Seismic microzonation of Chittagong city

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ABSTRACT

Bangladesh is an earthquake prone country. Recently, the southeastern part of Bangladesh, especially Chittagong and surrounding areas has experienced earthquakes at regular intervals that are causing significant damage. A strong earthquake affecting a major urban centre like Chittagong may result in damage and destruction of massive proportions and may have very severe long-term consequences for the entire country. Like most major urban centres in our country, Chittagong has grown tremendously in the last few decades due to unabated migration from the smaller towns and rural areas. There is, consequently, a need to be prepared against all possible natural and man-made disasters that are likely to occur here. The main goal of this study is to develop seismic micro-zonation maps for Chittagong City based on secondary site attributes such as soil amplification, liquefaction etc. Sub-soil characteristics of the city were estimated based on data from one hundred and fifteen borehole. Vibration characteristics at different points of the study area were ascertained by employing a one dimensional wave propagation program SHAKE. The liquefaction resistance factor and the resulting liquefaction potential were estimated by a method suggested by Seed et al.

1 INTRODUCTION

The 2001 Gujarat earthquake in India, 2003 Bam earthquake in Iran and 2005 Kashmir earthquake in Pakistan and India revealed the vulnerability of "non-earthquake-proof" cities and villages in Asia. In 1897, an earthquake of magnitude 8.1 caused serious damages to buildings in the northeastern part of India (including Bangladesh) and 1542 people were killed. Recently, Bilham et al. (2001) pointed out that there is a high possibility that a large earthquake will occur around the Himalayan region based on the difference between energy accumulation in this region and historical earthquake occurrence. The current regional population is at least 50 times greater than in 1897 and cities like Chittagong, Dhaka, Kathmandu, Guwahati have population exceeding several million. The next great earthquake may occur in this region at any time.

The first step for earthquake disaster mitigation in Bangladesh is to recognize the existence of earthquake hazard. The next step is to quantify the risk and to minimize its effect. The total elimination of risk may be difficult and impractical. The outcome of a hazard assessment is presented on a map in which locations or zones with different levels of hazard potential were identified. Seismic hazard maps are practical tools in seismic design of structures because they provide important land use guidance. The findings of this study would benefit engineers, city planners, emergency personnel, government officials, and anyone who may be concerned with the potential consequences of seismic activity in Dhaka.

2 GEOLOGY AND REGIONAL TECTONICS OF THE STUDY AREA

Quaternary sediments consisting of deltaic and alluvial deposits of the Ganges, Brahmaputra and Meghna rivers and their numerous tributaries underlie more than 80% of Bangladesh. According to the study of Morgan and McIntire (1959), there are two major areas of Pleistocene sediments, commonly known as Madhupur tract and Barind tract. The study area is situated on the southern tip of Bangladesh. The geological map of Chittagong metropolitan area (after Khan, 2006) is presented in Figure 1.

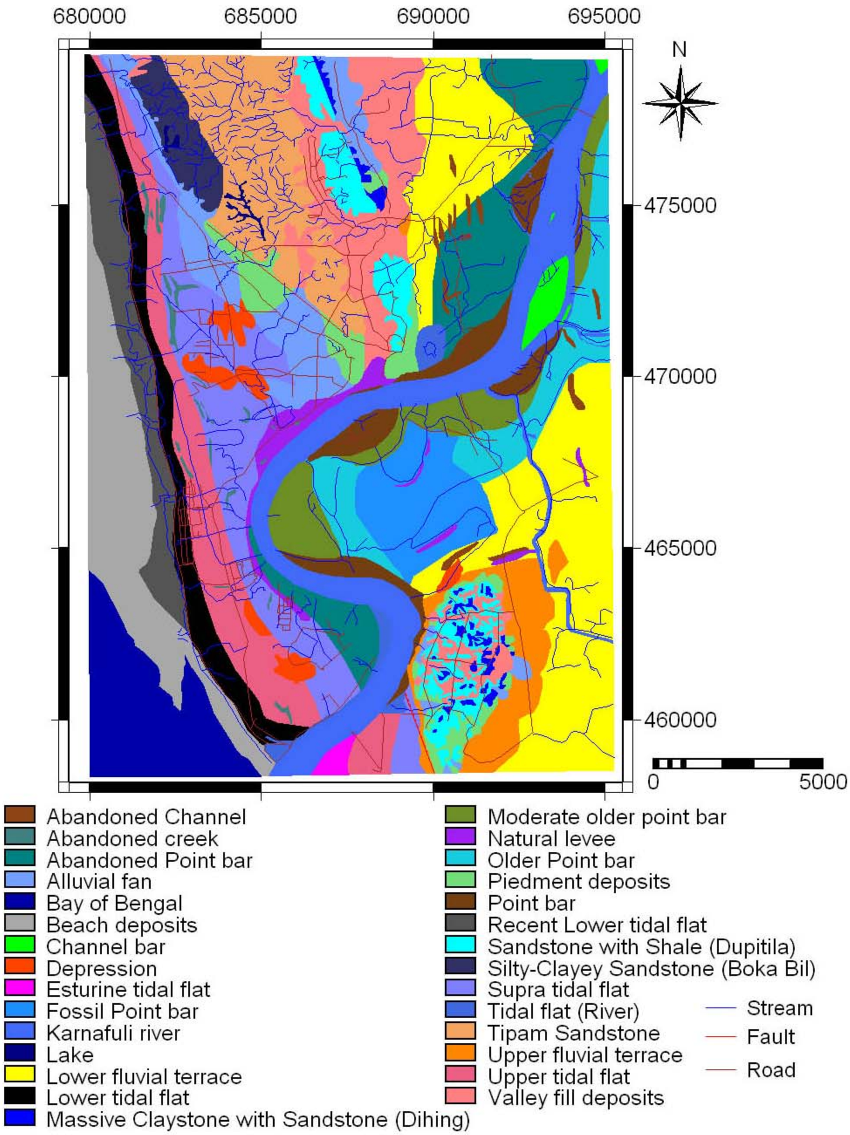


Figure 1: Updated Geological units using High resolution IRS-1D Panchromatic image (after Khan, 2006)

The region of northeastern India, northern Burma and Southwestern China is tectonically and seismically active. The region comprises the Himalayas, the Indo-Burma Ranges, and the Tripura folded belt, the Bengal Basin, the Shillong Plateau and the Assam Valley. Bolt (1987) analyzed different seismic sources in and around Bangladesh and arrived at conclusions related to maximum likely earthquake magnitude. Bolt identified the following four major sources:

(i) Assam fault zone
(ii) Tripura fault zone
(iii) Sub-Dauki fault zone
(iv) Bogra fault zone

3 SEISMICITY OF CHITTAGONG

Chittagong has a long history of earthquakes. According to the Bangladesh national Building Code (1993), Chittagong City is located in Zone-2 with peak ground acceleration (PGA) value of 0.15g. Hundreds of earthquakes have jolted Chittagong and its surrounding areas. One of the largest historical earthquakes occurred in 1762 at Arakan (in the southern part of Chittagong) and caused heavy damage. It also triggered the earliest documented tsunami in the Bay of Bengal. Another big earthquake occurred in 1869 with a surface-wave magnitude of 7.5 at Cachar, Assam. This was also strongly felt in the whole Chittagong division. The 1912 Mandalay earthquake with a surface-wave magnitude of 7.9 was strongly felt in Chittagong. The 1950 Assam earthquake with a magnitude of 8.6 was also strongly felt in the city and its surrounding areas. The most prominent historical earthquakes affecting Chittagong was listed in Table 1.

The recent earthquake that jolted Chittagong city and the adjoining hill districts occurred on 27th July, 2003. The magnitude of this earthquake was 5.6 (surface-wave magnitude). It's epicenter was at Kalabunia village of Barkal upazila of Rangamati district (Ansary and Sadek, 2006; Karim, 2003; Khan, 2003). Two people died and around three hundred people were injured. About 150 buildings including a school were damaged throughout the region, among them the Union Parishad building and the roof of a health complex collapsed. Five acres of land near Kalabunia village reportedly caved in. The shock was also strongly felt in the port city. During the earthquake power supply of some parts went out as a transformer exploded in a sub-station at Madhunaghat, Chittagong. Cracks developed in several buildings, including Public Library, Chittagong Jail and Polytechnic Institute buildings at Chittagong. Cracks also developed in buildings of Cox's Bazar, Moheshkhali, Kutubdia and Sonadia. Many mild aftershocks of different magnitude were felt in Barkal and Rangamati.

Table 1: Magnitude, EMS Intensities and distances of some major historical earthquakes around Chittagong (after Masud, 2007)

Name of Earthquake	Magnitude	Intensity at Chittagong	Distance to epicenter (km)
1762 Arakan Earthquake and Tsunami	-	-	-
1858 Sandoway Earthquake	6.5	VII	192
1869 Cachar Earthquake	7.5	V	234
1897 Great Indian Earthquake	8.7	VI+	350
1912 Mandalay Earthquake	7.9	VII	151
1918 Srimangal Earthquake	7.6	V	271
1936 Mawlaik Earthquake	7.2	VI	195
1954 Manipur Earthquake	7.4	-	310
1984 Cachar Earthquake	5.7	-	240
1997 Bangladesh-Myanmar Earthquake	5.3	VI	70
2003 Barkal Earthquake	5.6	V	80

4 SOIL DATA

Soil data was collected from different relevant sources of the City and accumulated in Microsoft Excel. A total of 115 boreholes with SPT data were collected from different organizations and used to study site amplification and soil liquefaction potential characteristics of the city corporation area. Among these data, 28 boreholes with SPT-N data up to a depth of 30 m were directly collected by BUET for checking the authenticity of other collected data. The representative available boring is up to a depth of 15 m. Figure 2 shows borehole locations.

5 ASSESSMENT OF SEISMIC HAZARD

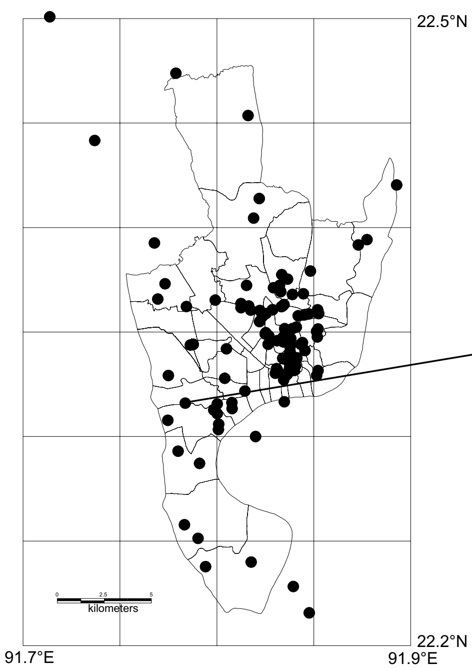
In the regional seismic loss estimation analysis it is considered necessary to determine the bedrock motion in the region. The most common method involves the use of an empirical attenuation relationship. These relationships communicate a given ground motion parameter in a region as function of the size and location of an earthquake event. Applying statistical regression analyses to recorded data, numerous relationships had been developed in the past. Often these relationships are developed with different functional forms and with different definitions of ground motion, magnitude, distance, and site conditions. To pick the most apposite attenuation law for predicting rock motions, 1858 Sandoway earthquake, 1897 Great Indian earthquake and 1912 Mandalay earthquake are considered.

In this study, the engineering bedrock is assumed to be the layer at which the shear wave velocity (V_s) exceeds 400 m/s, which exist almost 30 m deep from the surface of the study area. In this study, shear wave velocity is expected by using equation of Tamura and Yamazaki (2002) as follows:

$$V_s=105.8\ N^{0.187}D^{0.179} \qquad (1)$$

Where, V_s is shear wave velocity (m/s); N is Corrected SPT blow count (N-value) and D is Depth (m).

Distance versus PGA values for earthquakes is plotted on log-log paper. From isoseismal maps, the epicentral distances of different locations and their intensities are found. Finally, 1912 Mandalay earthquake as the scenario event with PGA value of approximately 0.10g at bedrock level for the study area was selected. Table 2 presents the PGA values at bedrock level from different attenuation laws for different events.



Location	Borehole	Soil Layer	Depth (m)	SPT-N
Munshipara High School Campus, Madha Halishpara, Bandar, Chittagong	CT18	Clayey Silt	1.52	6
		Silty Sand	3.05	9
		Clayey Silt	4.57	2
			6.10	1
			7.62	1
		Silty Sand	9.15	1
			10.67	14
			12.20	17
			13.72	35
		Clayey Silt	15.24	34
			16.77	36
			18.29	38
		Silty Sand	19.82	51
			21.34	55
			22.87	61
			24.39	55
			25.91	52
			27.44	53
			28.96	52
			30.49	57

Figure 2: Borehole locations

Table 2: PGA values (% of g) at bedrock level from different attenuation laws for different for events (after Masud, 2007)

Attenuation Law	1858 Sandoway Earthquake	Great Indian Earthquake (1897)	1912 Mandalay Earthquake	1997 Bangladesh-Myanmar Earthquake
McGuire (1978)	0.0212	0.0437	0.0977	0.0265
Sadigh et al. (1986)	0.0052	0.0087	0.0318	0.0086
Joyner and Boore (1988)	0.0054	0.0025	0.0184	0.0152
Boore et al. (1997)	0.0025	0.0036	0.0063	0.0029

6 SITE AMPLIFICATION STUDY

For the area under study, no shear-wave velocity profile exists. Shear-wave velocities were estimated from available geotechnical tests by using existing correlations (Jafari et al., 2002; Panah et al., 2002; Tamura and Yamazaki, 2002). After careful investigation of the different correlations, the correlation proposed by Tamura and Yamazaki (2002) based on 7677 soil data collected from 1000 Japanese strong motion accelerometer locations were selected for use in this study.

Using the soil configurations, transfer function for each site was calculated using the SHAKE numerical code. Figure 3 presents transfer functions for two sites. Figure 4 shows map of amplification of Chittagong city.

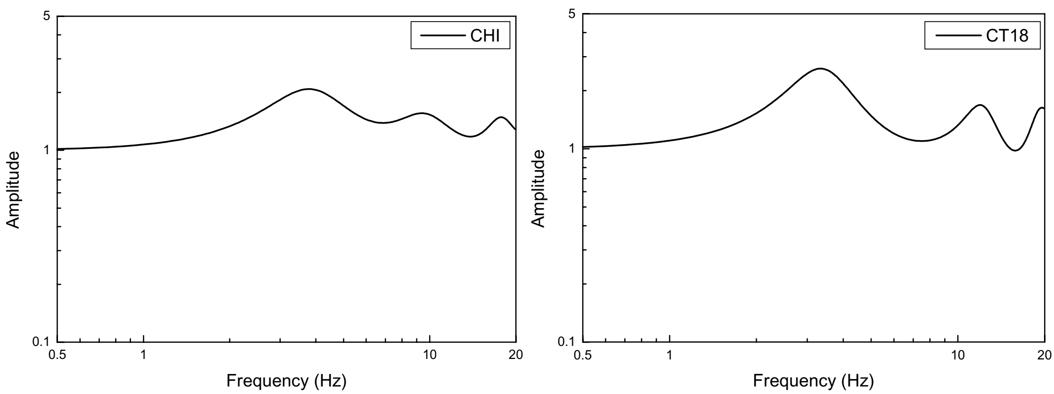


Figure 3: SHAKE transfer functions at two sites of Chittagong city

7 LIQUEFACTION STUDY

Liquefaction phenomena have been recorded and developed in many parts of the world where ground shaking is frequent and soils consist of loose fine sand under water table. Bangladesh including Chittagong is largely an alluvial plain consisting of loose fine sand and silt deposits. Although the older alluvium consisting of mainly silty clay with deeper ground water table is less susceptible to liquefaction, the recent deposits consisting of loose fine sand with shallower water table along the river flood plains may liquefy during a severe earthquake.

A simple method suggested by Seed et al. (1983) was used here to evaluate a liquefaction resistance factor, $F_{L.}$ In this method required parameters are SPT N-values, grain-size distribution curves of soils, overburden pressure, and estimated peak surface acceleration. The liquefaction resistance factor, F_L (defined by equation 2), for the top 20 m of soil, and the resulting liquefaction potential, P_L (defined by equation 3) for the 115 sites were estimated.

$$F_L = R / L \qquad (2)$$

Where L is the earthquake load and R is the soil resistance.

$$P_L = \int_0^{20} F(z)\, w(z)\, dz \qquad (3)$$

Where $F(z) = (1-F_L)$ for $F_L \leq 1.0$ and $F(z) = 0$ for $F_L > 1.0$; $w(z) = (10–0.5z)$ for $z \leq 20$ m and $w(z) = 0$ for $z > 20$ m.

The total area of Chittagong city are classed into three categories, two are liquefiable areas with liquefaction potential index (P_L) of 5 (medium risk) and 10 (high risk) and another is non-liquefiable area with P_L=0. Figure 5 shows the liquefaction map of Chittagong city.

8 CONCLUSIONS

A soil database of 115 boreholes was developed in MS EXCELL. The soil data were used to develop site amplification and soil liquefaction potential maps of the city. Both of these site effects are integrated in Geographical Information System (GIS) platform for combined hazard assessment. The GIS-based analysis is useful to engineers, planners, emergency personnel, government officials, and anyone else who may be concerned with the potential consequences of seismic activity in a given region. The results of a regional seismic hazard and risk analysis are presented in the form of microzone maps that serve as an effective means of transferring information from the scientific community to decision makers involved in hazard and risk mitigation

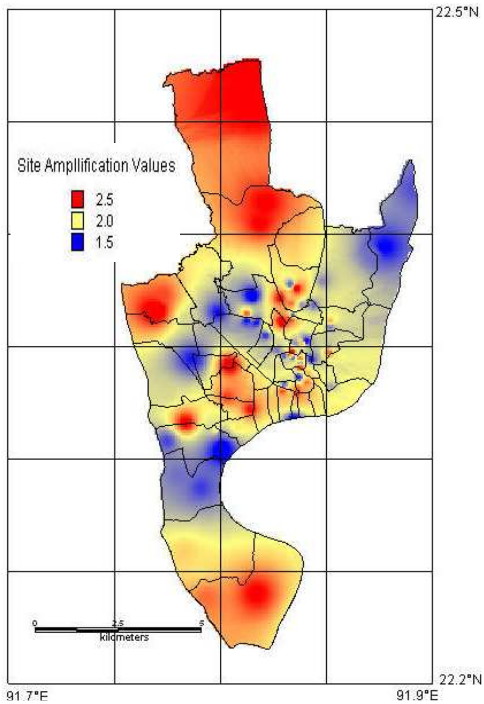


Figure 4: Site amplification values for different locations

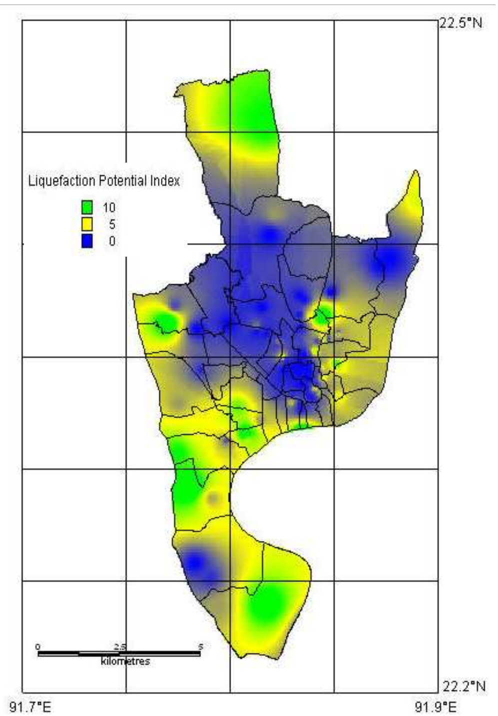


Figure 5: Liquefaction potential index for different locations

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