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Development of liquefaction potential map of Dhaka city using SPT test

M. A. Ansary[1], M. R. Arefin[2] and Ripon Hore[1]

[1]Department of Civil Engineering
Bangladesh University of Engineering and Technology, Dhaka 1000, Bangladesh
[2]Department of Geology and Mining
Rajshahi University, Rajshahi 6205, Bangladesh

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Abstract

The evaluation of liquefaction-resistance for saturated loose sandy and silty soils is an important component of geotechnical site characterization. The purpose of this research is to estimate the earthquake induced liquefaction potential of selected areas of Dhaka city based on Standard Penetration Test blow count (SPT-N) using a simplified procedure. SPT data have been gathered from 114 selected locations of greater Dhaka city. At each location, the liquefaction-resistance is evaluated using peak horizontal ground acceleration (PHGA) of 0.15g for a scenario earthquake of magnitude 7.0 (M_w). The liquefaction potential index (LPI) is estimated for each location to predict the severity of liquefaction. The LPI values of the city varied from 0 to 28 having very low to very high liquefaction hazard. The central and north-south areas of the city are found to have low liquefaction potential. The outer periphery of the study areas is found to have high liquefaction potential. The cumulative frequency at LPI = 5 has been used as a threshold value for observation effects of liquefaction on surface. Based on the geological units and cumulative frequency, the city has been grouped into three liquefaction hazard zones, i.e., Zone 1, Zone 2 and Zone 3. The hazard map of the city indicates that 11%, 41% and 74% of Zone 1, Zone 2 and Zone 3, respectively, will show surface manifestation of liquefaction. These results can be used to improve the ground condition for the construction of earthquake-resilient structures in Dhaka city.

Keywords: Dhaka city, liquefaction-resistance, SPT, LPI, cumulative frequency distribution, liquefaction potential map

1. Introduction

Liquefaction is the transformation of granular soils from a solid state to a liquefied state due to excess pore water pressure and reduced effective stress during an earthquake. Liquefaction problem has become important when it started to affect human and social activities by disturbing the function of facilities and also after rapid urbanization by expanding the cities in reclaimed areas. Ground failures generated by liquefaction has been a major cause of damage during past earthquakes e.g., 1964 Niigata, Japan (Yoshida et al., 2007) and 1964 Alaska, USA (Youd, 2014), 1971 San Fernando, USA (Youd and Olsen, 1971), 1989 Loma Prieta, USA (Holzer, 1998), 1995 Kobe, Japan (Soga, 1998), and 2011 Tohoku-Oki, Japan (Cox et al., 2013) earthquakes. Liquefaction affects buildings, bridges, buried pipelines and lifeline facilities etc. in many ways. Bangladesh is an earthquake prone country, which has been repeatedly affected by large destructive historical events (Bilham and England, 2001). The occurred historical earthquakes in Bangladesh and north-east India are presented in Table 1. The earthquakes of 1869 (Oldham, 1882), 1885 (Middlemiss, 1885), 1897 (Oldham, 1899), 1918 (Stuart, 1920) and 1930 (Gee, 1934) have caused serious damage to buildings and other infrastructures of Bangladesh. Although significant damage has been reported in Dhaka City during the 1897 Great Indian Earthquake and 1885 Bengal Earthquake, there is no document on the extent of the damage in Dhaka during the 1918 Srimangal and the 1930 Dhubri Earthquakes. Moderate to large earthquake magnitudes may occur in this region due to continuing tectonic deformation along the plate boundaries and active faults (CDMP, 2009). The soil liquefaction due to such earthquakes is one of the major reasons for the increase in damage to different infrastructures.

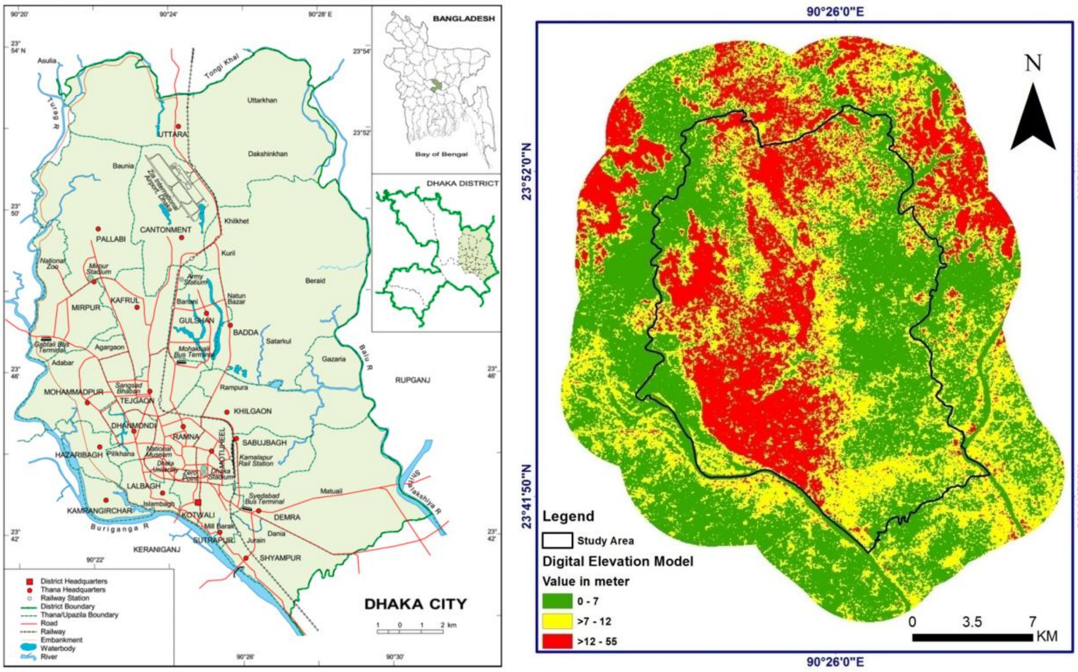
Table 1
List of historical earthquakes occurred in Bangladesh and NE India (Ansary and Meguro, 2003)

Date	Name of earthquake	Magnitude (Richter)	Intensity at Dhaka (EMS)	Epicentral distance from Dhaka (km)
10/01/1869	Cachar Earthquake	7.5	V	250
14/07/1885	Bengal Earthquake	7.0	VII	170
12/06/1897	Great Indian Earthquake	8.7	VIII+	230
08/07/1918	Srimangal Earthquake	7.6	VI	150
02/07/1930	Dhubri Earthquake	7.1	V+	250
15/01/1934	Bihar–Nepal Earthquake	8.3	IV	510
15/08/1950	Assam Earthquake	8.5	IV	780

Seed and Idriss (1971) have originally proposed the Simplified Procedure for the evaluation of liquefaction-resistance. This procedure has been modified and updated by many researchers over the years (Seed and Idriss, 1982; Iwasaki et al., 1978, 1982; Seed et al., 1984, 1985; Robertson and Wride, 1997; Chen and Juang, 2000; Youd and Idriss, 2001; Youd et al., 2001; Seed et al., 2003; Juang et al., 2003, 2008, 2009; Sonmez, 2003; Lee et al., 2004; Papathanassiou et al., 2005; Sonmez and Gokceoglu, 2005; Cox et al., 2007; Sonmez et al., 2008; Papathanassiou, 2008; Holzer, 2008; Jha and Suzuki, 2009; Heidari and Andrus, 2010; Dixit et al., 2012; Kang et al., 2014; Palacios et al., 2014; Goharzay et al., 2017; Akkaya et al., 2017; and others). Dhaka City falls within a seismically active zone. Most of the parts of the city are covered by the Holocene sand, silty sand, silty clay, sandy- and clayey-silt. There are few studies (Rashid, 2000; Rahman, 2004; CDMP, 2009) about the potential of liquefaction in Dhaka City. In this study an attempt has been made to prepare a liquefaction hazard map of Dhaka city. The objectives of this research are to compute liquefaction potential of Dhaka City using Simplified Procedure to estimate liquefaction potential index (LPI) and to develop a liquefaction hazard map for the city based on LPI values. Cumulative frequency distribution of LPI of different geological materials has also been estimated.

2. Geomorphology and geology

Dhaka, the capital of Bangladesh is situated in the central part of the country at the bank of the river Buriganga (Figure 1). The city having a population of around 9 million covers an area of 321 sq km. Tongi Khal is located in the north, the Buriganga River is located in the south and south-west, the Turag River is situated in the west and the Balu River is situated in the east of the city. Dhaka has been established as the capital of Bengal by the Mughals, a little over 400 years earlier (Mamoon, 2010). Many buildings in the old part of the city are non-engineered due to the unplanned civilization. The recent buildings, which are mostly engineered and some non-engineered, have been constructed on the artificial sand fillings of the recent floodplains of the four surrounding rivers. Dhaka and its surrounding areas are relatively flat. There exist some depressions as can be seen from Digital Elevation Model (DEM) of Figure 1. The general slope of the city is from the north to south and south-east. The southern part of the Pleistocene Terrace and the surrounding Holocene floodplains mainly covers the Dhaka city. Six geological units based on geomorphology, stratigraphy and geotechnical properties mainly cover the city. These units are Pleistocene terrace deposit, Holocene Alluvial valley fill deposit, Holocene Alluvial channel deposit, Holocene Alluvium, Holocene terrace deposit and Artificial fill (Figure 2) (after CDMP, 2009).



(a) Dhaka city (Islam, 2012). (b) Digital elevation model of the study area.

Fig. 1. Location map of the study area.

The central part of the city is generally composed of brown to reddish brown stiff silty clay and medium dense to dense silty sand from the Pleistocene Modhupur terrace deposit. The depressions or valleys of the Pleistocene terrace deposit, consisting of dark gray to gray soft silty clay, and yellowish brown, loose to medium dense silty sand of the Holocene Alluvial valley fill deposit. The present river channels are formed of gray loose to loose silty sand of the Holocene Alluvial channel deposit. The point bars, channel bars consisting of loose to medium dense silty sand, and soft to stiff silty clay of the Holocene terrace deposit.

The eastern, southeastern and northwestern parts of the city where the Holocene Alluvium is located is composed of gray very soft to medium stiff silty clay, clayey silt and loose to loose silty sand. The artificial fills in the western and eastern parts of the city are composed of gray clayey silt, silty sand and sand. Hydraulic dredging from the river has been mainly used to emplace the artificial fills in the western and eastern parts of the city. During or after artificial filling from the consideration of the liquefaction susceptibility of the soils, the ground has not been improved.

3. Seismotectonics

Figure 3 presents the plate boundaries and faults surrounding Dhaka region according to Maurin and Rangin (2009) and Steckler et al. (2008). The figure also shows the locations of some historical earthquakes which have occurred in the northeastern parts of India, Nepal, Myanmar, and Bangladesh during the last 250 years (Table 1). Among these earthquakes, the 1762 Bengal-Arakan, 1869 Cachar, 1885 Bengal, 1897 Great Indian, 1918 Srimangal, 1930 Dhubri and 1934 Nepal-Bihar Earthquakes are important for Bangladesh. In a megacity of this region, an earthquake of magnitude 8 or larger may cause one million casualties according to Bilham (2009). He has predicted this high level of casualties, since developed countries of this region are less vulnerable than those of developing countries due to high population density, unplanned urbanization, non-engineered construction practices, inadequate knowledge of the seismic design of structures, ignorance of building codes and poor monitoring system of the concerned government authorities during any structural construction.

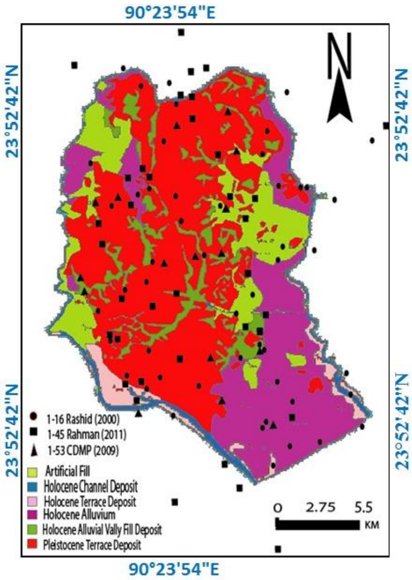


Fig. 2. Surface geological map of Dhaka City (modified from geomorphological map of CDMP (2009)) with locations of standard penetration test (SPT) measurement.

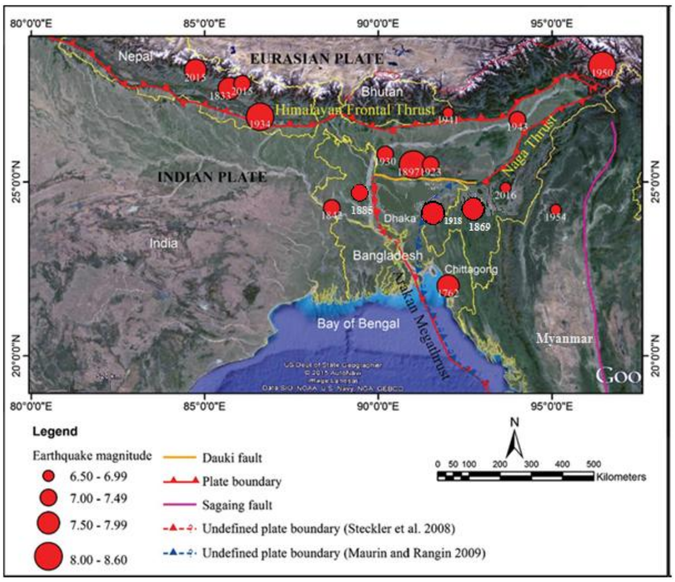


Fig. 3. Recent and Historical large earthquakes in the surrounding area of Bangladesh. Historical earthquakes locations and magnitudes are from Ambraseys and Douglas (2004), Sabri (2002) and Szeliga et al. (2010). Recent earthquake locations and magnitudes are from United States Geological Survey (USGS).

According to Sabri (2002), the most critical earthquake for Dhaka City is the 1885 Bengal Earthquake and the epicenter of this seismic event has been relocated near Sherpur Upazila of Bogra District. Middlemiss (1885) has located this event near Atia in Manikganj District. The intensity of this earthquake at Dhaka City is VII in European Microseismic Scale (Ansary and Meguro, 2003). A recent study indicated that this earthquake might have originated due to the Madhupur Fault (CDMP, 2009). Due to this fact, for Dhaka City, the Madhupur Fault is one of the important seismic sources (Figure 4). In the seismic zoning map, Bangladesh is divided into three seismic zones based on peak ground acceleration (BNBC, 1993). The zones are Zone I, Zone II and Zone III, where the values are 0.075g, 0.15g and 0.25g respectively (Figure 5a). The location of Dhaka City is in Zone II, where the peak ground acceleration is 0.15g. Recently (BNBC Proposed, 2017), this map has been updated (Figure 5b) and the zone factor of Dhaka has been upgraded to 0.20g.

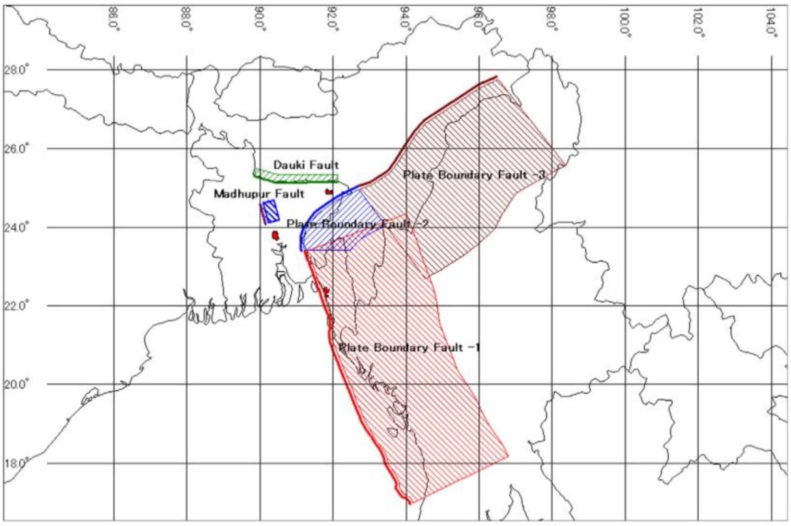


Fig. 4. Scenario earthquake fault model of Bangladesh (CDMP, 2009).

4. Soil database for liquefaction analyses

To evaluate the liquefaction potential of geological units up to a depth of 20 m from the ground surface, the Standard Penetration Test (SPT) data are widely used. In this study, SPT N-values, along with other necessary geotechnical properties of 114 borehole profiles are compiled. These boreholes located in different geological units of Dhaka City have been used to assess the factor of safety against liquefaction as per Youd et al. (2001). Finally, liquefaction potential index (LPI) as per definition of Iwasaki et al. (1978 and 1982) for each SPT profile has been estimated to produce a liquefaction hazard map of the Dhaka city. Out of total 114 data, 16 have been collected from Rashid (2000), 53 have been collected from Comprehensive Disaster Management Programme (CDMP, 2009) and 45 have been collected from Rahman (2011). The location of the boreholes has been shown in the surface geological map of the city (Figure 2). SPT N-values, geotechnical properties and geological information for determination of liquefaction potential index (LPI) are available for all the boreholes selected for this study. Based on the surface geological units of the city, the borehole locations have been classified. We can locate thirty eight (38) boreholes on the Pleistocene terrace deposit, twenty two (22) boreholes on the Holocene Alluvial valley fill and Holocene terrace deposit and fifty four (54) boreholes on the Holocene Alluvium and on artificial fill.

5. Simplified procedure for determination of factor of safety against liquefaction

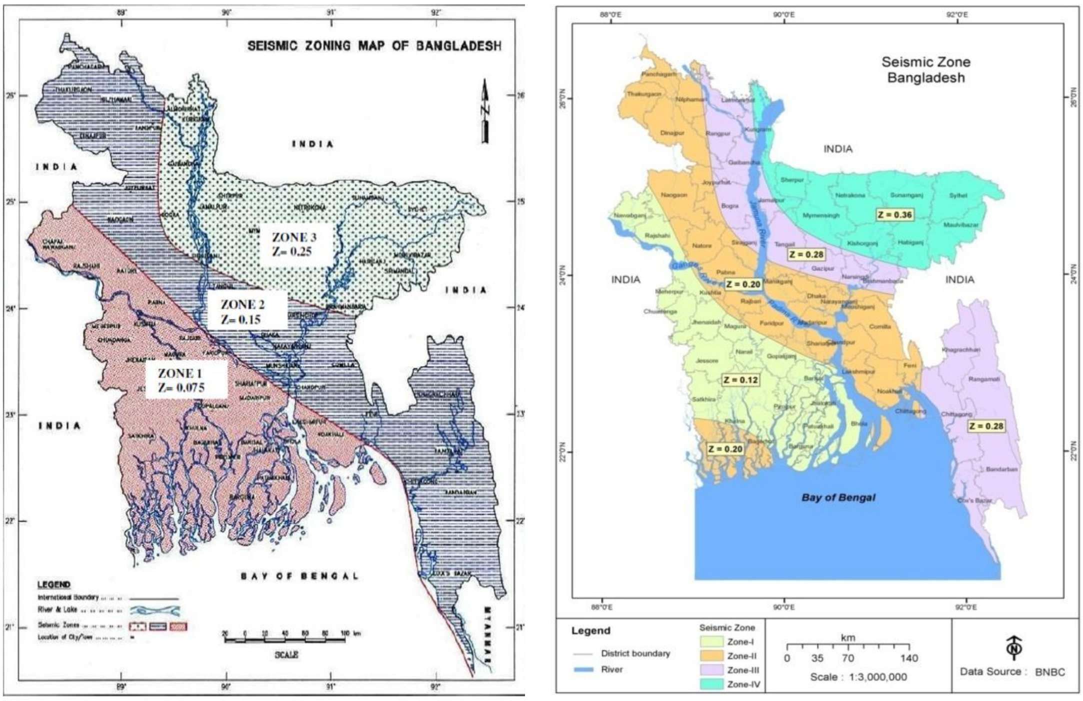
According to the Simplified Procedure of liquefaction resistance estimation proposed by Seed and Idriss (1971), the factor of safety against liquefaction is a comparison between the evaluation of the cyclic stress or strain developed in the field due to a design earthquake, i.e., cyclic stress ratio (CSR); and the evaluation of field liquefaction characteristics, i.e., cyclic resistance ratio (CRR). The two terms CSR and CRR are described below:

5.1 Evaluation of cyclic stress ratio (CSR)

The cyclic characteristic of soil is represented by cyclic stress ratio (CSR). It estimates the seismic demand on a soil layer of level ground condition. It is the ratio of the average cyclic shear stress (τ_{av}) developed on horizontal surface of soils due to cyclic or earthquake loading to the initial vertical effective stress (σ_0') acting on the soil layer before the cyclic stresses are applied (Robertson and Campanella, 1985). This parameter takes account into the depth of the soil layer involved, the depth of groundwater level, and the intensity of other cyclic loading phenomena or earthquake shaking (Seed et al., 1983). According to the Simplified Procedure of Seed and Idriss (1971), the CSR developed in the field due to an earthquake loading at a depth of z from the ground surface can be estimated using the following equation:

$$CSR = \frac{\tau_{av}}{\sigma_0'} = 0.65 \times \frac{a_{max}}{g} \times \frac{\sigma_0}{\sigma_0'} \times r_d \quad (1)$$

where, a_{max} = maximum horizontal acceleration at the ground surface generated by the earthquake; g = acceleration of gravity; σ_0 and σ_0' are total and effective vertical overburden stresses, respectively, at depth of z; and r_d = stress reduction coefficient that accounts for the flexibility of the soil column. Idriss and Boulanger (2004) have proposed a factor 0.65 to convert the peak cyclic shear stress ratio to a cyclic stress ratio which will represent most significant cycles over the full duration of loading.



(a) Existing BNBC (1993). (b) BNBC proposed (2017).

Fig. 5. Seismic zoning maps of Bangladesh.

5.2 *Evaluation of cyclic resistance ratio (CRR)*

The cyclic resistance ratio (CRR) represents the capacity of the soil to resist liquefaction. According to Youd et al. (2001), the CRR for 7.5 magnitude (M_w) earthquake ($CRR_{7.5}$) is estimated from the overburden stress-corrected SPT resistance of equivalent clean sand.

5.3 *Determination of factor of safety (F_L)*

According to the Simplified Procedure of liquefaction resistance estimation proposed by Seed and Idriss (1971), the cyclic stress ratio (CSR) is compared to the liquefaction-resistance of the soil represented by the cyclic resistance ratio (CRR) for M_w = 7.5 earthquake (i.e., $CRR_{7.5}$). For other earthquake magnitudes, a magnitude scaling factor (MSF) is used to adjust $CRR_{7.5}$ to determine the CRR. The factor of safety (F_L) against liquefaction is defined in terms of the CRR, CSR, and MSF as follows:

$$F_L = (CRR_{7.5}/CSR)MSF \quad (2)$$

5.4 Seismic factors

According to the Simplified Procedure, two seismic ground-motion parameters are required to evaluate the liquefaction-resistance of soils. The parameters are peak horizontal ground acceleration and earthquake magnitude. As stated earlier, the 1885 Bengal Earthquake (M_w = 7.0), which has occurred about 170 km northwest from Dhaka City, is the most important earthquake for the city. In addition, in seismic zoning map of Bangladesh the peak horizontal ground acceleration for the city is 0.15g (BNBC, 1993).

Therefore for the calculation of the liquefaction resistance of soils in Dhaka city, the peak horizontal ground acceleration and magnitude of the earthquake used are 0.15g and 7.0 (M_w), respectively.

5.5 Liquefaction potential index (LPI)

The proposed LPI value by Iwasaki et al. (1982) has assumed that the severity of liquefaction is proportional to: the thickness of the liquefied layer, the proximity of the liquefied layer from the ground surface and the amount by which the factor of safety (F_L) is less than 1.0. The LPI is estimated using the following equations.

$$LPI = \int_0^{20} F(z)W(z)dz \tag{3}$$

$$F(z) = 1 - F_L \; for \; F_L < 1.0 \tag{4a}$$

$$F(z) = 0 \; for \; F_L \; \geq 1.0 \tag{4b}$$

$$W(z) = 10 - 0.5z \; for \; z < 20m \tag{4c}$$

$$W(z) = 0 \; for \; z > 20m \tag{4d}$$

where z is the depth from the ground surface in meters.

Iwasaki et al. (1978, 1982) has defined the effect of the factor of safety on liquefaction potential as linear from zero to one. The layer having the smallest factor of safety generally will cause more damage on the surface. Sonmez (2003) and Sonmez and Gokceoglu (2005) have performed some studies to overcome the application of linear relation for impact of the factor of safety on liquefaction potential. The classification of liquefaction severity by considering probability of liquefaction classes based on P_L values has also been rearranged by Sonmez and Gokceoglu (2005) based on Chen and Juang's (2000) proposal. In this study the original form of the LPI has been used instead of probability based liquefaction classes to develop the liquefaction hazard map of Dhaka City. Some validation of the obtained values is made based on previous findings.

According to Iwasaki et al. (1982) from SPT measurements at 85 Japanese sites under six earthquakes, LPI values of 5 and 15 may be considered as the lower bounds of “moderate” and “major” liquefaction, respectively. To correlate with surface manifestation of liquefaction, Toprak and Holzer (2003) has also found similar results using 50 CPT sounding at 20 sites affected by the 1989 Loma Prieta (M_w=6.9) earthquake. Both the above findings have ascertained that median values of LPI equal to 5 correspond to the occurrence of sand boils. From the liquefaction data study of 2003 San Simeon earthquake, Holzer et al., (2005) also has drawn similar conclusions that LPI=5 may be used as the threshold for surface manifestations of liquefaction. According to Luna and Frost (1998), LPI may be used for the spatial analysis of the liquefaction hazards since it allows to develop a two-dimensional representation of a three-dimensional phenomenon (liquefaction resistance value versus depth), which is ideal for mapping.

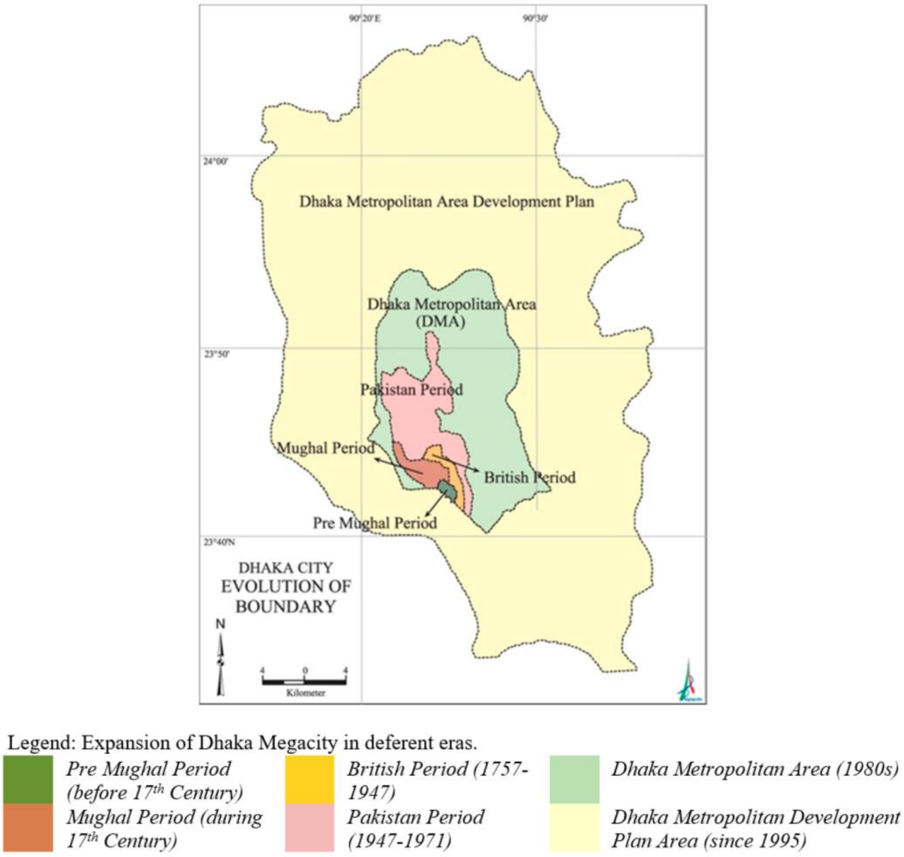


Fig. 6. Growth of Dhaka City over different periods (Islam, 2012).

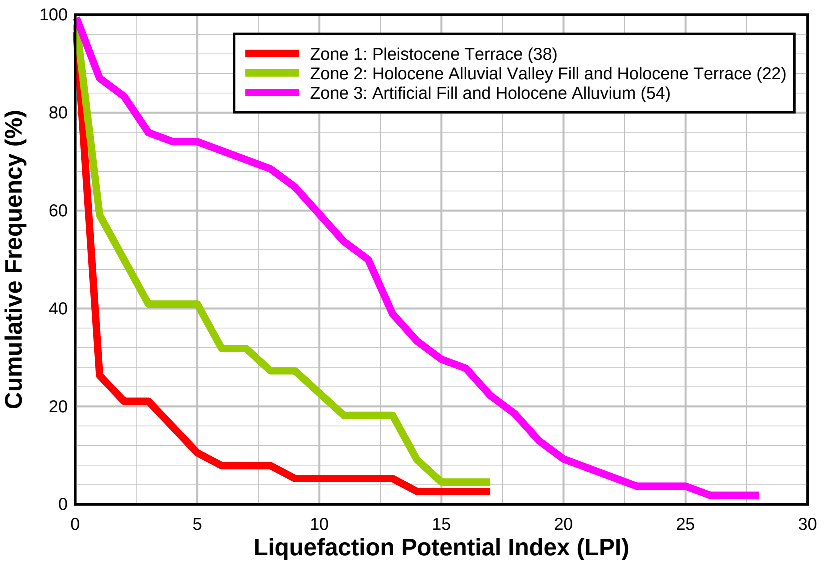


Fig. 7. Cumulative frequency distributions of liquefaction potential index (LPI) for three zones of Dhaka City. Number of SPT profiles used in each zone is shown in parentheses of the legend.

Bangladesh is a flood prone country, especially Dhaka city gets inundated with heavy rain within a short spell of time (Mowla and Islam, 2013). For the LPI analysis, the ground water table (GWT) has been assumed to be at a depth of 1.5m below the existing ground level due to the above flooding condition as a conservative approach. The fines content of each SPT profile is available in the grain size distribution data. LPI values for whole borehole locations are determined for an earthquake scenario having a magnitude of 7.0 (Mw) and a peak horizontal ground acceleration of 0.15g (Table 2). Liquefaction has not been observed at the ground surface of Dhaka City during any historical earthquakes mentioned in Table 1.

There is a surfacial evidence of liquefaction during the 1897 Great Indian Earthquake in Rowmari, Rangpur (Oldham, 1899). The size and population of Dhaka city is only 30 sq. km and 90,000 respectively in 1897 (Siddiqui, 1990; Ansary and Meguro, 2003). Figure 6 shows the growth of the city, which has mainly occurred along the northern direction and later along western and eastern direction through land filling.

The city during the British period has been situated in the southern part of Figure 2 located mainly on the Pleistocene Terrace Deposit. This type of soil deposit generally has low liquefaction susceptibility. During all the major earthquake events according to the Table 1, Dhaka has been a small city located on less liquefaction susceptible soil. On the other hand, from early 1980's Dhaka has become a megacity. To accommodate its growing population, it has filled almost all its depressions with Artificial Fill, which is relatively more liquefaction susceptible.

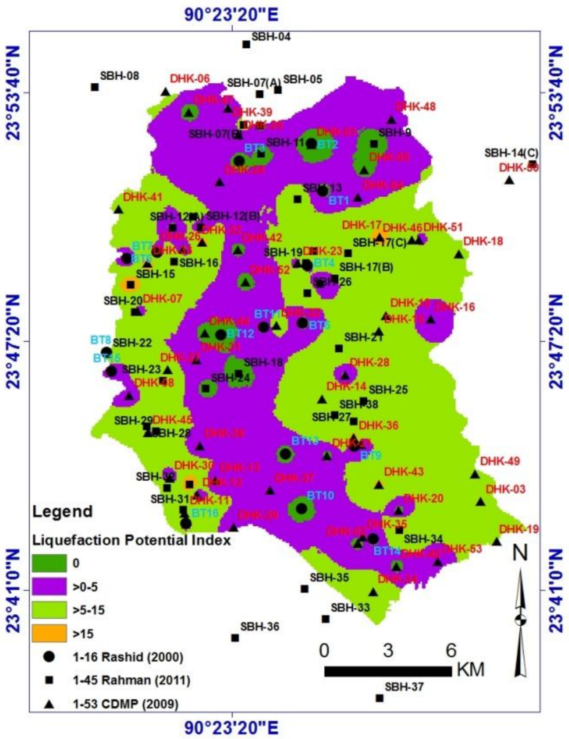


Fig. 8. Liquefaction potential index Map based on SPT data.

According to Toprak and Holzer (2003), surface demonstration of liquefaction generally occur where LPI ≥ 5. Holzer et al. (2006) also indicated that the cumulative percentage of the LPI values having LPI ≥ 5 for each surfacial geologic unit may be used to approximate percentage of the surface area underlain by that zone which will show a surface display of liquefaction. According to the surfacial geologic condition, Dhaka city may be divided into three broad zones as shown in Figure 7.

It has been found that 74% of the areas underlain by Zone 3 (the Holocene Alluvium and artificial fill) will exhibit surface demonstration of liquefaction for a peak horizontal ground acceleration of 0.15g for an earthquake of magnitude of 7.0 (M_w). The percentages of areas that will show surface effects for each zone of Dhaka City are shown in Figure 7.

6. Results of the liquefaction analyses

Using the SPT, soil type, groundwater level and earthquake scenario, the units in the first 20 m in the study area have been evaluated in terms of liquefaction potential. Figure 8 shows the liquefaction potential map prepared according to the LPI. According to the method proposed by Iwasaki et al. (1982), the map has been divided into very low liquefiable zone (LPI=0), low liquefiable zone (0 < LPI ≤ 5), high liquefiable zone (5 < LPI ≤ 15) and very high liquefiable zone (LPI > 15).

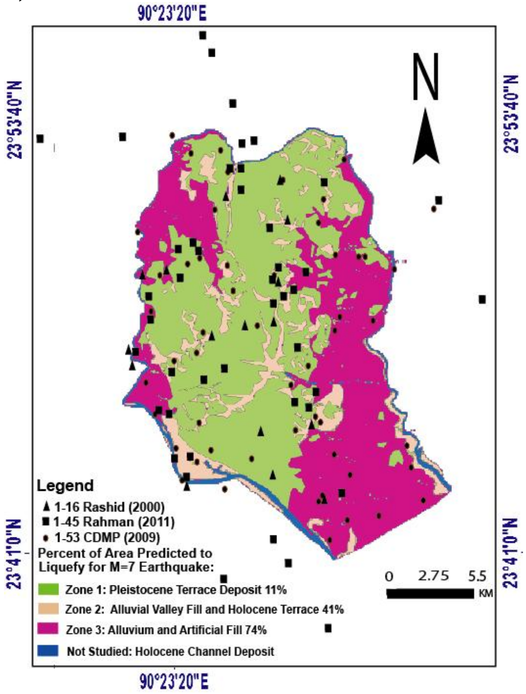


Fig. 9. Liquefaction hazard map of Dhaka City. Liquefaction hazard has been categorized as very low for LPI=0; low 0<LPI≤ 5; high for 5<LPI≤ 15 and very high for LPI>15. The 11%, 41% and 74% of areas in Zone 1, Zone 2 and Zone 3 respectively, will show surface effects of liquefaction for a scenario earthquake of Mw 7.0 having peak horizontal ground acceleration of 0.15 g.

According to Holzer et al. (2006), based on the cumulative frequency distribution of LPI, the surface geological units of Dhaka City have been divided into three liquefaction hazard zones to define liquefaction probability (Figures 7 and 9). The surfacial geologic unit containing Pleistocene terrace deposit is defined as Zone 1, the combined surfacial geologic units of Holocene Alluvial valley fill and Holocene terrace deposit is defined as Zone 2 and the combined surfacial geologic units of Holocene Alluvium and artificial fill is defined as Zone 3. Zone 1 and Zone 3 occupy large areas that contain thirty eight (38) and fifty four (54) LPI values, respectively. Zone 2 covers a small area having twenty two (22) LPI values. Since the number of LPI values in each zone is proportional to its area, we can consider the distribution of LPI values in each zone to be uniform, which is important for cumulative frequency distribution analysis. The liquefaction probability is quantified as percentage of the cumulative frequency distribution at LPI=5 for each zone. The map presented in Figure 9 indicates that 11%, 41% and 74% areas of Zone 1, Zone 2 and Zone 3 will show surface manifestation of liquefaction, respectively.

7. Discussions

The liquefaction based hazard map of Dhaka City presents a quantitative approach for producing liquefaction susceptibility map. Based on LPI values at each borehole location, the liquefaction potentiality of a specific location has been predicted. Also in terms of cumulative percentage of LPI in each hazard zone, the liquefaction probability has been evaluated. The probability map can be used to estimate the area of coverage that is expected to show surface manifestations of liquefaction at any specific zone. Pleistocene yellowish brown to reddish brown clayey soils and Plio-Pleistocene yellowish brown sandy soils form the subsurface soil of Zone 1 up to the depth of 20 m. The clayey soils are stiff to hard and the sandy soils are medium dense to very dense in nature. The liquefaction potential of this zone has varied from very low to low having LPI values from 0 to 5.63, except three boreholes having LPI values between 8.66 and 17.13. Eleven percent (11%) of the area of Zone 1 will show surface manifestations of liquefaction (Figure 9). Holocene Alluvial valley fills and terrace deposits are present in Zone 2. Dark gray to gray clayey and sandy soils deposited in the valleys and depressions of the Pleistocene terrace mainly compose of the valley fill deposits. Gray silty and sandy soils mainly compose of the terrace deposits which include natural levees, point bars and channel bars of the present rivers. LPI values of this zone varied from 0 to 17.86 and the liquefaction potentials of this zone are categorized from very low to very high. Forty One percent (41%) of the area of Zone 2 will exhibit surface effects of liquefaction. Alluvium and artificial fills consisting of gray clayey, silty and sandy soils are present in Zone 3. The LPI values of this zone varied from 0 to 28.3 having the liquefaction potentials from very low to very high. Seventy four percent (74%) of the area of Zone 3 will exhibit surface effects of liquefaction. LPI values have not been calibrated with actual liquefaction phenomena, as the liquefaction records have not been documented in Dhaka City during the past earthquakes. But a large percentage of the area (74%) in Zone 3 (Alluvium and artificial fill) showing surface manifestation of liquefaction is consistent with the extensive liquefaction of loose fills during the 1995 and 2011 earthquakes in Japan (Hamada et al., 1995; Cox et al., 2013). Holzer et al. (2006) has also reported high liquefaction hazard in Alluvium and artificial fills and less liquefaction hazard in the Pleistocene deposit.

8. Conclusion

The LPI map for Dhaka city has been drawn to define the liquefaction potential at different locations of the city based on a horizontal peak ground acceleration of 0.15g for a magnitude of 7.0 (M_w). The liquefaction potential of the city varied from very low to very high. The geological units of Dhaka City have been grouped into three liquefaction hazard zones, such as Zone 1, Zone 2 and Zone 3 based on cumulative frequency distribution of LPI in each zone. The cumulative percentages of LPI indicate that 11%, 41% and 74% of the areas of Zone 1, Zone 2 and Zone 3, respectively, will show the surface effects of liquefaction. Using the factor of safety proposed in the Simplified Procedure, LPI value of each SPT profile has been estimated. The limitations of this study are due to delineation of surface geological unit boundaries, a moderate number of SPT profiles and groundwater level variation. These limitations could be overcome by delineating the boundaries of the surface geological units properly, including a large number of SPT profiles and measuring groundwater levels in different seasons of the year for future application of the method. Another limitation of the study is the selection of appropriate peak horizontal ground acceleration (PHGA) for the scenario earthquake. Considering average distance of the study area from the fault of the scenario earthquake and average soil conditions, the PGHA can be estimated by using appropriate ground motion prediction equation (GMPE). The map prepared in the present study using LPI is considered as a preliminary liquefaction hazard map for the City of Dhaka. This type of microzonation map based on liquefaction susceptibility can be used as an additional tool for future development and planning of a mega city like Dhaka.

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