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SITE CLASSIFICATION AND SEISMIC RESPONSE OF DHAKA CITY SOILS

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ABSTRACT

Dhaka, one of the fastest growing megacities of the world, is located in a seismic zone with an equivalent peak ground acceleration value of 0.15g. One of the major concerns during an earthquake in Dhaka is the presence of soft soils which may result in amplification of ground motion. Many low lying lands in the city area have been filled up for urban construction to meet the population growth, which have not been properly compacted. Soil boring data including Standard Penetration Test (SPT) values from 34 sites around Dhaka have been collected to estimate equivalent dynamic properties of the top 30 m soil. These sites can be classified into three groups S2, S3 and S4 as per the 1993 Bangladesh national building code. This code, based on UBC 1990, recognizes site amplification effects and specifies design response spectrum with maximum spectral acceleration ratio of 2.5 for soil types S1, S2 and S3. Soil type S4 needs site-specific analysis. Seismic site response of the top 30 m soil at eighteen selected sites of the city belonging to S2, S3 and S4 class is computed using the computer program 'SHAKE'. Seven different earthquake records scaled and suited to soil type S2 have been used. Results obtained suggest that the maximum spectral acceleration ratio of the response spectrum should be around 2.75 for soil type S2 and around 3.75 for soil type S3. The current building code is thus on the unsafe side. The results presented thus indicate the necessity of revising the existing national code.

Keywords: seismic site response, site classification, response spectrum, code provisions, Dhaka city

INTRODUCTION

Bangladesh faces significant earthquake risk due to its close proximity to the plate margins of Indian and Eurasian plates. The collision of the northward moving Indian plate with the Eurasian plate is the cause of frequent earthquakes in the region comprising North-East India, Bangladesh, Nepal and Myanmar. Historically Bangladesh has been affected by five earthquakes of large magnitude greater than 7.0 (Richter scale) during the 61 year period from 1869 to 1930 (Ali and Choudhury, 1994; Sabri, 2001). Two of them had their epicenters within Bangladesh. The 8.7 magnitude Great Indian earthquake in 1897 had an epicentral distance of only 230 km from Dhaka. That earthquake caused extensive damages to masonry buildings in many parts of Bangladesh including Dhaka. According to Bolt (1987), there are four tectonic source zones capable of producing major earthquakes in the future. Assam fault zone (to the north) and Tripura fault zone (to the east) can produce magnitude 8.0 and 7.0 earthquakes respectively, while Sub-Dauki fault zone (in the north-east) and Bogra fault zone (in the west) can produce magnitude 7.3 and 7.0 earthquakes respectively. Dhaka, located in the central region of Bangladesh, could be affected by any of these sources. It should be noted that a large earthquake in the region has not occurred since 1930.The present generation of people in Bangladesh

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hasn't witnessed any major earthquake. As a result the population has been generally complacent about the risk of earthquakes. In recent years, this has changed to some extent by the occurrence and damage caused by earthquakes (Magnitude between 4 and 6) particularly in the south-eastern region of the country (Al-Hussaini, 2005). The damage has been mainly restricted to rural areas or towns near the epicentre, but there has been some instances of damage in urban areas 50 to 100 km away. The people of the capital were shaken and frightened by the Dec.19, 2001 jolt, a minor earthquake (M=4+) with epicentre very close to the city. The location of a probable source so near the Dhaka city is another point of great concern, which needs to be investigated. To accommodate the rapid population growth of Dhaka city, construction of buildings has taken place in an unregulated manner, many of them without earthquake resistant features. The consequences of a major earthquake event can be catastrophic if a densely populated urban area like Dhaka is affected. This would be due to lack of awareness about earthquakes, construction lacking earthquake resistant design, poor quality of construction and absence of post-earthquake preparedness planning. Moreover, exorbitant land prices and lack of available land has led to the filling up of many low lying lands (which used to act as water bodies) in the city area for urban construction. The filled soils in many cases have not been properly compacted or consolidated. Furthermore, the low lying lands may also possess soft soils. These soft soil sites may cause amplification and modification of ground motion, producing larger seismic forces in buildings. Other soft soil effects include settlement of unconsolidated soils and liquefaction of loose sandy deposits. This paper deals with the site amplification effect of various localities within Dhaka city.

CODE PROVISIONS FOR DESIGN RESPONSE SPECTRA IN BANGLADESH

Various seismic hazard assessment studies (Hattori, 1979; Sharfuddin, 2001), based on earthquake catalogues, as well as the local building code have placed Dhaka in a seismic zone with an equivalent peak ground acceleration value of 0.15g, where g is the acceleration due to gravity. The 1993 Bangladesh National Building Code (BNBC) presents earthquake resistant design provisions (DDC, 1993) which is largely based on UBC 1990 seismic design provisions. The code provides a seismic zoning map which divides the country into three seismic zones. Dhaka falls in Zone II with a seismic zone coefficient Z=0.15. This may be considered equivalent to a design earthquake intensity of around VIII (Modified Mercalli Intensity Scale). Site amplification effects can lead to greater damage (i.e., higher intensities) at soft soil sites. The code recognizes site amplification effects and classifies soil into 4 categories S1, S2, S3 and S4, as shown in Table 1. The soil factor used in calculating seismic shear forces on a building by the equivalent static load method is given in Table 1. Design response spectrum for dynamic analysis of buildings is given in the code for three soil types S1, S2 and S3 (Fig.1), the effect of softer soils on longer period buildings is evident. No response spectrum is given for soil type S4, which needs site-specific analysis.

Table 1. Site classification as per BNBC-1993

SITE CLASSIFICATIO	SOIL CHARACTERISTICS	SOIL FACTOR
S1	Rock-like material with shear wave velocity > 762 m/sec, or Stiff or dense soil where soil depth<61 m	1.0
S2	Soil profile with dense or stiff soil 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

Ansary et al (2000) proposed new design response spectra curves (Fig.2) based on simulated earthquakes for soil types I ($T<0.2$ sec), II ($0.2\leq T<0.4$ sec), III ($0.4\leq T<0.6$ sec), IV ($T\geq 0.6$ sec) where T is the predominant period of a site. These curves are based on response spectra of simulated earthquake records calculated using a predominant frequency relevant for different soil types. They used the SHAKE program (Schnabel et al., 1972) to determine predominant frequencies for some Dhaka soil profiles from plots of amplification versus frequency (harmonic wave propagation). They did not consider the effect of random earthquake wave propagation through soil layers. The present study was undertaken to include this aspect, considering wave propagation of random earthquake waves through the soil layers using the program SHAKE.

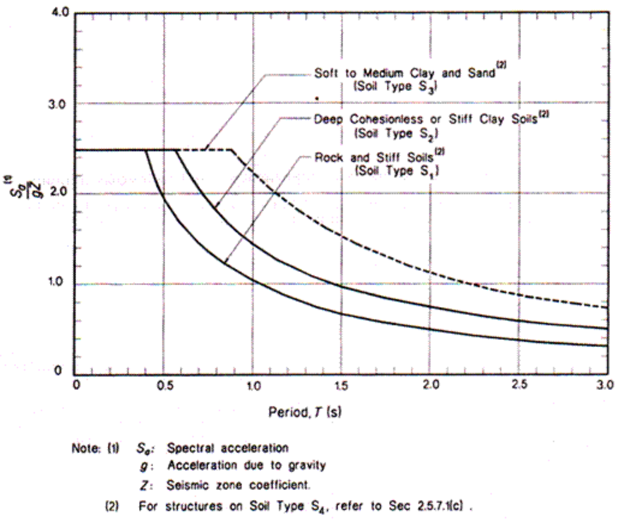

Figure 1. BNBC-1993 specified normalized design response spectra for soil types S1, S2, S3.

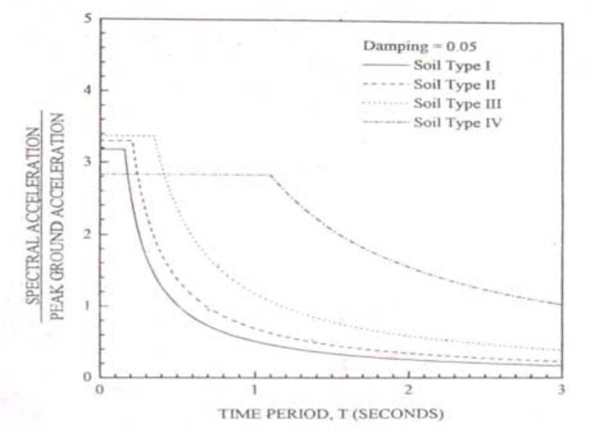

Figure 2: Proposed design response spectra based on simulated earthquakes for different soil types (after Ansary et al., 2000).

SITE CHARACTERIZATION IN DHAKA CITY

Borelog data is collected for 83 boreholes from 34 sites in Dhaka city from two leading geotechnical investigation firms. In the absence of test data on dynamic soil properties and such test facilities, soil boring data with Standard Penetration Test (SPT) values have been used to obtain equivalent dynamic properties of the soil using empirical relationships. Empirical relations have been used to determine the shear wave velocity V_s at different depths of the soil profiles. The dynamic shear modulus G_{max} (in kPa) is obtained from SPT (N) values using Eq.(1) given by Ohsaki and Iwasaki (1973). Eq.(1) is valid for both sand and clay soils. The shear wave velocity is computed using G_{max} and density ρ.

$$G_{\max} = 12000 * N^{0.8} \tag{1}$$

Other empirical equations (2a,b) are also used to estimate V_s.

For sand, $$V_s = 80 * N^{1/3} \tag{2a}$$

For clay, $$V_s = 100 * N^{1/3} \tag{2b}$$

Shear wave velocities obtained by both equations (1) and (2) are considered. The equivalent shear wave velocity $V_{s(eq)}$ for the top 30 m soil is estimated for all boreholes using IBC 2000 code (ICA, 2000) provisions. $V_{s(eq)}$ ranges from 163 m/sec to 408 m/sec for the boreholes studied.

These sites have been classified as soil types S2, S3, S4 based on BNBC code provisions. The sites are mostly S2 and S3 type. Fig 3 shows a map of Dhaka City with approximate location of the sites. It is observed that softer sites S3 are more common in the eastern and south-western portions of the city. Two S4 sites are identified in the eastern part at Goran and Rampura. The existence of long stretch of water bodies in the eastern or south-western parts of the city indicate that these soft sites are likely to be land reclaimed from such water bodies. It is therefore expected that there will be several S4 sites in these areas.

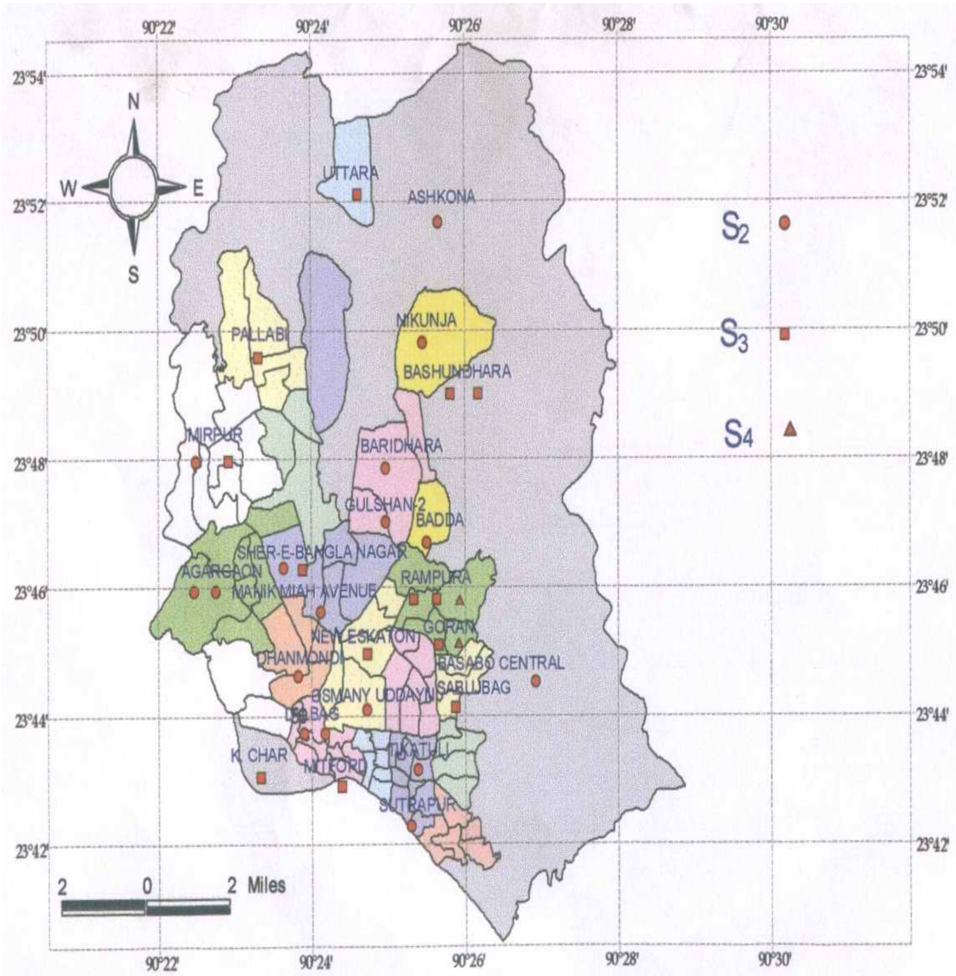

Figure 3. Map of Dhaka city showing approximate location of sites and soil types.

Table 2. Selected locations of Dhaka city for site response analysis

SOIL TYPE	NO. OF SITES	LOCATION
S2	6	Ashkona, Tikatuli, Badda, Nikunja, Lalbagh, Basabo Central.
S3	10	West Rampura, Uttara, Sabujbagh, Goran, BHS, Keller Morh, Rampura(Banosree), Niketon, Basundhara, Eskaton.
S4	2	Rampura, Goran.

A total of 18 sites are selected to perform the wave propagation analysis using SHAKE program. Table 2 lists the sites according to soil type.

SITE RESPONSE ANALYSIS FOR DHAKA CITY SOILS

One dimensional wave propagation analysis is performed using an advanced version ‘SHAKE91’

(Idriss and Sun, 1992) of the original computer program 'SHAKE' (Schnabel et al., 1972) for studying local soil effects on the resulting ground motion. SHAKE91 computes the response in a system of homogeneous, visco-elastic layers of infinite horizontal extent subjected to vertically propagating shear waves. Each layer is completely defined by its value of shear modulus, damping ratio, density and thickness The program is based on the continuous solution to the wave equation adapted for use with transient motions through the Fast Fourier Transform algorithm. The nonlinearity of the shear modulus and damping of soils is accounted for by the use of equivalent linear soil properties (Seed and Idriss, 1970; Sun et al., 1988) using an iterative procedure to obtain values for modulus and damping compatible with the effective shear strains in each layer.

Table 3 Characteristics of Earthquake Records used.

DATE	EARTHQUAKE	EARTHQUAKE RECORD	MAGNITUDE (RICHTER SCALE)	PEAK GROUND ACCELERATIO N
JULY 21, 1952	KERN COUNTY	TAFT EW	7.7	0.18
MAY 18, 1940	IMPERIAL VALLEY	ELCENT NS	6.7	0.35
OCT. 17, 1989	LOMA PRIETA	LOMA PRIETA2	7.1	0.44
MAY 16, 1968	HACHINE	HACHINE	7.9	0.23
	OKAYAMA	OKAYAMA NS	6.8	0.08
APRIL 30, 1962	NORTHERN MIYAGI	SND501	6.5	0.05
JAN.17, 1994	NORTHRIDGE	SYLMARFF	6.7	0.60

Available earthquake records (Table 3) suited to the existing soil conditions are selected for use in the study. As mentioned earlier, the soil types in Dhaka city belongs to soil classification S2, S3 and S4. The soil type S2 is therefore considered as the basis for the input motion. Seven earthquake records are selected that correspond quite well (Fig.4) with the design response spectra for S2 given in BNBC-1993 code.

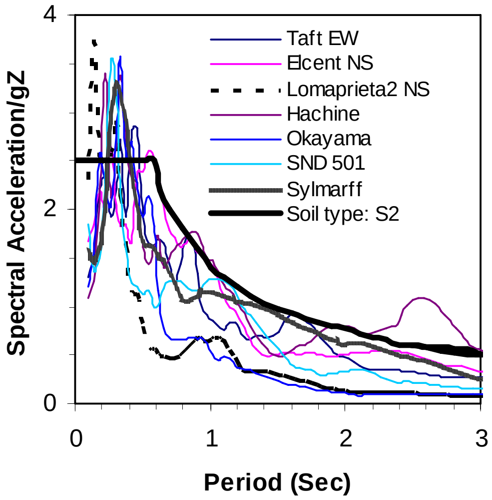

Figure 4. Normalised Response Spectra of Seven Earthquakes

The analysis was performed using these seven earthquake records with their magnitude scaled up or down to a peak acceleration (PGA) value of 0.15g. For each of 18 selected sites, all seven records were used for wave propagation analysis using SHAKE91.

RESULTS OF ANALYSIS

The spectral acceleration (Sa) values obtained for different sites for 5% damping ratio are normalized with respect to the PGA (gZ) value and then compared with the design response spectra curves given in local building code (BNBC).

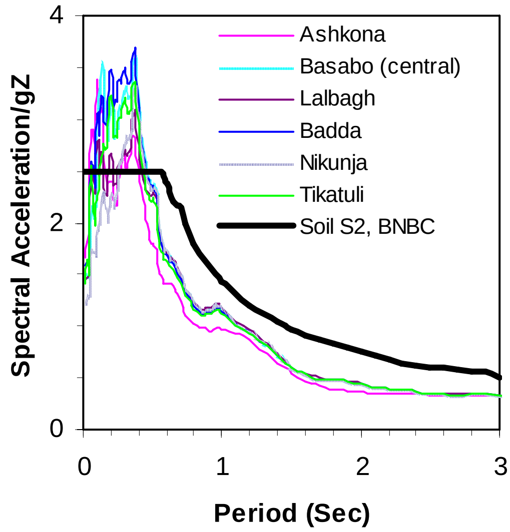

Figure 5. Mean response of six S2 sites for selected earthquakes

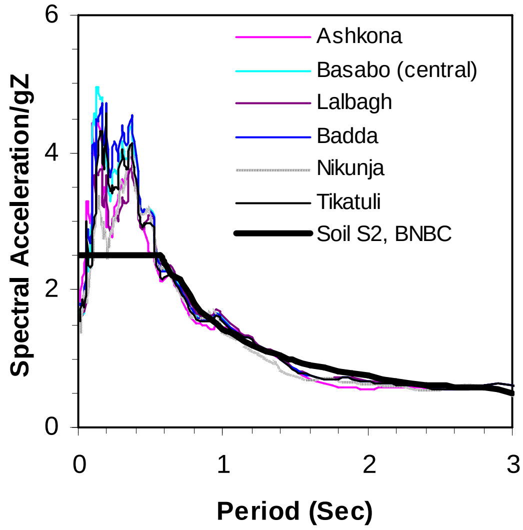

Figure 6. Mean plus standard deviation of response of six S2 sites for selected earthquakes

Figs.5 and 6 present comparison of numerical results for S2 type sites with the BNBC design response spectrum. For each site, seven response curves are obtained for seven earthquake records (Table 3) scaled to a peak value of 0.15g. The mean response spectrum for each site has been computed by taking the mean of such curves for different earthquakes. The mean curves have been presented for all six sites along with the code specified curve in Fig.5. The (normalized) spectral acceleration values of the mean curves, in general, exceed the corresponding values of the BNBC curve in the period range of 0.1 to 0.4 sec. This suggests that it might be better to have Sa/gZ value of around 2.75 instead of 2.5 for the initial flat portion of the early period range up to about 0.4 sec. The long period portion (sloping down portion) of all the curves fall within the code specified curve. The difference between mean curves and the code in the (sloping down) longer period portion is quite significant and could lead to significant under-prediction of seismic forces in buildings with period greater than 0.4 secs. Realizing this significance, the mean plus standard deviation for the six sites has also been considered and compared with code in Fig.6. These curves have been obtained by taking the mean plus standard deviation of the responses obtained for the same earthquakes. Fig.6 shows that the sloping down portion of code agrees very well with the mean plus standard deviation. This suggests that the sloping down portion of the code curve is alright but the peak spectral acceleration value may be increased to 2.75 in the early period range up to about 0.6 secs.

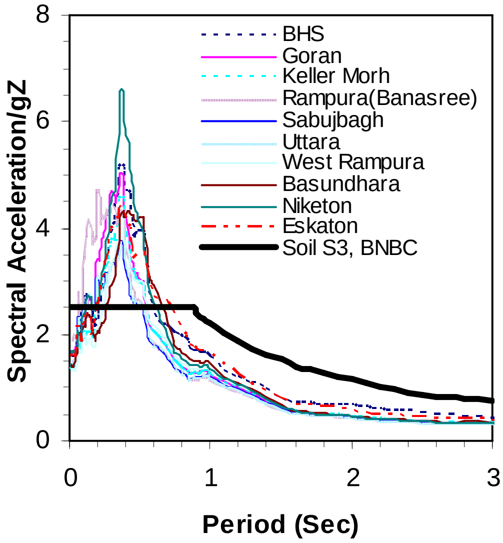

Figure 7. Mean response of ten S3 sites for selected earthquakes

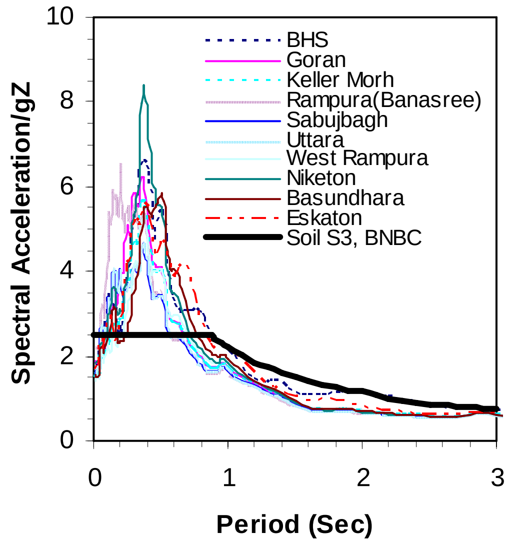

Figure 8. Mean plus standard deviation of response of ten S3 sites for selected earthquakes

Fig.7 presents comparison of numerical results with the BNBC design response spectrum for S3 type soils. The average response spectrum, computed by taking the mean of such curves for different earthquakes, has been presented for each of the 10 sites along with the code specified curve. 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 0.1 to 0.6 sec. These curves suggest a Sa/gZ value of around 3.5 to 4.0 instead of 2.5 for the early period range from 0.2 to about 0.6 sec. The long period portion of all the curves are below the code specified curve. With the same reasoning discussed earlier, the mean plus standard deviation for the ten sites has also been considered and compared with BNBC curve in Fig.8. Fig.8 shows that the sloping down portion of BNBC curve agrees with the mean plus standard deviation. It may, therefore, be concluded that the sloping down portion of the code curve is alright but the peak spectral acceleration value may be increased to a value around 3.5 to 4.0 in the early period range up to 0.6 secs. Increase in peak Sa/gZ values (comparing Figs. 5 and 7) for softer soils for moderate ground shaking (PGA value of 0.15g) appears to be in general agreement with some calculations done using recent IBC 2000 code (ICA, 2000) provisions.

Only two sites at Rampura and Goran were studied which belonged to the S4 type soil based on the criteria of having more than 12 m of soft soils. The mean curves and the mean plus standard deviation curves have been presented for the two S4 sites in Figs.9 and 10 respectively. Comparison is done with the code specified curve for S3 type soil, as there is no curve specified for S4 soil. Comparing these results with Figs. 7 and 8, the numerical results for the two S4 type sites appear to be of the same order as S3 type soils. This is possibly due to the fact that although these two sites belong to S4 class, their property is not very different from S3 soils. Further investigations are needed for study of S4 type soils with deeper soft soil deposits.

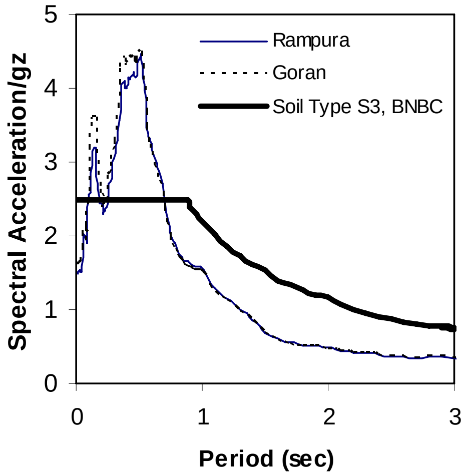

Figure 9. Mean response of two S4 sites for selected earthquakes

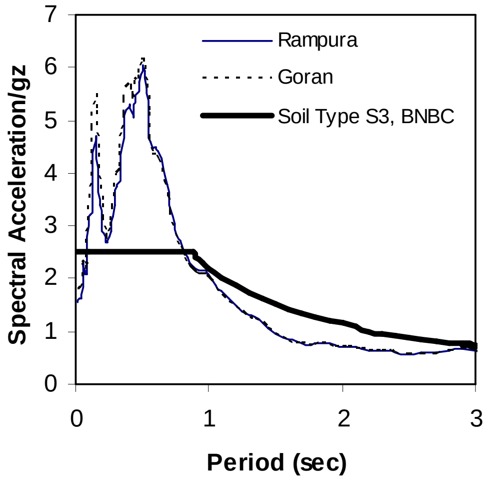

Figure 10. Mean plus standard deviation of response of two S4 sites for selected earthquakes

CONCLUSIONS

A numerical study has been performed to assess the local soil effects on ground motion in Dhaka city which has a design peak ground acceleration of 0.15g. Soil boring data with SPT values have been used to estimate equivalent dynamic properties of different sites using empirical correlations. The estimated equivalent shear wave velocity for top 30 m soil varying from 163 to 408 m/sec gives an impression of the soil types in the city. Soils of the city belong to three classes S2, S3 and S4 specified in the 1993 Bangladesh national building code. Response spectra are developed for different soil profiles at eighteen different locations of Dhaka city using one-dimensional wave propagation analysis for several design basis earthquakes and estimated soil properties. The results, presented in a statistical sense, are compared with the design response spectra for soil types S2 and S3 given in the national building code. It is observed that the peak spectral acceleration values are underestimated by the existing code, the difference is very significant for soil type S3. Sites with S4 type soils showed similar trend as S3 type soils, in fact there is little difference between the two types of soils studied. S4 sites with deeper soft soil deposits are expected to show different response. Results suggest that the peak spectral acceleration of the code specified curves for S2 and S3 type soils need to be increased, particularly for S3 soils, while the longer period portion needs no change. These results need to be validated when direct measurement of dynamic soil properties will be available, nevertheless the results clearly indicate the need for revision of the local building code for application in Dhaka city located in a moderately seismic zone.

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