4th International Conference on Earthquake Engineering
Taipei, Taiwan
October 12-13, 2006

Paper No. 283

# GENERATION OF LIQUEFACTION POTENTIAL MAP FOR CHITTAGONG CITY AREA, BANGLADESH

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## ABSTRACT

The historical seismicity data of Bangladesh and Adjoining area indicates that Bangladesh is vulnerable to earthquake. As Bangladesh is the world's most densely populated area, any future earthquake shall effect more people per unit area that any other seismically active regions of the world. 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. Most of the parts of Chittagong, the port city of Bangladesh consisting of fine sand and silt deposits are susceptible to liquefaction. The susceptibility of liquefaction within an area of approximately 200 sq. kilometer in the greater Chittagong metropolitan area are assessed based on the Standard Penetration Test (SPT) data from 182 bore holes. The liquefaction potential has been evaluated using three simplified procedures. The analysis results have been classified in to several groups according to susceptibility of liquefaction. To this end, using the analytical results, a liquefaction potential map for the Chittagong city has been drawn to help the Engineers, builders, Architects and Policy Makers to have a general guide to ground-failure susceptibility, effective land use, effective town planning and disaster mitigation.

Keywords: SPT, liquefaction potential and liquefaction resistance factor.

## INTRODUCTION

Liquefaction phenomena have been recorded and developed in many parts of the world where ground shaking is frequent and soils consist of loose find sand under water table. Chittagong is the major sea-port and second largest city of Bangladesh with a population of over 6 million. It is situated in the south-east portion of the country near Myanmar. The city was built on the banks of Karnaphuli River, which ends nearby, in the Bay of Bengal. Chittagong City is mostly a hilly region, but it also consists of alluvial flood plain and sandy sea-shore area. Although the hilly region is less susceptible to liquefaction, it is formed by sandy and clayey soil and the area bottom of the hill also liquefy if the intensity of shaking is high, which may cause landslide in the highly region. On the other hand, flood plains and sea shore areas consisting of fine sand and silt deposit with shallow water table in most of the places, which may liquefy during a strong earthquake. Fig 1 shows the location of Chittagong city.

Any structure, if not properly designed for liquefaction, may lead to its failure or incur excessive cost through conservative design. No study has so far been undertaken to establish liquefaction possibilities

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for Chittagong city area in Bangladesh. In the absence of a definite knowledge of liquefaction possibilities at various localities, difficulties arise in finalizing design of many important structures. This adds to the construction time and cost. Many buildings and physical infrastructures such as sea port, air port, export processing zone (EPZ), refineries, power station, industries etc. at Chittagong, were constructed 10, 20, 50, 100 and 200 years ago without considering seismic safety provisions, especially soil liquefaction, are now essentially needed to strengthen or retrofit in order to protect human lives, economy and environmental hazards in this region. It has been, therefore, felt necessary to undertake a study to develop a liquefaction potential map of Chittagong. This paper deals with the development of a liquefaction potential map for Chittagong City area, comprising of 41 administrative wards. The administrative units of Chittagong City Corporation are shown in Fig 2.

## SEISMO-TECTONIC HISTORY OF BANGLADESH

Bangladesh is one of the most disastrous prone countries in the world. Although it is located in a region of significant seismic activity, most of the population and policy makers do not perceive seismic risk to be important. The tectonic evaluation of Bangladesh can be explained as a result of collision of the north moving Indian Plate with the Eurasian Plate. Records of the earthquakes show that Bangladesh and surrounding area experienced at least 1000 earthquakes having $M \geq 4$ in the last 100 years. Table 1 presents a list of historical earthquakes in the neighborhood of Bangladesh.


Figure 1: Location map of Chittagong City

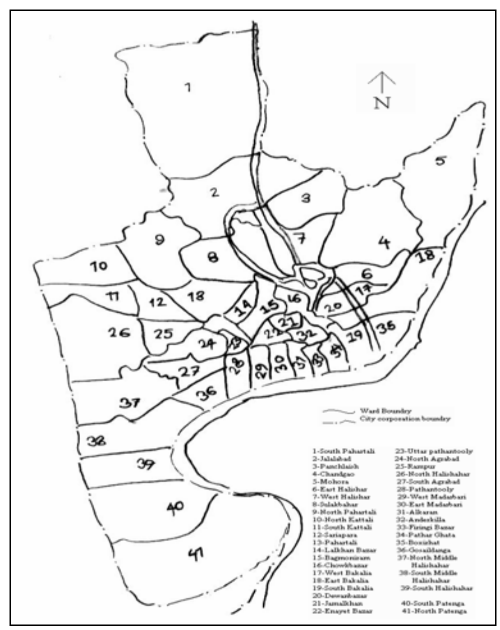



Figure 2: Chittagong City Corporation Area with 41 Wards

According to the Global Seismic Hazard Assessment Program (GSHAP), the most hazardous division in Bangladesh is the port city, Chittagong. Chittagong metropolis together with its surroundings is situated in the seismic zone 2, which has a basic seismic coefficient, Z=0.15 (BNBC, 1993). The Seismic zoning

Table 1. Earthquake magnitude and distance of historical earthquakes (after Ali, 1997)

| 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 |

Map of Bangladesh is shown in Fig.3. About 80-90% buildings and physical infrastructures in Chittagong are vulnerable to future massive earthquakes, as most of these were not designed to withstand this. The southern part of Khulna division has the lowest hazard in the country, while Chittagong division's Hill Tracts area has the highest hazard. In Khulna division, the maximum peak ground acceleration (PGA) would be expected to be in the range of 0.02 to 0.08g. Rajshahi division could expect a maximum PGA between 0.16g. to 0.24g in the southern sections to 0.24g to 0.32g in the northern sections. A small section of this division, along the border with India's West Bengal State, could expect a maximum PGA of 0.32g to 0.40g. The most hazardous division in Bangladesh is Chittagong division. Northern and southern sections could expect to have a maximum PGA ranging between 0.24g to 0.40g. The Chittagong Hill Tracts region can expect the highest PGA of up to 0.4g to 0.48g. If the Indian seismic zones were extended across the border into Bangladesh, the country would lie in zones IV and V. Southern Chittagong division also would lay in zone IV with a PGA of 0.4g. But Bangladesh National Building Code-1993 (BNBC-1993) is specified a maximum PGA of 0.15g for Chittagong and its surrounding area. The seismicity of India and Bangladesh are shown in Figs. 4 and 5, respectively.

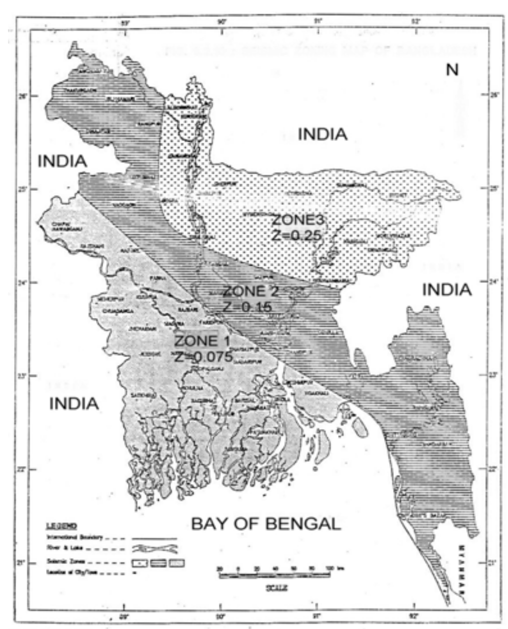



Figure 3. Earthquake Zoning Map of Bangladesh (BNBC 1993)

## FIELD STANDARD PENETRATION TEST DATA COLLECTION

The procedures employed in this paper to assess the liquefaction resistance of a soil deposit and predict the liquefied thickness, is based on Standard Penetration Test (SPT) blow counts in soil bore logs. A total 182 soil boring logs with SPT have been used for liquefaction potential study of Chittagong City. Most of the soil data collected are from the depth of 50 ft. to 150 ft. The soil borehole locations used in this study are shown in Fig. 6.

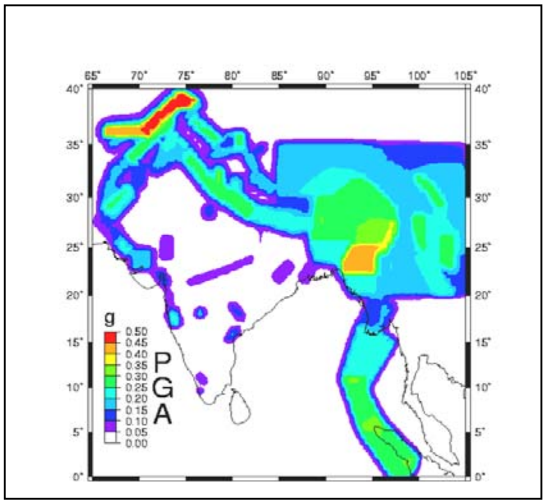



Figure 4: Seismic Activity of India

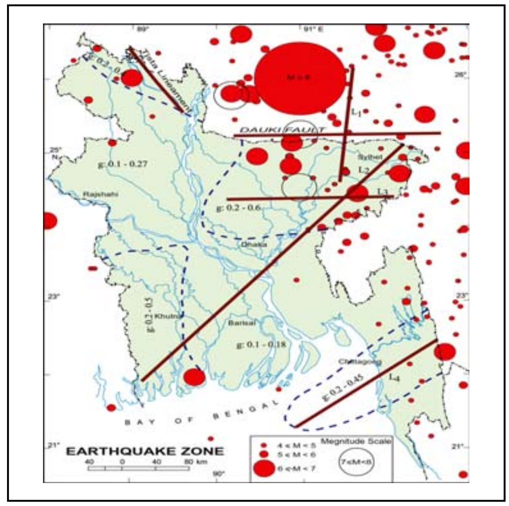



Figure 5: Seismic Activity of Bangladesh

## METHODS USED FOR LIQUEFACTION POTENTIAL STUDY

Recently, several methods for evaluating the liquefaction potential of sandy soil due to earthquake motions have been developed. Because of their simplicity, liquefaction potential have been evaluated in this study based on topographical and geological information (Iwasaki *et al.,* 1982) and using SPT N-value and grain size distribution data, and estimates of peak surface acceleration (Seed *et al.,* 1983). Moreover an additional method developed by Japanese Road Association (1991) has also been employed in this work to study the liquefaction potentiality of Chittagong city.

### Microzonation for Liquefaction Potential Based on Topographical Information

Kuribayashi and Tatsuoka (1975) classified several hundred sites, which liquefied as a result of 44 historic Japanese earthquakes. Following this survey, topographical conditions at theses sites and at surrounding sites which did not liquefy were studied by Iwasaki *et. al.* (1982). Most of these liquefied areas are present riverbeds, old riverbeds or flood plains. It can be judged that the present riverbeds, old riverbeds and reclaimed lands are almost likely to liquefy. General flood plains, and other areas are not likely to liquefy. Based on similar studies on many other plains in Japan, a microzonation procedure was developed using topographical information. This information is outlined in Table 2.

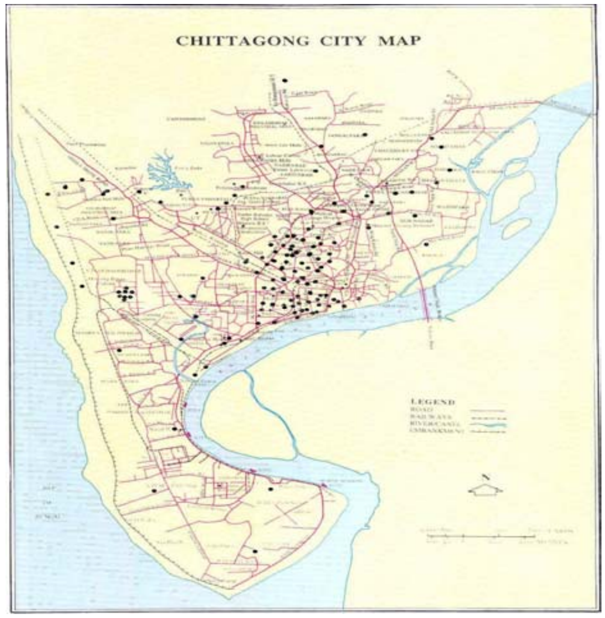



Figure 6. Soil Bore Hole Locations on Chittagong City Map

Table 2. Microzonation procedure based on topographical information (after Iwasaki *et al.,* 1982)

| Topography | Liquefaction Potential |
|---|---|
| Present river bed, Old river bed, Swamp, Reclaimed land, Interdune lowland, Fan, Natural levee, Sand dune, Flood plain, Beach, other plains | Liquefiable |
| Terrace, Hill, Mountain | Non-liquefiable |

According to the FEMA 356 section 4.2, the estimated susceptibility to liquefaction of surficial deposits during strong ground shaking is also given in Table 3.

**Microzonation for Liquefaction Potential Based on N- Values, Grainsize Distribution Curves and Estimated Peak Surface Acceleration**

A simple method suggested by Seed *et al.* (1983) has been used here to evaluate liquefaction resistance factor, $F_{L.}$ In this method the required parameters are SPT N-values, grain-size distribution curves of soils, overburden pressure, and estimated peak surface acceleration. The assessment of the liquefaction resistance factor at any depth by this method involves comparison between the predicted cyclic stress ratio $(\tau/\sigma'_o)$ and the shear stress that would be induced by a given design earthquake. For this method, $F_L$ is calculated for a given depth by the following formula as shown in Eq. 1. Liquefaction is judged to occur at that depth if $F_L$ is less than 1.0.

$$F_L = R / L \qquad (1)$$

Where, L is the ratio of dynamic load induced by seismic motion and effective overburden pressure and R is the ratio of insitu cyclic shearing strength of soil and effective overburden pressure. The average cyclic stress ration $(\tau_{av} / \sigma'_o)$ induced by an earthquake is given by the expression (Seed *et al.,* 1983) and is given in Eq. 2:

Table 3. Estimated Susceptibility to Liquefaction (After FEMA 356)

| Type of Deposit | Susceptible to Liquefaction |
|---|---|
| **A. Continental Deposit** | |
| 1. River Channel | Very High |
| 2. Flood Plain | High |
| 3. Alluvial Fan, Plain | Moderate |
| 4. Delta, Fan | High |
| **B. Coastal Zone Deposit** | |
| 1. Delta | Very High |
| 2. Beach, Lagoon, Foreshore | High |
| **C. Fill Materials** | |
| 1. Uncompacted Fill | Very High |
| 2. Compacted Fill | High |

$$L = \tau_{av}/\sigma'_o = 0.65\,(a_{max}/g)\,(\sigma_o/\sigma'_o)\,r_d \qquad (2)$$

Where, $\sigma'_o$ is effective overburden pressure, $\sigma_o$ is total overburden pressure, is estimate of the peak surface acceleration (in percentage of g), g is acceleration due to gravity, $r_d$ is a stress reduction factor given by (1-0.015z) in which z is depth of ground surface in meters. The cyclic stress ratio required to cause liquefaction has been evaluated using empirical relationship between cyclic stress ratio and corrected N values (Seed et al. 1979). A modification to the field SPT-N value is needed as given in Eq. 3:

$$N_1 = C_N N \qquad (3)$$

Where, $N_1$ is modified N values and $C_N$ is a correction factor. The correction factor, $C_N$ has been provided by Seed *et al.* (1983). The severity of foundation damage caused by soil liquefaction depends to a great extent on the severity of liquefaction, which cannot be evaluated solely by the $F_L$. In order to take care the above effect, the Japanese bridge code recommended (Japanese Road Associations, 1991) a modified procedure. In this method, the liquefaction potential index ($I_L$) is given by the Eq. 4 (Iwasaki *et al.,* 1982).

$$I_L = \int_0^{20} F(z)w(z)dz \qquad (4)$$

Where, $F(z) = (1-F_L)$ for $F_L \leq 1.0$ and ($F(z) = 0$ for $F_L > 1.0$, $w(z) = (10 – 0.5 Z)$ for $z \leq 20$ m and $w(z) = 0$ for $z > 20$ m, $I_L = 0$ for non-liquefiable soil and $I_L > 0$ for liquefiable soil.

Japan Road Association (1991) introduced the concept of liquefaction resistance factor $F_L$ that can also be defined by the Equation (1) with some modification of R. The value of R depends on relative density, effective overburden pressure and means particle size and is given in Eqs. 5 & 6.

$$R = 0.882\sqrt{\frac{N_1}{\sigma'_v + 70}} + 0.225\log_{10}\left(\frac{0.35}{D_{50}}\right) \quad \text{for } 0.02<D_{50}<0.6 \text{ mm} \qquad (5)$$

$$R = 0.882\sqrt{\frac{N_1}{\sigma'_v + 70}} - 0.05 \quad \text{for } 0.6<D_{50}<2.0 \text{ mm} \qquad (6)$$

Where $D_{50}$ is the mean particle diameter in mm $N_1$ is obtained through the correction factor $C_N$ and $\sigma'_v$ is the effective overburden pressure in kN/m$^2$

The above equations are valid when the material is identified as clean sand with fines content less than 5%.

If $F_L < 1.0$ Liquefaction is said to occur.

If $F_L \geq 1.0$ No Liquefaction occur.

Using above equations the liquefaction susceptibility (L.S.) is calculated by the weighted average method and is given in Eq. 7:

$$L.S. = (F_{L1} * h_1 + F_{L2} * h_2 + \ldots\ldots) / (h_1 + h_2 + \ldots\ldots) \quad (7)$$

Where, $F_{L1}$ and $F_{L2}$ are the liquefaction potential factor at depth $h_1$ and $h_2$, respectively.

The Susceptibility of liquefaction within an area of Approximately 200 sq. km. in the greater Chittagong Metropolitan area has been evaluated using the above procedures based on the Standard Penetration Test (SPT) data from 182 bore holes.

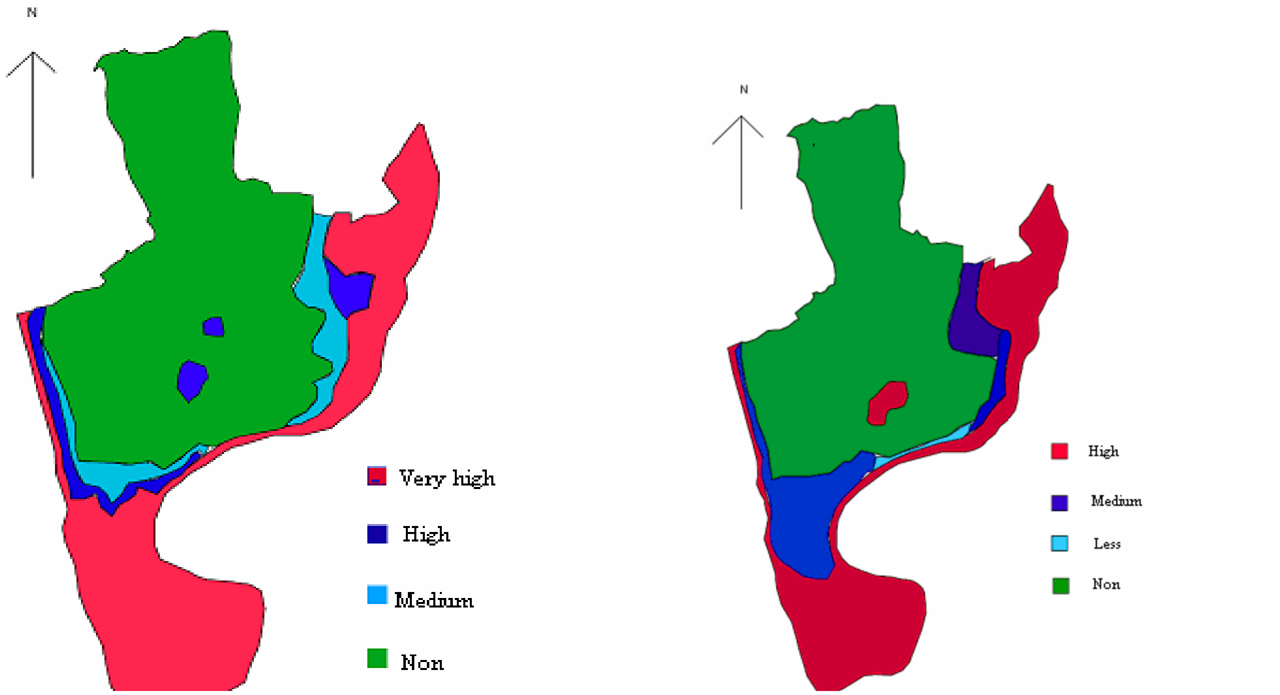
## RESULTS AND DISCUSSIONS

Table 2 presents the criteria for the liquefaction potential of different zones in accordance with the past liquefaction behavior of such zones and with the levels and aerial extent of the causative ground motions. Table 3 presents the estimated susceptibility to liquefaction of surficial deposits during strong ground shaking.

A microzonation map of the Chittagong city's liquefaction potential has been developed based on N-Values, Grain size Distribution Curves and Estimated Peak Surface Acceleration. Data from about 180 borings in Chittagong City has been collected. Almost all the boring data include SPT N- values measured at 1.5 m (5 feet) interval, because the Standard Penetration Test (SPT) is the most commonly used sounding test in Bangladesh. On the other hand, sieve analysis and unit weight determinations for sandy soils are not widely available, and thus the author has estimated mean particle diameter and unit weight from the classification of soil layers. The liquefaction resistance factor, $F_L$, for the top 20 m of soil, and the resulting potential, $F_L$, for the 182 sites have been calculated.

The maximum ground surface acceleration has been estimated from the seismic map based on 200-year return period ground motion contour and earthquake data from 1900 to 1977 (Hattori, 1979). For Chittagong, the peak ground surface acceleration is around 0.15g. A microzonation map for liquefaction potential has been made at each boring sites as shown in Fig. 7 and presented in Fig. 8. Comparing between the Figs. 7 (a) and (b), it can be seen that the liquefaction risk areas identified by Seed et al.'s method coincide fairly to those pointed out by Iwasaki et al.'s method, and Japanese Road Association's method.

Results from liquefaction potential analysis has been plotted on the Chittagong City Map dividing the study area into 3 zones namely, high probability of liquefaction, medium probability of liquefaction and no liquefaction zones and is shown in Fig. 8. It can be seen from the Fig. 8 that Chittagong City Ward No. 4, 8, 10, 11, 16, 19, 26, 29, 30, 31, 34, 35, 36, 38, 39, 40, 41 are highly susceptible to liquefaction and are marked with red shades and City Ward No. 4, 5, 9, 10, 15, 16, 21, 22, 26, 38, 40 are medium susceptible to liquefaction and are marked with blue shades. It can be also seen from Fig. 7 that mainly the sea shore and flood plain, river side area are highly susceptible to liquefaction and the hilly area at the middle of the City are not susceptible to liquefaction




(a) (b)

Figure 7: Liquefaction Potential map of Chittagong City (a) Map generated using Japan Road Association Code (1991) (b) Map generated using Seed et al. 1983

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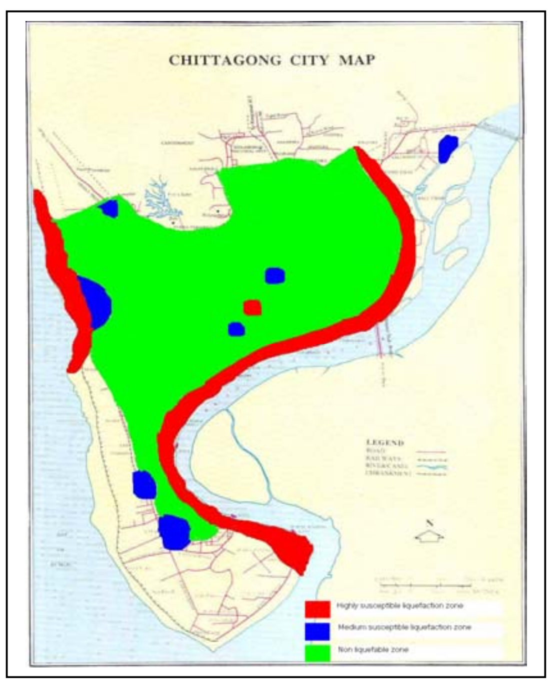


Figure 8. Liquefaction Potential Map of Chittagong City Based on SPT

## CONCLUSIONS

Seismic microzonation of Chittagong city is a complex and multi-disciplinary undertaking. In this paper, the seismic microzonation aspect with respect to soil liquefaction has been conducted using three different simplified procedures proposed by Iwasaki et al. (1982), Seed et al. (1983) Japanese Road Association (1991). Although time and budget constraints have prevented more refinements, the authors believe that by initiating this microzonation study for Chittagong city area in Bangladesh, a primary earthquake hazard mitigation step can be formulated. This investigation would be guideline for town Planners, Professionals, Architects and Land Developers.

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