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# Site amplification characteristics of Dhaka city

M. A. Ansary, M. A. Noor and M. A. Rashid[1]

*Department of Civil Engineering*
*Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh*

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**Abstract**

Microzonation is a systematic way for the management of earthquake vulnerability, integrating the earth and engineering sciences. In the present study local site conditions were used for microzonation of Dhaka City. Dhaka was first divided into small grids. At the grid points shear wave velocities were estimated by using SPT test results. Around two hundred borehole data were collected and converted into shear wave velocities using empirical relations. All these data were used to estimate vibration characteristics at different grid points of the city employing a one-dimensional wave propagation program SHAKE. The computations were made in the frequency range of 0 to 20 Hz, at frequency interval of 0.05 Hz. The loss of energy of seismic waves in the soil layers was also considered. The vibration characteristics of each site such as predominant frequency and amplification amplitudes were found. The results of the amplification analysis were transformed into microzonation maps depicting: (i) zones showing quantitative estimates of site amplification and (ii) zones showing the natural frequency of the soils. These maps could be useful for preliminary selection of a project site, land use planning, zoning ordinances, pre-disaster planning, capital investment planning, etc.



*Keywords*: Earthquake, site amplification, predominant period, shear-wave velocity, borehole data.

## 1. Introduction

Earthquake is a common natural phenomenon occurring since the inception of the world. Several earthquakes of large magnitude (7 or higher on Richter scale) with epicentres within Bangladesh and close to Indo-Bangladesh border, have occurred. The Great Indian earthquake with magnitude of 8.7 on surface-wave magnitude scale, one of the world's strongest, had its epicentre only about 230 km from Dhaka [Ali and Chowdhury, 1992]. Although Bangladesh is located in a region of moderate seismic activity, the low

[1] Former student

incidence of severe earthquake during this century has led to a situation where most of the people and policy makers don’t perceive seismic risk to be important.

There are two aspects for safety against earthquake hazards: firstly, safety against potentially destructive dynamic forces and secondly, the safety of a site itself related with geotechnical phenomena such as amplification, land sliding and liquefaction. In order to mitigate the risk from earthquakes and to ensure the safety of structures under earthquake loading, dynamic effects have been taken into consideration in design codes in many countries around the world, often using zoning maps based on geological assessments of seismic hazards which are embodied in building codes or regulations. However, little attention has been paid to the assessment of safety of individual site in the form of regulations on land use. The site safety during earthquakes is related to geotechnical phenomena such as amplification, land-sliding, mudflow and fault movements.

Assessment of these specific geotechnical phenomena has been made in several countries in a variety of ways but attempts have seldom been made to formalize a standard approach in terms of regulations or code requirements. The importance of site safety from earthquake hazards has received increasing attention in recent years among engineers, scientists and land users in seismically active regions in the world. The importance of this issue has been exemplified in many disastrous large-scale landslides and liquefaction- induced ground failures observed in recent major earthquakes. There is growing awareness among scientists and policy makers that many large cities are exposed to a high level of risk from geotechnical hazards in case of future earthquakes.

In response to these new developments, several attempts have been made to identify and appraise geotechnical hazards and to represent them in the form of maps or inventories. Generally, the outcome of a hazard assessment is presented on a zoning map in which locations or zones with different levels of hazard potential are identified. The zoning map may be used in a variety of ways in aiding mitigation of seismically induced geotechnical hazards.

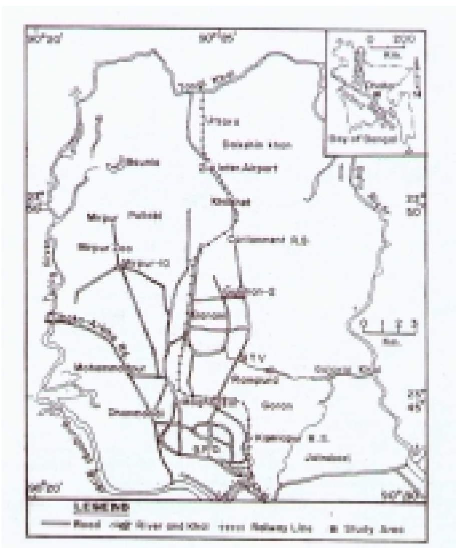


Fig. 1. Location map of the study area

In this study, the microzonation study was done for Dhaka city based on site amplification characteristics of different locations. The soil stratigraphy for the sites was modelled from existing borehole data collected from different sources. The study area is shown in Figure 1. The objectives of the study are: (a) to study soil amplification characteristics, and (b) to develop microzonation maps based on site amplification factors of different locations of Dhaka.

## 2. Characteristics of the study area

### *2.1 Geology of the study area*

Bangladesh is subdivided into several physiographic units of which the following are important: (i) Himalayan Piedmont Plain, (ii) Flood Plains of Teesta, Old Brahmaputra, Jamuna, Ganges and Meghna rivers, (iii) Barind Tract, (iv) Madhupur Tract, (v) Foothills of the Shillong Massif, (vi) Haor Basin, (vii) Tippera Surface, (viii) Delta, (ix) Chittagong Hill Tracts.

The generalized physiographic map of Bangladesh is shown in Figure 2. More than 80% of Bangladesh is underlain by quarternary sediments consisting deltaic and alluvial deposits of the Ganges, Brahmaputra and Meghna rivers and their tributaries. The study area (Dhaka) is located between the Megna and Brahmaputra Flood Plains. The soil deposits mainly consist of the following types of soil.

*Alluvial Silt and Clay*: Medium to dark grey silt to clay; and organic rich clay in sag ponds and large depressions. Some depressions contain peat. Large areas underlain by this unit remain dry only few months of the year; the deeper part of the depressions and bils contain water throughout the year.

*Madhupur Clay Residuum*: Light yellowish grey, orange, light to brick red and greyish-white, micaceoussilty clay to sandy clay; sand fraction dominantly quartz, minor feldspar and mica. Dominant clay minerals are kaolinite and illite.

*Marsh Clay and Peat*: Grey or bluish grey clay, black herbaceous peat, and yellowish grey silt. Alternating beds of peat and peaty clay is common in bils and large structurally controlled depressions; peat is thickest in the deeper parts.

### *2.2 Tectonics and seismicity of the study area*

The metropolis Dhaka is an integral part in the southern tip of Madhupur Tract encircled by some very active tectonic units viz., the Sylhet Trough on the north, the Jamuna Graben on the west, the Dhaka Depression on the south, and NE-SW trending Meghna Fault Zone on the east. “Sylhet Trough” is structurally the most down-warped part of the Bengal Basin and a rapidly sinking fault block (Hoque et al., 1994). The subsidence in the northern part is in the order of 11 m within the last few hundred years. “Jamuna Graben” is a recently reactivated graben and is associated with the Jamuna fault. Its eastern margin coincides with the NNW-SSE trending Madhupur fault. “Dhaka Depression” is traversed by many active cross faults. The NW-SE block, defined by the Dhaleshwari and the Padma faults, is possibly downthrown from the elevated Madhupur Tract. It is a region of recent subsidence at a rate of 1.82 mm/year. “Meghna Fault Zone” is a NE-SW trending basement controlled fault showing step-like faulting and representing a tectonic zone of weakness. Figure 3 shows the tectonic map of Dhaka region.

Bangladesh is one of the most disastrous prone countries in the world. Although Bangladesh is located in a region of significant seismic activity, most of the population and policy makers do not perceive seismic risk to be important. Bangladesh does not even have any earthquake observatory. The tectonic evaluation of Bangladesh can be explained as a result of collision of the north moving Indian Plate with the Eurasian Plate and the south-western arm of the Burma sub Plate. The Dhauki fault and Sylhet fault in Sylhet, in close proximity of the highly disturbed south-eastern Assam with Jaflong thrust, Naga thrust and Disang thrust, is a zone of high seismic risk. Northern Bangladesh comprising greater Rangpur and Dinajpur Districts are also high seismic regions because of Jamuna fault and faults in India. The Chittagong–Tripura folded belt experiences frequent earthquakes due to the proximity to the Burmese Arc. Dhaka is also located in a region not far from the above mentioned earthquake sources and can be subjected to severe damage in the event of a major earthquake.

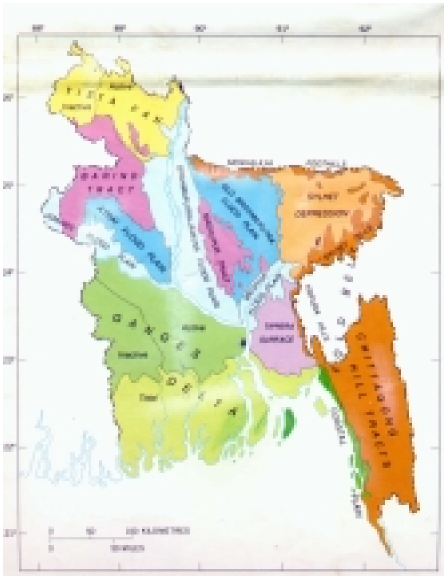

Fig. 2. Generalized physiographic map of Bangladesh (after GSB, *1990)*

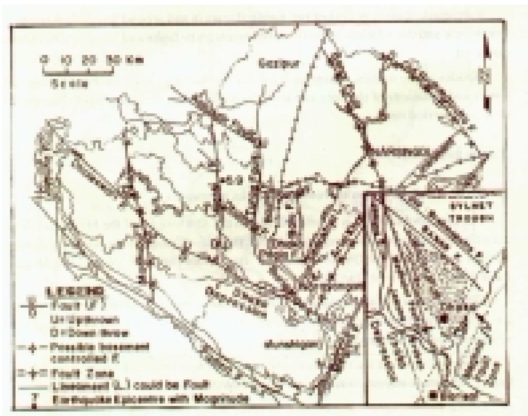

Fig. 3. Tectonic map of Dhaka region (after EPC/MMP, 1991)

Records of the earthquakes show that Bangladesh and its surrounding areas experienced at least 1200 earthquakes having M $\geq$ 4 between 1865 to 1995 (Sharifuddin, 2001). During the last hundred years, it also experienced several historical earthquakes of which two having M > 7, e.g., the Bengal earthquake (M=7) of 1885 and the Srimangal Earthquake (M=7.6) of 1918 had their epicentres located at Sirajgonj and Srimangal, respectively. Table 1 presents a list of historical earthquakes in the neighbourhood of Bangladesh.

Table 1
Earthquake Magnitude and Distance between Epicentre and Dhaka for some Famous Historical Earthquakes (after Ali and Choudhury 1992)

| Name of Earthquake | Magnitude | Distance (km) |
|---|---|---|
| Cachar Earthquake, 1869 | 7.5 | 250 |
| Bengal Earthquake, 1885 | 7.0 | 170 |
| Great Indian Earthquake, 1897 | 8.7 | 230 |
| Srimangal Earthquake, 1918 | 7.6 | 150 |
| Dhubri Earthquake, 1930 | 7.1 | 250 |

Dhaka metropolis together with its surroundings is situated in the seismic zone 2, which has a basic seismic coefficient, Z=0.15 (BNBC, 1993). It has been observed by Hoque et al. (1994) that the NNW-SSE trending Madhupur fault is associated with two earthquake epicentres of magnitude 6 and 7. Also the N-S Bansi fault is associated with another earthquake epicentre of magnitude 5.9. As both the Madhupur and the Bansi faults are very close to the metropolis Dhaka and magnitudes with which they are associated are remarkably high in the context of seismicity, it is evident that the metropolis and its surroundings are very much active seismically as well as tectonically.

### *2.3 Site amplification for Dhaka city*

The effect of local soil conditions on the amplitude and frequency content of earthquake motions has been the subject of considerable interest and research in recent years. Physically the problem is to predict the characteristics of the seismic motions that can be expected at the free surface (or at any depth) of a soil stratum. Mathematically the problem is one of wave propagation in a continuous medium. If the medium is linearly elastic and the geometry is relatively simple, analytical solutions can be obtained for any kind of waves. In practice, since the wave content of a potential earthquake is hard to predict, solutions are often limited to the simple case of shear wave propagating vertically.

Many results for this case have been presented, and a discrete model with lumped masses and springs, based on a finite difference formulation, has enjoyed great popularity among practicing engineers. The continuous and the discrete formulations are equivalent. The next section of the paper describes the use of a one-dimensional wave propagation program to develop a microzonation map of Dhaka City.

## 3. Methodology

Several methods for evaluating the effect of local soil conditions on ground response during earthquakes are presently available. Most of these methods are based on the assumption that the main responses in a soil deposit are caused by the upward propagation of shear waves from the underlying rock formation. Analytical procedures based on this concept incorporating non-linear soil behavior, have been shown to give results in good agreement with field observations in a number of cases. Accordingly they are finding increasing use in earthquake engineering for predicting responses within soil deposits and the characteristics of ground surface motions.

The analytical procedure generally involves the following steps. The first step involves determination of the characteristics of the motions likely to develop in the rock formation underlying the site, and selection of an accelerogram with these characteristics for use in the analysis. The maximum acceleration, predominant period, and effective duration are the most important parameters of an earthquake motion. Empirical relationships between these parameters and the distance from the causative fault to the site have been established for earthquakes of different magnitudes (Gutenberg and Richter, 1956, Seed et al., 1969, Schnable and Seed, 1972). A design motion with the desired characteristics can be selected from the strong motion accelerograms that have been recorded during previous earthquakes (Seed and Idriss, 1969) or from artificially generated accelerograms (Housner and Jennings, 1964).

The next step involves determination of the dynamic properties of the soil deposit. Average relationships between the dynamic shear moduli and damping ratios of soils, as functions of shear strain and static properties, have been established for various soil types (Hardin and Drnevich, 1970, Seed and Idriss, 1970). Thus a relatively simple testing program to obtain the static properties for use in these relationships will often serve to establish the dynamic properties with a sufficient degree of accuracy. However, more elaborate dynamic testing procedures are required for special problems and for cases involving soil types for which empirical relationships with static properties have not been established.

The next step in the computation of the response of the soil deposit to the base rock motions. A one-dimensional method of analysis can be used if the soil structure is essentially horizontal. Programs developed for performing this analysis are in general based on either the solution to the wave equation (Kanai, 1951) or on a lumped mass simulation (Idriss and Seed, 1968). More irregular soil deposits may require a finite element analysis.

### *3.1 Description of the program used*

The program can compute the responses for a design motion given anywhere in the system. Thus accelerograms obtained from instruments on soil deposits can be used to generate new rock motions which, in turn, can be used as design motion for other soil deposits as shown in Figure 4 (after Schnable et al., 1971). The program also incorporates non-linear soil behaviour, the effect of the elasticity of the base rock and systems with variable damping.

### *3.2 Theory behind the program*

The theory considers the responses associated with vertical propagation of shear waves through the linear visco-elastic system shown in Fig. 5. The system consists of N horizontal layers which extend to infinity in the horizontal direction and has a halfspace as the bottom layer. Each layer is homogeneous and isotropic, and is characterized by the thickness, $h$, mass density, $\rho$, shear modulus, $G$, and damping factor, $\beta$.

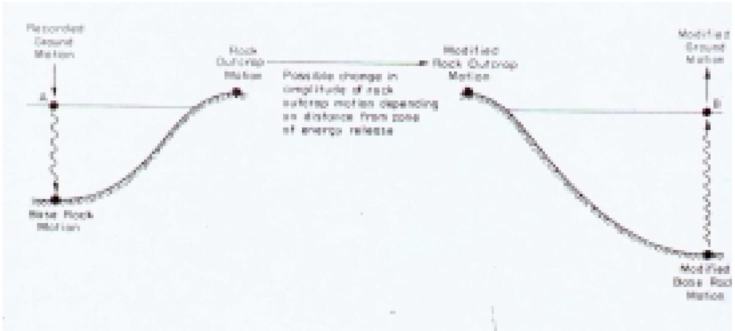


Fig. 4. Schematic representation of procedure for computing effects of local soil conditions on ground motions (after Schnabel et al., 1971)

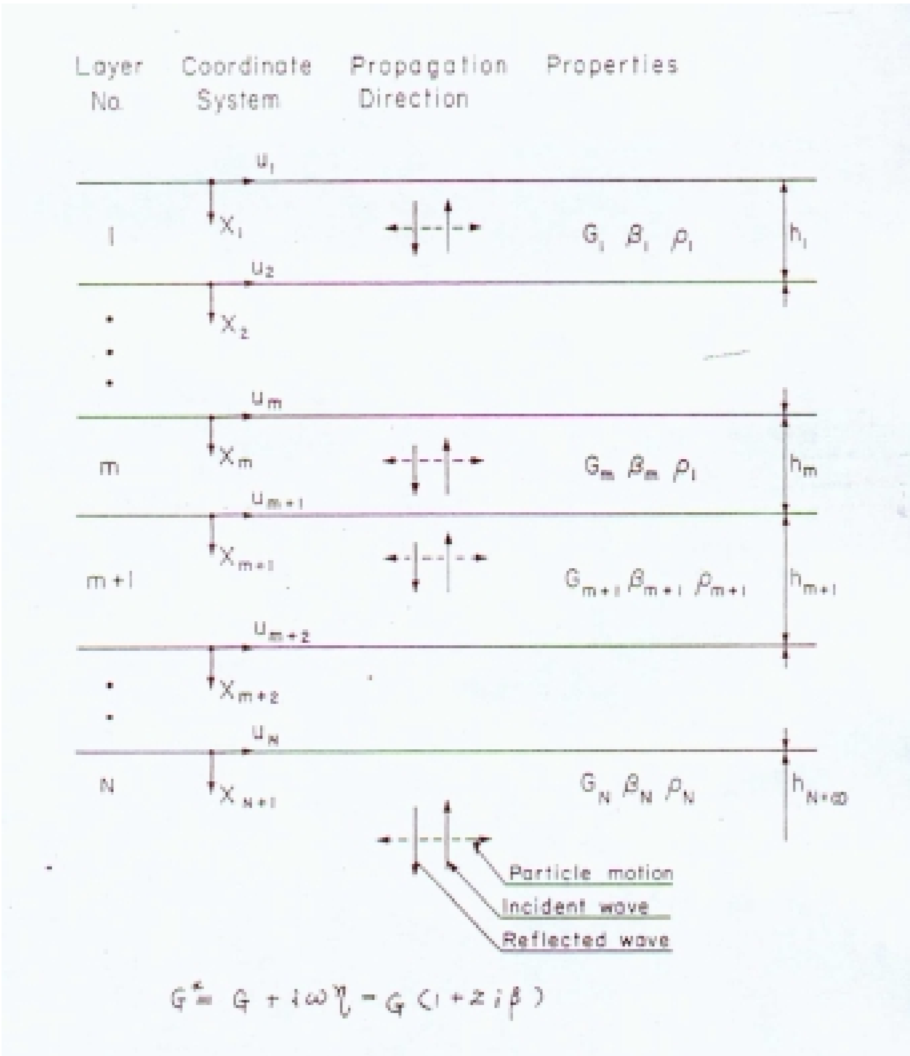


Fig. 5. One-dimensional wave propagation system (after Schnabel et al., 1971)

Program SHAKE computes the responses in a system of homogeneous, visco-elastic layers of infinite horizontal extent subjected to vertically travelling shear waves. The system is shown in Fig. 5. The program is based on the continuous solution to the wave-equation (Kanai, 1951) adapted for use with transient motions through the fast Fourier transform algorithm. The nonlinearity of the shear modulus and damping is accounted for by the use of equivalent linear soil properties (Idriss and Seed, 1968, Seed and Idriss, 1970) using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer.

A number of assumptions are implied in the analysis. For example, the soil system is assumed to extend infinitely in the horizontal direction. Each layer in the system is completely defined by its value of shear modulus, critical damping ratio, density, and thickness. These values are independent of frequency. The responses in the system are caused by the upward propagation of shear waves from the underlying rock formation. The shear waves are given as acceleration values of equally spaced time intervals. Cyclic repetition of the acceleration time history is implied in the solution. The strain dependence of modulus and damping is accounted for by an equivalent linear procedure based on an average effective strain level computed for each layer.

The program is able to handle systems with variation in both moduli and damping, and takes into account the effect of the elastic base. The motion used as a basis for the analysis, the object motion, can be given in any one layer in the system and new motions can be computed in any other layer.

### *3.3 Relationship between shear wave velocity ($V_s$) and SPT (N) value*

There are several empirical relations correlating the SPT N-value and shear-wave velocity ($V_s$) as shown in Table 2. One of the convenient ways to identify subsurface soil profiles is the use of penetration tests. The standard penetration test (SPT) has been widely used to investigate deposits in this regard. The empirical relations presented here will be used to convert SPT value into shear-wave velocity which is needed as one of the input parameters for the program SHAKE. In this study, Ohta and Goto's (1978) empirical relation was used to convert corrected SPT-N value into Shear-wave velocity.

### *3.4 Soil data used*

A total of 190 borehole SPT data were collected and used in this study to assess site amplification characteristics of Dhaka city. Among these data, 16 boreholes with SPT-N data upto a depth of 100 ft were directly collected for this study. The rest of the data were collected from different private and government soil testing agencies. The typical soil data are upto a depth of 50 ft but some of the data collected from WASA database (EPC/MMP, 1991) are up to a depth of 150 ft. Table 3 presents locations and number of borehole data from different areas of Dhaka used for this study. Figure 6 shows borehole locations. Figure 7 shows borehole profile of two sites, which presents SPT values and water table locations.

### *3.5 Site amplification for different locations of Dhaka city*

For site amplification study, the collected borehole data were converted into shear wave velocity using the relationship proposed by Ohta and Goto (1978) as presented in Table 2. Then Dhaka was divided into small grids (1000 m by 1000 m) using the coordinates as shown in Figure 6.

The effects of “Bedrock” and “Outcrop” motion on the various soil layers at the above-mentioned sites due to the multiple reflections of shear waves in the surface layers were then computed using the program SHAKE. The computations were made in the frequency range from 0 to 20 Hz, at frequency interval of 0.05 Hz. The loss of energy of seismic waves in the soil layers was also taken into consideration by taking damping ratio of 2%, because the output of the program SHAKE is not highly sensitive to errors in the damping ratio and values selected between 2% to 10% usually give compatible values. No earthquake motion was used here. Instead a characteristic curve or transfer function of surface layer with respect to the deepest layer obtained from soil profile was used. The peak of the transfer function is the site amplification factor and the corresponding frequency is the predominant frequency for a particular site. A typical transfer function for a site is presented in Figure 8.

Table 2
Empirical Relations Correlating SPT N-value and
Shear-wave Velocity (after TC4, ISSMFE, 1993)

| Researchers | Equation |
|---|---|
| Imai and Yoshimura (1970) | $V_s = 76\ N^{0.33}$ |
| Ohba and Toriumi (1970) | $V_s = 84\ N^{0.31}$ |
| Ohta and Goto (1978) | $V_s = 69\ N^{0.17}\ D^{0.2}\ F_1\ F_2$<br>In which,<br>$F_1 = 1.0$(H); $F_2 = 1.00$ (clay)<br>=1.3(P) = 1.09 (f. sand)<br>= 1.07 (m.sand)<br>= 1.14 (c. sand)<br>= 1.15 (g. sand)<br>= 1.45 (gravel) |
| Imai (1977) | $Vs = a\ N^b$<br>a = 102 b = 0.29 (H.clay)<br>= 81 = 0.33 (H.sand)<br>= 114 = 0.29 (P.clay)<br>= 97 = 0.32 (P.sand) |
| Okamoto et al. (1989) | Vs = 125 N0.3 (P.sand) |

$V_s$: Shear wave velocity (m/s); N: Corrected SPT blow count (N-value); D: Depth (m) ; H: Holocene ; P: Pleistocene; f: Fine ; m: Medium ; c: Coarse ; g: Gravelly

The common base rock under the Dhaka region is situated at a depth of approximately 10-km (Khan, 1990). For the present study, the maximum depth of borehole was assumed to be the bedrock level. Figure 9 shows the effect of depth of assumed bedrock on site amplification and predominant frequency. In Fig. 9, three base rock levels, namely, 40 ft, 80 ft and 120 ft have been considered at a location of Segunbagicha whose location index is S8 as shown in Table 3. In general, it can be said that the higher the depth of base rock level, the larger the value of amplification and lower the value of predominant frequency. Figure 9 shows one of the limitations of the present study due to the unavailability of soil data up to sufficient depth.

Most of the methods for evaluating the effect of local soil conditions on ground response during earthquakes are based on the assumption that the main responses in a soil deposit are caused by the upward propagation of shear waves. Therefore, only shear waves (SH component) are considered in the study as they are expected to have the greatest effect on engineering design.

Table 3
Locations and number of borehole data from different areas of Dhaka

| Area code | Locations Included | LCODE | Number of data |
|---|---|---|---|
| Mirpur | Aminbazar, Gabtoli, Kazipara, Senpara etc. | Mn** | 33 |
| Uttara | Tongi, Ashulia, Dakhin Khan, Khilkhet etc. | Un | 21 |
| Gulshan | Banani, Baridhara, Joarsahara, Kuril, Bosundhara, Mohakhali etc. | Gn | 28 |
| Tejgaon | Nakhalpara, Kawranbazar, Maghbazar, New Eskaton etc.) | Tn | 13 |
| Basabo | Malibag, Shahjahanpur, Khilgaon, Goran, Kamlapur, Mugdapara etc. | Bn | 11 |
| Keranigonj | Kamrangirchar Area | Kn | 4 |
| Dhanmondi | Rayerbazar, Newmarket, Elephant Road, Hazaribagh, Zigatola, Lalmatia | Dn | 22 |
| Kalabagan | Razabazar, Green road, Panthopath, Kathalbagan, Kejurbagan, Central Road, Paribagh, Shahbagh etc. | KAn | 7 |
| Segunbagicha | Ramna, Paltons, Shantinagar, Sidheshwary, Rajarbagh, Motijheel etc.) | Sn | 11 |
| Mohammadpur | Ring road, Sher-e-Banglanagar, Agargaon, Monipuripara etc. | MOn | 8 |
| Old | Old Town -DU, BUET, Azimpur, Nawabgonj, Lalbag, Choukbazar, Narinda, Banglabazar, Sutrapur, Dayagonj etc. | On | 11 |
| Rampura | Baddha (including Madhubag, Hazipara etc.) | Rn | 8 |
| Jatrabari | Saidabad, Jurain, Demra, Postogola, Gandaria etc. | Jn | 8 |
| Narayangonj | Bagabari, Siddirgonj | Nn | 5 |

** n = 1,2,3,4----------- ,i.e., say M1 means one specified point and correspondingly M2 means another point within the place of Mirpur and so on. But the data from WASA database has different codes.

## 4. Results and discussion

Amplification factors for the 190 investigated sites of Dhaka vary between 1.2 to 2.6. In general, low values are encountered for stiff soils and high values for soft soils. Figure 10 presents amplification capability map of Dhaka City.

Figure 11 presents predominant frequency map of Dhaka City. This map is based on frequency as obtained from the transfer function of the program SHAKE (as in Fig. 8). The high frequencies correspond to stiff soil zones, while low frequencies correspond to zones of soft soils.

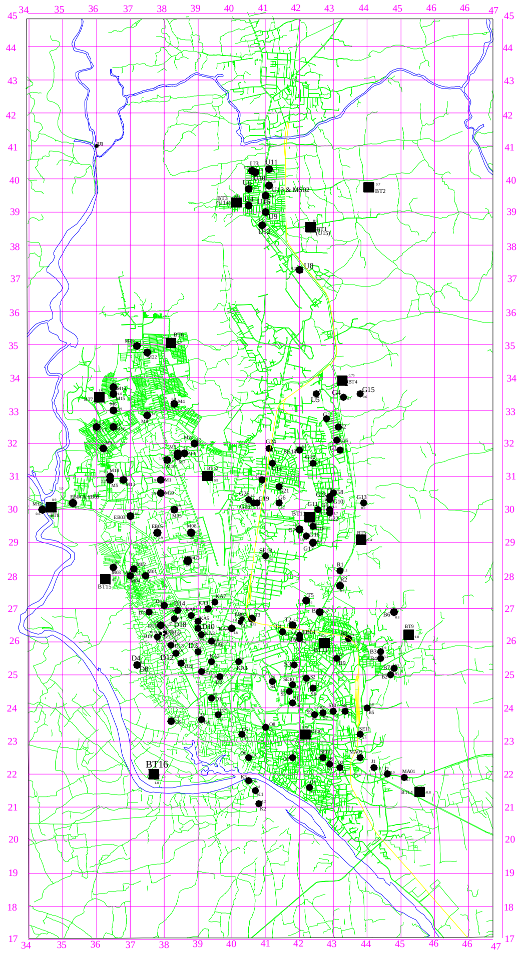

Fig. 6. Borehole location (grids are expressed in thousands of meters)

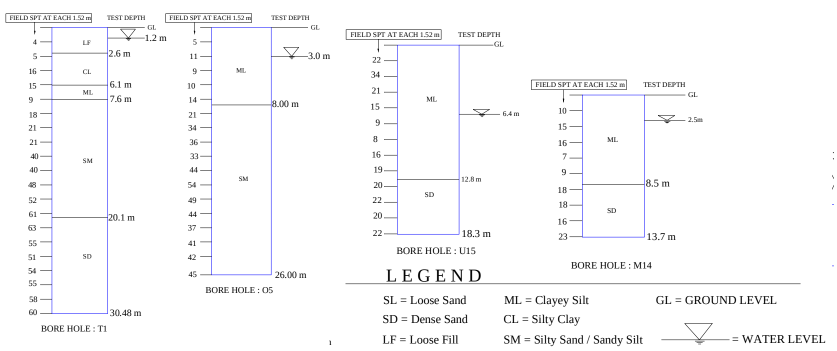


Fig. 7. Typical borehole sites

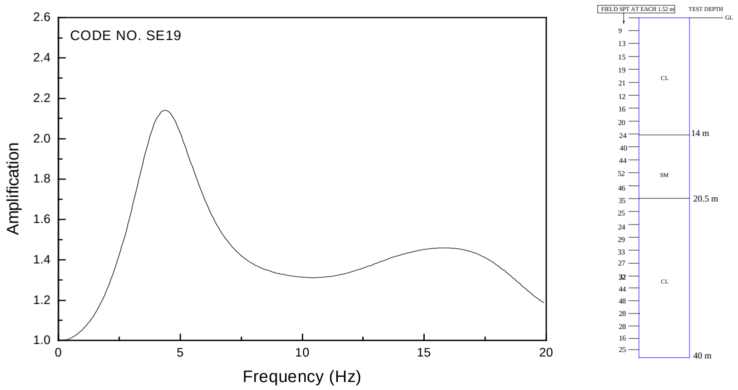


Fig. 8 Typical site amplification versus frequency curves for a site of Dhaka

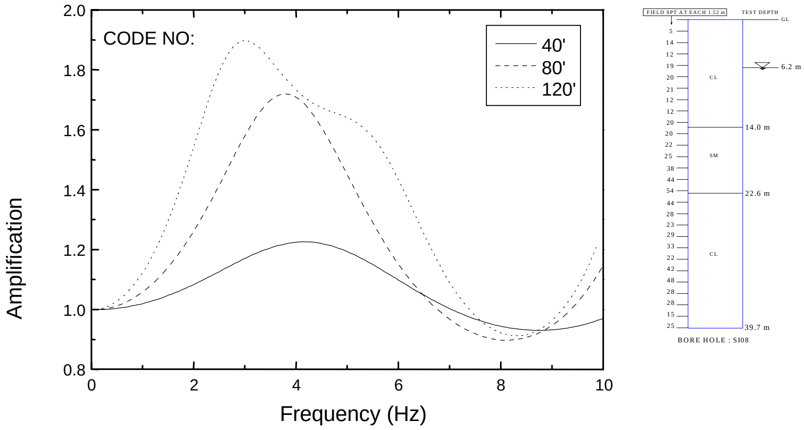


Fig. 9 Effect of depth of assumed base rock on site amplification and

The frequency has been shown instead of predominant period since the range of period is very narrow in comparison to that of frequency. It is well known that period (T) is the inverse of frequency (f). Generally, in Building Codes the relationship $T = 0.1N_s$ is used to estimate natural period of a building; where, $N_s$ is the number of building storey. So, the suitability of building height for a specific site can be estimated by observing the predominant frequency of a site.

From the nature of the amplification versus frequency curve, it is seen that for the peak value of amplification, the higher the depth of base rock level, the shorter the value of predominant frequency and vice versa.

## 5. Conclusions

In order to mitigate the risk from earthquakes and to ensure the safety of structures under earthquake loading, dynamic effects have been taken into consideration in design codes of many countries around the world, often using zoning maps based on geological assessments of seismic hazards which are embodied in building codes or regulations. The system proposed in this paper could be used in support of a variety of areas

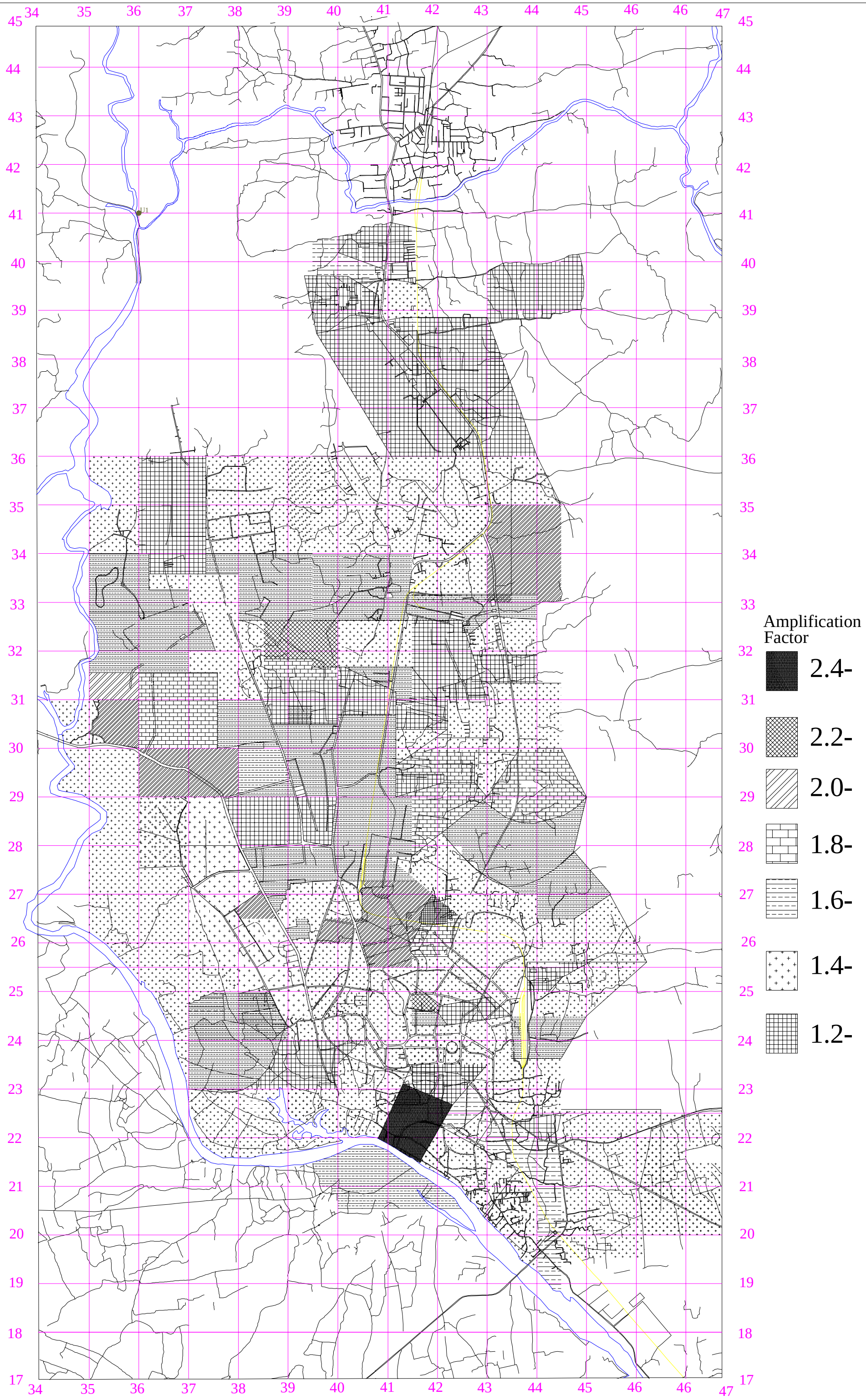


Fig. 2.7 Seismic Amplification Capability Map of Dhaka City ( grids are expressed in thousands of meters)

Fig. 10. Seismic amplification capability map of Dhaka city

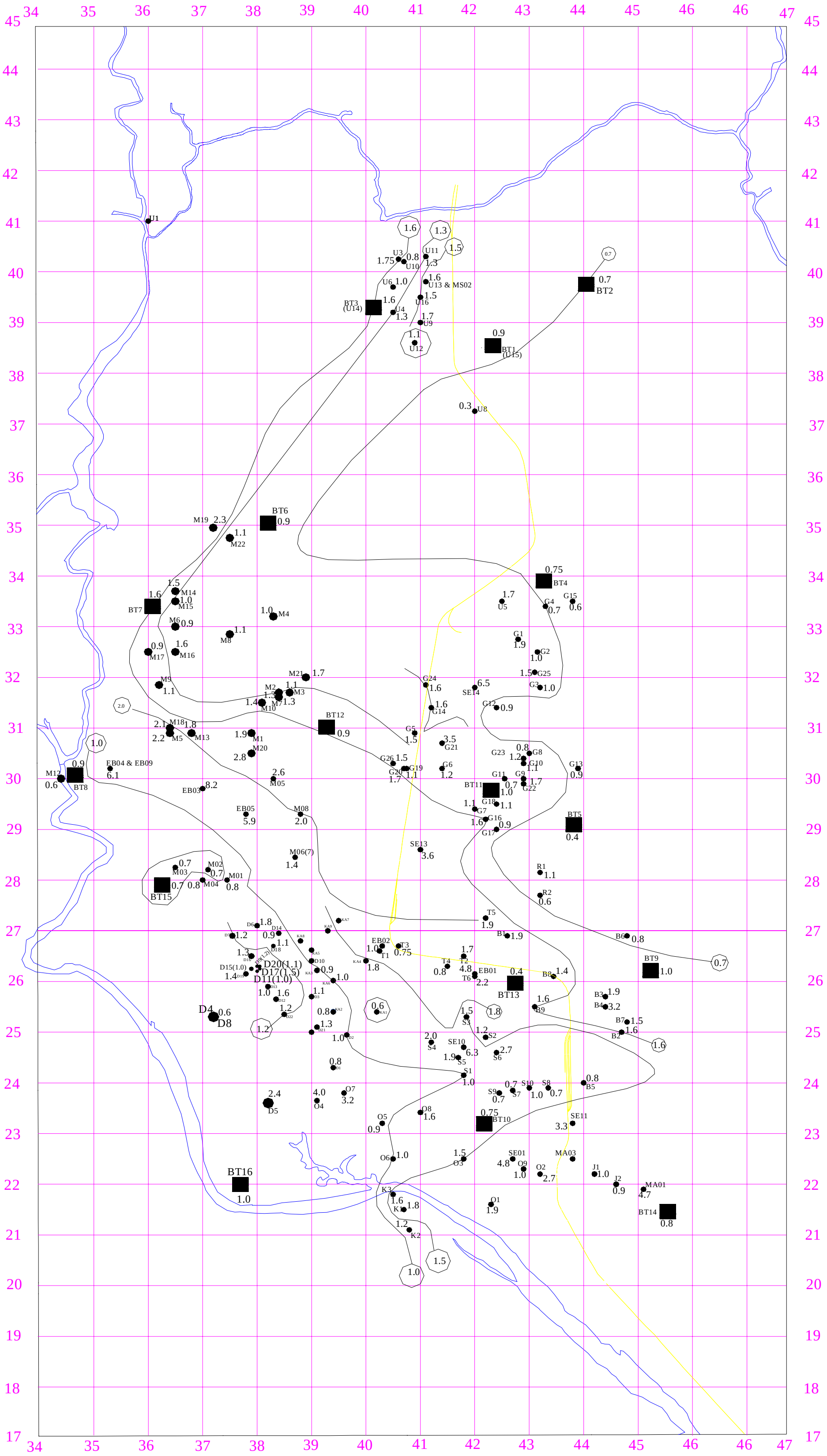

Fig. 11. Predominant frequency map of Dhaka city

including general planning, post disaster planning, zoning ordinances, capital investment planning, hazard mitigation, etc. The final results could be used at several different levels.

In the present study, site amplification characteristics and liquefaction potential of sites were used for microzonation of Dhaka city. Dhaka was first divided into small grids. At and near the grid points shear wave velocities were estimated by using SPT test results. Around two hundred bore hole data were collected and converted into shear wave velocities using empirical relations. All these data were used to estimate vibration characteristics at different grid points of the city employing one dimensional wave propagation program SHAKE. The computations were made in the frequency range of 0 to 20 Hz, at frequency interval of 0.05 Hz. The loss of energy of seismic waves in the soil layers due to damping was also considered. The vibration characteristics of each site such as predominant frequency and amplification amplitudes were calculated. The amplification amplitude in Dhaka was classified into 7 categories and an amplification capability map of Dhaka city has been developed. Similarly a predominant frequency map of Dhaka city has been proposed.

Although time and resource constraints have precluded a few desirable refinements, by introducing the microzonation concept for the first time in the country with specific reference to amplification, this study initiates research work on a very important tool for earthquake hazard mitigation. This investigation would be of practical importance for town planners, professionals, architects and builders. The maps generated indicate the specific zones with various degrees of susceptibility to amplification, which could be used to formulate plans for mitigation of disaster during future earthquakes.

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**Notations**

| | |
|---|---|
| $h$ | layer thickness |
| $\rho$ | density |
| $G$ | shear modulus |
| $\beta$ | damping factor |
| $N$ | Standard Penetration Value |
| $V_s$ | shear-wave velocity |
| $N_s$ | number of building storey |
| U and X | co-ordinate system |