (building) period and soil type (site class) as defined by Eqs. 7a-d

$$C_s = S\left(1+\frac{T}{T_B}(2.5\eta-1)\right) \quad for \quad 0 \le T \le T_B \tag{7a}$$

$$C_s = 2.5S\eta \quad for \quad T_B \le T \le T_C \tag{7b}$$

$$C_s = 2.5S\eta\left(\frac{T_C}{T}\right) \quad for \quad T_C \le T \le T_D \tag{7c}$$

$$C_s = 2.5S\eta\left(\frac{T_C T_D}{T^2}\right) \quad for \quad T_D \le T \le 4\sec \tag{7d}$$

where,
S = Soil factor (Table 5)
T = Structure (building) period calculated using structural dynamics procedures or using empirical equation
η = Damping correction factor as a function of damping with a reference value of η=1 for 5% viscous damping.

The normalized acceleration response spectrum C_s depends on S and values of T_B, T_C and T_D, (Figure 6) which are all functions (Table 5) of the site class. The function C_s is defined in accordance with provisions of Eurocode (ECS, 2004). Constant C_s value between periods T_B and T_C represents peak spectral acceleration.

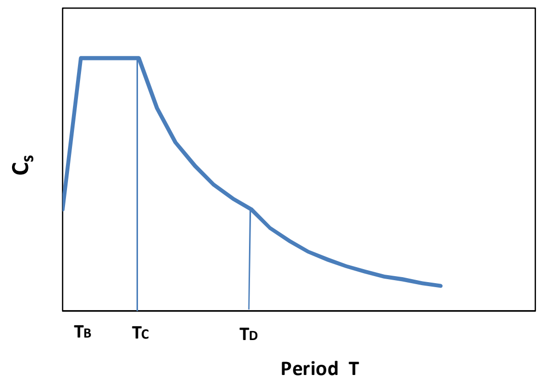

Figure 6 Typical Shape of the Elastic Response Spectrum Coefficient C_s

Table 5 Site dependent soil factor and other parameters defining elastic response spectrum

Soil type	*S*	T_B(s)	T_C (s)	T_D (s)
SA	1.0	0.15	0.40	2.0
SB	1.2	0.15	0.50	2.0
SC	1.15	0.20	0.60	2.0
SD	1.35	0.20	0.80	2.0
SE	1.4	0.15	0.50	2.0

C_s is plotted in Figure 7 as a function of period T and site class. Discussions and implications of the C_s values are described below.

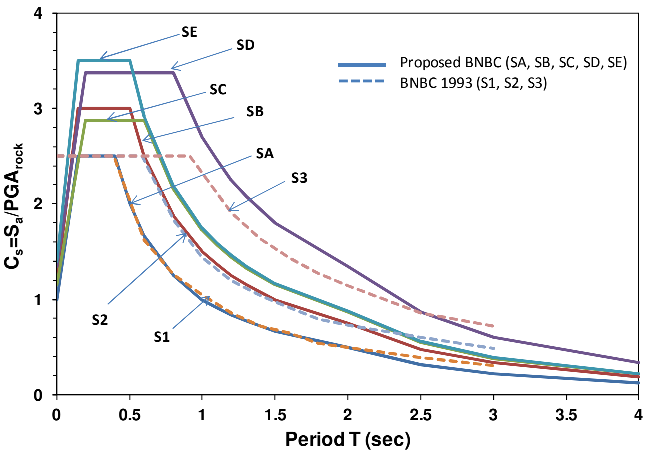

Figure 7 Normalized acceleration response spectrum for different site classes.

The design basis earthquake ground motion is given by 2/3*Z, the corresponding spectral acceleration is 2/3*Z*C_s. This ground motion represents the motion for rock or very stiff soil site (PGA_{rock}=2/3*Z), and hence does not include the local site effect. Hence C_s may be defined as the ratio between the spectral acceleration and PGA_{rock}. The PGA at the given site is given by PGA_{rock}*S. The local site effect is incorporated in C_s which is amply illustrated in Figure 7. The solid lines represent site class SA, SB, SC, SD and SE of proposed BNBC, while dotted lines represent site class S1, S2 and S3 of BNBC-1993. The proposed maximum value of C_s varies from 2.5 to 3.5 depending on site class. Only for rock-like sites (Site SA), maximum C_s is equal to 2.5. For stiff soils (Site SB, SC), maximum C_s is equal to 2.875 to 3, while for softer soils (Site SD, SE), maximum C_s is equal to 3.375 to 3.5. In BNBC-1993, this value is limited to 2.5, which may be unsafe for soft soils, as described earlier in Sec. 3.2.

In order to take advantage of the inherent inelastic energy dissipation in the structure, the building is designed for a reduced spectral acceleration. The reduction is ensured by using the response reduction factor R. For important structures, the spectral acceleration is increased by the importance factor I. Hence, the use of I/R in Eq.(6). Since the response spectrum is by definition linear elastic, C_s may also be visualized as the ratio of the reduced spectral acceleration (S_a in Eq.6) to the reduced ground motion (Reduced PGA_{rock}=2/3*Z*I/R).

For elastic analysis methods, for site classes SA to SE, the design acceleration response spectrum is obtained using Eq.(6) to compute Sa (in units of g) as a function of period T. The design acceleration response spectrum represents the expected ground motion (Design Basis Earthquake) divided by the factor R/I.

For inelastic analysis methods, the anticipated ground motion (Design Basis Earthquake) is directly used. Corresponding real design acceleration response spectrum is used, which is obtained by using R=1 and I=1 in Eq.(6). The 'real design acceleration response spectrum' is equal to 'design acceleration response spectrum' multiplied by R/I.

For site classes S_1 and S_2, site-specific studies are needed to obtain design response spectrum. For important projects, site-specific studies may also be carried out to determine spectrum instead of using Eq.(6). The objective of such site-specific ground-motion analysis is to determine ground motions for local seismic and site conditions with higher confidence than is possible using simplified equations.

4.4 Design Base Shear

In the equivalent static analysis procedure, the seismic design base shear force in a given direction shall be determined from the following relation:

$$V = S_a W \tag{8}$$

where,
S_a = Design spectral acceleration computed using Eq.6
W= Total seismic weight of the building
Once the base shear is calculated, the seismic shear forces induced in other stories can be calculated using an assumed vertical distribution of forces.

4.5 Seismic Design Category

Buildings shall be assigned a seismic design category B, C or D based on seismic zone, local site conditions and importance class of building, as given in Table 6. The concept of seismic deisgn category has been described in ASCE (2006). Seismic design category D has the most stringent seismic design detailing, while seismic design category B has the least seismic design detailing requirements. Certain structural systems are not permitted for seismic design categories C and D.

Table 6 Seismic Design Category of Buildings

	Importance Class I, II				Importance Class III, IV			
Site Class	Zone 1	Zone 2	Zone 3	Zone 4	Zone 1	Zone 2	Zone 3	Zone 4
SA	B	C	C	D	C	D	D	D
SB	B	C	D	D	C	D	D	D
SC	B	C	D	D	C	D	D	D
SD	C	D	D	D	D	D	D	D
SE, S_1, S_2	D	D	D	D	D	D	D	D

Seismic Design Category has strict implications for geotechnical investigations as well. For a structure belonging to Seismic Design Category C or D, site investigation should include determination of soil parameters for the analysis of the following phenomena under conditions of expected earthquake ground motion:

- Slope instability.
- Potential for Liquefaction and loss of soil strength.
- Differential settlement, settlement due to densification of loose granular soils
- Surface displacement due to faulting or lateral spreading.
- Lateral pressures on basement walls and retaining walls due to earthquake ground motion.

4.6 Vertical Ground Motion

The maximum vertical ground acceleration shall be taken as 50% of the expected horizontal peak ground acceleration (PGA). The vertical seismic load effect E_v may be determined as:

$$E_v = 0.5(a_h)D \tag{9}$$

where,
a_h = expected horizontal peak ground acceleration (in g) = 2/3*Z*S
D = effect of dead load

5. CONCLUSIONS

As part of a recent project for updating the Bangladesh National Building Code (BNBC) prepared way back in 1993, new seismic design provisions have been introduced in a draft submission in December 2010. Some of these new provisions, particularly those dealing with defining the ground motion and building base shear forces have been discussed in this paper, along with some research findings. In comparison with BNBC-1993, the following major changes have been proposed that relate to the geotechnical earthquake engineering provisions of the Bangladesh National Building Code:

- The concept of Maximum Considered Earthquake (MCE) motion having a 2% probability of exceedance in 50 years i.e., having a 2475 years return period is introduced. Previous zoning map was based on 200 year return period.
- The country has been divided into four (instead of three) seismic zones with the seismic zone coefficient (Z) value corresponding to probabilistic estimates of peak ground acceleration for 2475 year return period (MCE motion). The Z values for the zones are 0.12, 0.20, 0.28 and 0.36 which do not include local site amplification effects. The design basis earthquake (DBE) motion is taken as 2/3 of MCE motion.
- Some cities/towns such as Chittagong, Pabna, Faridpur have significantly increased ground motion.
- Soil has been classified principally based on shear wave velocity along with Standard Penetration Test (SPT) values.
- More realistic response spectrum curves for different class of soils have been adopted which will be the basis for both static and dynamic analyses. The peak spectral acceleration values have been increased for different soil types. The peak normalized spectral acceleration values are in the range of 2.875 to 3.5, whereas it was 2.5 in the earlier code.
- The equation to calculate total base shear in equivalent static analysis method has changed.
- The importance classification of buildings have been revised.
- A new term Seismic Design Category is introduced which is a function of site class, importance class which is later used important for ensuring appropriate level of ductility.
- Response reduction factors (R) for different structural systems allowed in different seismic category have been updated.
- The definition of seismic weight and method of estimating building fundamental time period has been changed.
- Detail guidelines have been included for specification of ground motion record or response spectrum for dynamic analysis methods i.e., Response Spectrum and Time History Analyses.
- Guidelines for seismic analysis of base isolated structures have been introduced.
- Vertical ground motion effect has been quantified.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Abrahamson, N. A. and Silva, W. J. (1997). "Empirical Response Spectral Attenuation Relations for Shallow Crustal Earthquakes", Seismological Research Letters, 68(1), pp94-127.

Al-Hussaini, T.M. (2005) "Facing the earthquake and tsunami risk in Bangladesh" Proc., Seminar on Tsunami and Seismic Risk – Action for Bangladesh, organized by Military Institute of Science and Technology, Dhaka, pp31-43

Al-Hussaini, T.M. and Al-Noman, M.N. (2010) "Probabilistic Estimates of PGA and Spectral Acceleration in Bangladesh", Proc. 3rd International Earthquake Symposium, Bangladesh, Dhaka, pp473-480.

Al-Hussaini, T.M. and Hossain, T.R. (2010). "Earthquake Loads", Section 2.5 of Chapter 2: Loads on Buildings and Structures, included in Draft Submission for Updated Bangladesh National Building Code.

Al-Hussaini, T.M., Talukder, M.K., Chowdhury, S., Saha, D. and Chowdhury, M.B. (2007). "Site Classification and Seismic Response of Dhaka City Soils", Proc. 4th International Conference on Earthquake Geotechnical Engineering, Thessaloniki, Greece, Paper no. 1457.

Ali, M.H. and Choudhury, J.R. (1994) "Seismic Zoning of Bangladesh" Paper presented at the International Seminar on Recent Developments in Earthquake Disaster Mitigation, Institution of Engineers, Dhaka

Ambraseys, N. and Bilham. R (2003) "Re-evaluated intensities for the great Assam earthquake of 12 June 1897, Shillong, India", Bull. Seismol. Soc. of Amer., 93(2), pp655-673.

Ansary, M.A. and Sharfuddin, M. (2002). "Proposal for a New Seismic Zoning Map for Bangladesh", Journal of Civil Engineering Division, IEB, 30(2), pp77-89.

ASCE (2006) "Minimum Design Loads for Buildings and Other Structures", ASCE/SEI 7-05, American Society for Civil Engineers.

BIS (2005) "National Building Code of India 2005, part 6: Structural Design- Section 1: Load, Forces and Effects", Bureau of Indian Standards, 2nd revision.

Bolt, B.A. (1987) "Site Specific Study of Seismic Intensity and Ground Motion Parameters for Proposed Jamuna River Bridge, Bangladesh", Report prepared for Jamuna Bridge Project, Bangladesh

DDC (1993) "Bangladesh National Building Code 1993", published by Development Design Consultants for Housing and Building Research Instititute, Dhaka.

Duggal, R. (1989) "Estimation of Seismic Risk and Damage and their Utilization as Design Criteria", M. Engineering Thesis, University of Tokyo, Japan.

ECS (2004) "EuroCode 8 2004: Design of structures for earthquake resistance, part 1: General rules, seismic actions and rules for buildings", European Committee For Standardization, EN 1998-1:2004: E.

Gutenberg, B. and Richter, C.F. (1956) "Earthquake Magnitude, Intensity, Energy, and Acceleration", Bulletin Seismological Society of America, 46(2), pp105-146.

Hattori, S. (1979). "Seismic Risk Maps in the World (Maximum Acceleration and Maximum Particle Velocity) (II) – Balkan, Middle East, Southeast Asia, Central America, South America and Others", Bulletin of the International Institute of Seismology and Earthquake Engineering, Building Research Institute, Ministry of Construction, Tokyo, 17, pp33-96.

ICA (2006) "International Building Code", published by International Code Council, USA.

Idriss, I.M. and Sun, J.I. (1992) "Users manual for SHAKE91" Center for Geotechnical Modelling, University of California at Davis.

Islam, M.S., Huda, M.M., Al-Noman, M.N. and Al-Hussaini, T.M. (2010) "Attenuation of Earthquake Intensity in Bangladesh" Proc. 3rd International Earthquake Symposium Bangladesh (IBES-3), Dhaka, pp481-488.

Schnabel, P.B., Lysmer, J. and Seed, H.B. (1972) "SHAKE-A computer program for earthquake response analysis of horizontally layered sites" Report No. UCB/EERC 72-12, Earthquake Engineering Research Center, University of California at Berkeley.

UNAM (1999). CRISIS99 ver.1.017, Program for Computing Seismic Hazard, Revision 17 written by Ordaz, Aguilar & Arboleda, Instituto De Ingeneria, UNAM, Mexico.