# Seismic Microzonation of Cox's Bazar Municipal Area Bangladesh

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**ABSTRACT:** Cox's Bazar municipal area runs a high risk of earthquake exposure due to geologic and tectonic structures. As a part of adopting earthquake mitigation approaches for the region, a seismic microzonation map was developed on the basis of potential of earthquake occurrences and ground susceptibility to earthquake. For microzonation purposes, a total of 26 borelogs were used to study site amplification as well as soil liquefaction potential of the municipality area. Site responses were estimated through one dimensional wave propagation software SHAKE. The liquefaction potential was evaluated using two simplified procedures, proposed by Seed et al. (1983) and Iwasaki et al. (1986) to measure whether the site is liquefiable or non-liquefiable. For slope stability analysis, XSTABL programme was used which performs two dimensional limit equilibrium analyses to evaluate the factor of safety for a layered slope using the simplified Bishop Method. These results were transformed into a map which will serve as a general guide to ground-failure susceptibility, effective land use, and efficient town-planning.

**KEYWORDS:** Seismicity, Ground Liquefaction, Site Amplification, Slope Stability, Microzonation

## 1. INTRODUCTION

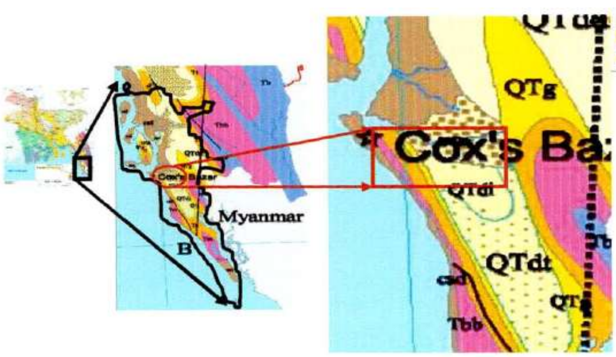
Cox's Bazar Municipal is located in the Southeastern part of Bangladesh, beside the Bay of Bengal under the district Cox's Bazar. The area is famous for her outstanding natural beauty. The district has an area of 2491.9 sq km with a population of 1.8 Million (BBS, 2001). Cox's Bazar municipality covering an area of 6.85 sq. km is located at 21.58°N, 92.02°E. Cox's Bazar falls in zone 2 with a seismic coefficient of 0.15g. Recent earthquakes in adjoining areas of Cox's Bazar indicate a warning that the people of that area should take adequate measures against earthquakes.

Anbazhagan and Sitharam (2010) presented seismic site classification using boreholes and shear wave velocity and assessed the suitable method for shallow engineering rock region. Islam and Hossain (2010) estimated liquefaction potential of selected reclaimed areas of Dhaka city based on standard penetration test and shear wave velocity. Motazedian et al. (2011) applied four different seismic methods which were down hole interval vs. measurements at 15 borehole sites, seismic refraction–reflection profile measurements for 686 sites, high-resolution shear wave reflection "landstreamer" profiling for 25 km in total, and horizontal-to-vertical spectral ratio (HVSR) of ambient seismic noise to evaluate the fundamental frequency for ~400 sites for development of a Vs30 (NEHRP) map for the city of Ottawa, Ontario, Canada. Louie et al. (2011) made earthquake hazard class mapping by Parcel in Las Vegas Valley which included more than 10,000 measurements that classify individual parcels on the NEHRP hazard scale. Another earthquake hazard class mapping by Parcel was made by Louie et al. (2012) which included 10,721 surface-wave array measurements that classify individual parcels on the NEHRP hazard scale. Cox et al. (2012) worked on frozen and unfrozen shear wave velocity seismic site classification of Fairbanks, Alaska which was based on 59 shear wave velocity (Vs) profiles collected using the spectral analysis of surface waves (SASW) method. Mohanty and Patra (2012) assessed liquefaction potential of pond ash at Panipat in India using SHAKE2000 where the liquefaction analysis of pond ash was carried out by using Seed and Idriss method and 1-D ground response analysis. Irfan et al. (2012) worked on local site effects on seismic ground response of Dubai-Sharjah metropolitan area where dynamic properties of selected soil profiles were evaluated using empirical relations between Standard Penetration Test (SPT) N-values and shear wave velocity (Vs). Manne and Satyam (2013) estimated the local site effects using microtremor testing in Vijayawada city, India where microtremor surveys were carried out at 75 different locations in the Vijayawada urban area and analysis was carried out using the Nakamura technique. Natural Resources Canada (NRCan) (2013) adapted Hazus for seismic risk assessment in Canada which was a standardized best-practice methodology developed by the US Federal Emergency Management Agency (FEMA) for estimating potential losses from common natural hazards, such as earthquakes, floods, and hurricanes. Thaker and Rao (2014) worked on seismic hazard analysis for urban territories at Ahmedabad region in the state of Gujarat, India where earthquake data has been analyzed statically and the seismicity of the region is evaluated by defining 'a' and 'b' parameters of the Gutenberg-Richter relationship. Desai and Choudhury (2014) worked on deterministic seismic hazard analysis for Greater Mumbai, India where the seismic sources were identified from the seismotectonic atlas of India within the control region of 300 km radius around Mumbai City and the epistemic uncertainty involved in estimation of different input parameters was accounted within a logic tree framework. Sil and Sitharam (2016) researched on detection of local site conditions in Tripura and Mizoram using the topographic gradient extracted from remote sensing data and GIS techniques where Peak Ground Acceleration (PGA) at the bedrock for the states of Tripura and Mizoram in NE India was estimated using Probabilistic Seismic Hazard Analysis (PSHA), which considered linear sources and events (from 1731 to 2010) with appropriate ground motion prediction equations applicable for NE India.

In this study, for microzonation purposes, bore holes with SPT data and historical large earthquakes were used as scenario events. From attenuation laws, Peak Ground Acceleration (PGA) in the bedrock level was estimated and used to develop a regional combined seismic hazard map based on site liquefaction, amplification and slope stability.

## 2. GEOLOGY OF THE AREA

Cox's Bazar town is located at the Middle-West part of the district bounded by the Bakkhali River on the North and North-East. The area lies within the Eastern flank of Inani Anticline, trending towards NNW-SSW, whose Western Flank is eroded. The existing Eastern Flank of the anticline is also in the process of continuous erosion. Figure 1 shows the Surface Geology of Cox's Bazar Municipal area according to the Geological Map of Bangladesh (Alam et al., 1990). The Western Figure reveals that the area around the city of Cox's Bazar predominantly composed of Valley Alluvium and Colluvium and Dihing Formation of Pliocene-Pleistocene age. Rocks of the Pliestoeene, Pliocene and Neogene ages are also exposed in the area. The exposed rock units are mostly composed of sandstone and claystone. Six Lithostratigraphic units have been observed from the Geological Map of Bangladesh. To the west of the Municipal Boundary, the strand of coastal Deposit, Beach and Dune Sand, lies extending towards south. To the East of Beach and Sandstone, there lies another narrow zone of Boka Bil Formation of Neogene age. A slight narrow zone Tipam Sandstone of Neogene age forms the Eastern side of BokaBil zone. Along the East of Tipam Sandstone zone, another formation of Bedrock from Tipam Group that is Girujan Clay of Pleistocene and Neogene age lines. The North Eastern boundary of the town consists of Alluvial Deposits of Valley Alluvium and Colluvium. The south eastern part of the town has basically Dihing Formation Bedrock which is characterized as yellow to yellowish-grey, massive, fine to medium grained poorly consolidated sandstone and clayey sandstone. Dupi Tila Formation of Pleistocene and Pilocene age lies to the south of Dihing Formation which might have a slight influence in the surface geology of the city. Dupi Tila is characterized as yellow to ochre, pink, light-brown, light-grey to grayish-white or bluish-grey sandstone, siltstone and conglomerate.




| Lithostratigraphic Units and Descriptions | |
|---|---|
| csd | Beach and Dune sand (Coastal deposit- Holocene Sediment) |
| QTdi | Dihing Formation (Pleistocene and Pilocene- Bedrock) |
| Tt | Tipam Sandstone (Neogene- Bedrock : Tipam Group ) |
| ava | Valley alluvium and colluviums (Coastal deposit- Holocene Sediment) |
| QTg | Girujan Clay (Pleistocene & Neogene- Bedrock : Tipam Group) |
| Tbb | Boka Bil Formation (Neogene- Bedrock : Tipam Group ) |
| QTdt | Dupitila Formation (Pleistocene and Pilocene- Bedrock) |

Figure 1 Geology of Cox's Bazar Municipal (after Alam et al, 1990)

## 3. SEISMOTECTONIC SETUP

The generalized tectonic map of Bangladesh and adjoining areas is given in Figure 2. The junction between the platform and the fore deep running southeast from Mymensingh to Calcutta (the Hinge line) is considered to be a zone of weakness. Some major earthquakes can be related to the Dauki fault which terminates the fore deep in the Northeast. Most recorded earthquakes had epicenter further East in Burma. The Himalayan arc can be regarded as one of the most intensely active seismic regions in this area. In Northeast India, the Shillong plateau and adjacent syntax is between the two accurate structures are one of the most unstable regions in the Alpine-Himalayan belt. Earthquake data suggest that the basement of the Indian plate below the Indo-Burma ranges is moving north. Thus the shortening in the overlying rocks is partly decoupled from the basement. The Main Boundary Thrust (MBT) fault initiated in late Miocene or Pliocene time is regarded as the present thrust front of the Himalayas and forms the northern margin of the Himalayan foredeep. Bengal Basin is bounded on the East by the western fold belt of the Indo-Burma ranges. The northern and the Central portion of this fold belt are seismically active. Tripura fault zone is characterized by the high concentration of earthquake events. A number of morphotectonic lineaments have been identified. Among these the Kopili lineament trending NW-SE is remarkable. At the north of this zone Halflong-Dissang thrust is present. Morphotectonic lineaments around the Halflong-Dissang thrust zone trend NE-SW, E-W and NW-SE. Mikir hill is present to the northeast corner of the Halflong-Dissang thrust, which separates the Shillong plateau by Kopili fault.

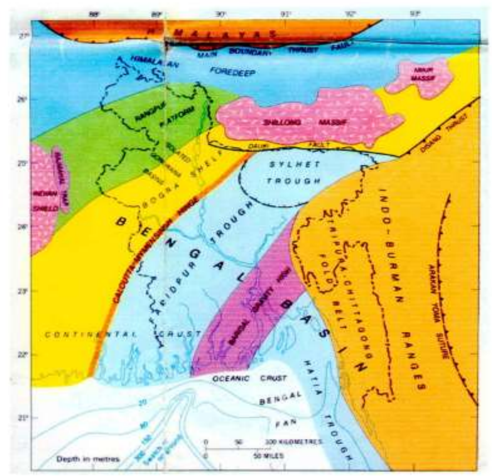



Figure 2 Generalized tectonic map of Bangladesh and adjoining areas (after GSB, 1991)

## 4. REGIONAL TECTONICS

According to Molnar and Tapponier (1975), for the past 40 million years the Indian subcontinent has been pushing northward against the Eurasian plate at a rate of 5 cm/year, giving rise to the severest earthquakes and most diverse land forms known. Figure 3 shows continued drift of the Indian plate towards the Eurasian plate. Recently, Bilham et al. (2001) pointed out that there is high possibility that a large earthquake may occur around the Himalayan region based on the difference between energy accumulations in this region. There is a seismic gap that is accumulating stress, and a large earthquake may occur some day when the stress is relieved. Figure 3 shows the estimated slip potential along the Himalaya. The major earthquakes that have affected Cox's Bazar area are presented in Table 1.

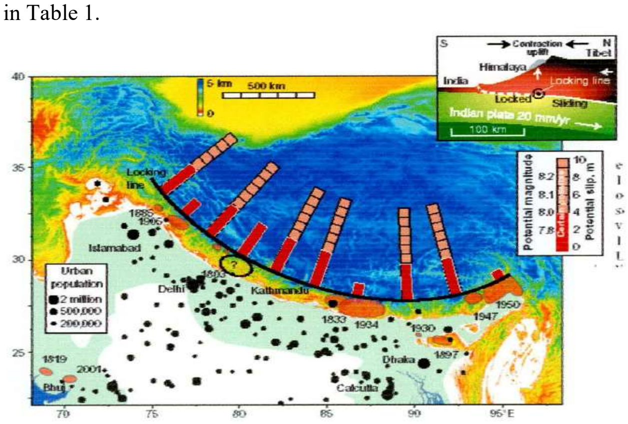



Figure 3 Estimated slip potential along the Himalaya (after (Bilham et al., 2001)

Table 1 Large earthquakes in and around Cox's Bazar

| Year | Name | Epicentre | Magnitude (M) |
|---|---|---|---|
| 1762 | Arakan Earthquake | 50 km northwest of Cox's Bazar | 8.5 |
| 1858 | Prome Earthquake | Sandaway, Myanmar | 7.0 |
| 1912 | Mandalay Earthquake | Sagaing, Myanmar | 7.7 |
| 1956 | Sagaing Earthquake | Sagaing, Myanmar | 7.1 |
| 1997 | Bandarban Earthquake | Ruma, Bandarban | 6.0 |
| 1999 | Moheskhali Earthquake | Moheskhali Island | 5.1 |

## 5. DATA COLLECTION

A total of 26 borelogs were used in this study. SPT were carried out in each boring at nominal 1.5 m intervals to study site amplification as well as soil liquefaction potential characteristics of municipality area. Among them, twelve subsoil investigations were carried out by the first author (Imtiaz, 2009). The other fourteen borelogs up to a depth of 30 meters were collected from a research project on Cox's Bazar District (Dhar et. al. 2008). Figure 4 shows 26 borehole locations.

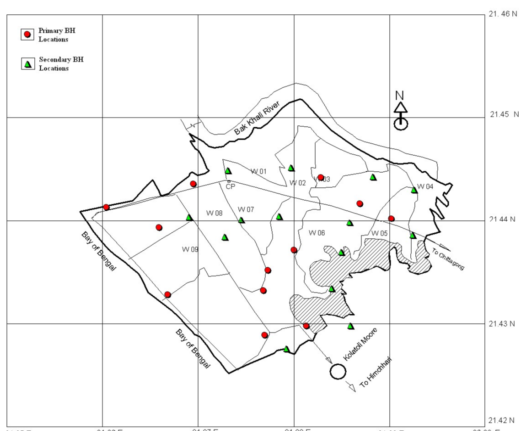



Figure 4 Cox's Bazar municipal area map showing soil borehole locations

At entire area under Cox's Bazar Municipality necessary data such as subsoil reports and geology, topography etc was collected from different relevant sources. The GPS locations of all the borehole investigation points and hill soil samples have been presented on the digitized municipality map and were saved in MS Excel. For assessment of landslide potential Geological Map and Aerial Photograph were not available in the concerned authorities' office considering this limitation this study was carried out.

For slope stability analysis, hilly regions of this area have been surveyed and data of location, height, and slope have been collected (see Figure 5). Where eleven disturbed samples from different locations of the municipal area were collected for laboratory investigations including specific gravity test, grain size analysis, Atterberg limits, Standard compaction test and direct shear test.

## 6. ASSESSMENT OF SEISMIC HAZARD

The first step in reducing the risk of the society from earthquake hazard is the assessment of the hazard itself. Seismic microzonation map for strong-ground shaking, liquefaction, and landslide can play a significant role in mitigating the effects of earthquake in urbanized regions. The seismic hazard evaluation at a specified site depends upon the definition of the following four models:

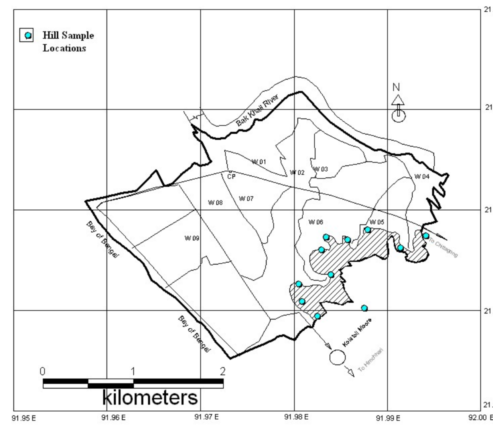



Figure 5 Soil sample locations for estimation of landslide potential

Earthquake source model: It is based on geological evidence, Seismic sources are identified and modelled as a point, line, area or dipping plane. In this study, a point source model is used.

Seismicity model: The seismicity of each of the modeled sources is first determined from past data available. The recurrence relationship relating the size of the past events in terms of Magnitude (M) and Peak Ground Acceleration (PGA) is derived, the seismicity model used in Molas and Yamazaki (1994) is usually taken as

$$\log(v) = a + b*M \quad (1)$$

$$\log(v) = a + b*\log(y) \quad (2)$$

Where M is the earthquake magnitude and y is the peak ground acceleration. v is occurrence rate per year and a and b are regression constants. These relations can be written as

$$M = (-\log(T) - a)/b \quad (3)$$

$$\log(y) = (-\log(T) - a)/b \quad (4)$$

where $T$ (=1/v) is the return period in years. Thus, the above equations represent magnitude and the peak ground acceleration for a return period of $T$ years.

Attenuation model of ground motion: This describes the transfer of ground motions from the source to a particular site as a function of magnitude, distance and soil conditions. Here, the peak ground acceleration is used to characterize the ground motion; the attenuation law is in the form

$$\log(y) = b_1 + b_2\,(Ms) - b_3 \log(r) - b_4\,(r) \quad (5)$$

where,

$r^2 = d^2 + h^2$,

$r$ = the hypo central distance (km),
$d$ = the epicentral distance (km),
$h$ = the focal depth and Ms is the surface-wave magnitude.

The attenuation law is required to determine the peak ground acceleration at the site for different events and then to determine the regression constants $a$ and $b$.

Recurrence forecasting model: For practical purposes, earthquakes are considered to be random events, and the Poisson process is used, which implies assumptions of stability and independence over time. For a Poisson process this may be expressed as

$$p = 1 - exp(-vt) \quad (6)$$

where,
v = the mean annual occurrence rate of events of particular peak ground acceleration over a given time t.

The most common method involves the use of an empirical attenuation relationship. These relationships express a given ground motion parameter in a region as function of the size and location of an earthquake event. The evaluation of seismic hazard at a site is carried out only if the number of earthquakes in the area considered (200 km radius) is larger than 10 and the surface-wave magnitude is equal to or greater than 4.0. In this study evaluation of seismic parameter has been carried out using the seismic data over an area having a 250 km radius around Cox's Bazar Municipal area (see Figure 6).

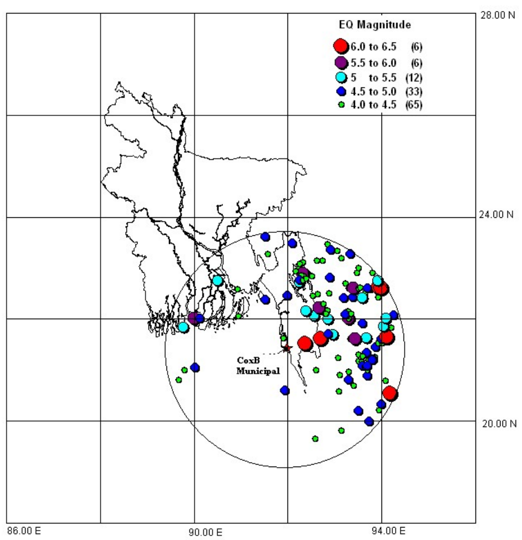



Figure 6 Historical Earthquakes around Cox's Bazar Municipality

### 6.1 Selection of Attenuation Law for Peak Ground Acceleration

To select the most suitable attenuation law for predicting rock motions, the formula adopted in the previous studies were followed (Sabri 2001, Sharfuddin 2001). From these studies, it was found that McGuire (1978) as well as Joyner and Boore (1981) equations follow the PGA trend of most large earthquakes in and around Bangladesh. Since, McGuire equation was already used for Bangladesh for seismic hazard analysis (Sharfuddin, 2001) and due to its simple form, it was selected for further use. The attenuation laws for rock used in this study, are presented below:

$$\text{PGA (from McGuire)} = 0.0306e^{0.89M}r^{-1.17} \quad (7)$$

$$\text{PGA (from Joyner \& Boore)} = 0.0955e^{(.573\mathbf{M})}\,d^{-1}e^{(.\mathbf{0.0058})} \quad (8)$$

Where,
M = Earthquake Magnitude,
d = Epicentral Distance,
r = Hypocentral Distance and
h = Depth

### 6.2 Regression Analysis

Seismic parameter b was evaluated from G-R relationship (Gutenberg and Richter.1944), a method utilizing extreme, instrumented and complete catalogs. Linear regression was applied to each site which is taken as the centre of an area of 250 km radius where past earthquakes are likely to occur again. The hazard curves of Mean Annual Rate of Exceedance (v) versus Peak Ground Acceleration (PGA) and Mean Annual Rate of Exceedance (v) versus Earthquake Magnitude (M) were generated at the rock levels. The hazard in terms of the rock level PGA values and probable earthquake magnitude corresponding to return periods of 200 years are quantified from equation 3 and 4 as, 0.18g and 8.3 consecutively. Since the largest Magnitude earthquake around the 350-450 km radius of the study area exceeds 7.9 and around 250 km radius is 6.5, a cut-off Magnitude of 7.5 earthquake was considered as the expected one in 200 years return period and thus used for further analyses.

## 7. SITE AMPLIFICATION ANALYSIS

For site amplification, in this study, the engineering bedrock was assumed to be the layer at which the shear wave velocity (Vs) exceeds 400 *m/s,* which exist almost 30 m deep from the surface of the study area. The calculations show that the shear wave velocities at bedrock level vary from 400 *m/s* to 500 *m/s.* Vibration characteristics plotted as transfer functions at different points of the study area were estimated by employing one dimensional wave propagation program SHAKE. The computations were made in the frequency range 0 to 20 Hz at frequencies every 0.05 Hz interval. The loss of energy of seismic waves in the soil layers was also considered. The computed results from the site amplification potential analysis were exported to a GIS environment for further processing and visualization. They were classified into different classes according to the extent of amplification factors and plotted on the Cox's Bazar municipal map (see Figure 7).

From the site amplification study, the average amplification factor was found to be 2.3 and 1.7 respectively for extreme and average conditions. The rock level PGA for return period of 200 years was estimated as 0.18g. Thus the surface level PGAs calculated by multiplying the rock level PGA with amplification factor were 0.4g at extreme condition and 0.31 g considering AHSA.

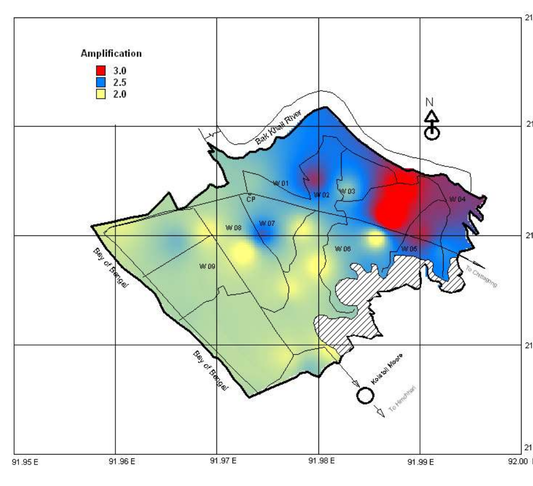



Figure 7 Microzonation map based on amplification at fundamental frequencies

## 8. LIQUEFACTION ANALYSIS

The first step in calculation of liquefaction potential is to determine whether the soil has the potential to liquefy during the earthquake. This analysis is usually carried out by using simplified empirical procedure, originally developed by Seed and Idriss (1971). Since the largest earthquake magnitude has been considered as 7.5, the relevant Magnitude Scaling Factor (MSF) was selected as 1.0. The Factor of Safety against Liquefaction for earthquakes other than that of magnitude 7.5 and calculated as

$$FS = FL = \frac{CRR7.5}{CSR} MSF \quad (9)$$

Where,
CRR7.5= Cyclic Resistance Ratio for the earthquake of magnitude 7.5
CSR= Cyclic Stress Ratio

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 FL. Liquefaction under the following condition tends to be severe:

I. The liquefied layer is thick
2. The liquefied layer is shallow
3. The FL of the liquefied layer is far less than 1.00

In this method, the factor of safety values, FL (Seed and Idriss, 1971) against resistance to liquefaction have been computed up to top 20 meters depth for all the boreholes and these values have been subsequently converted into liquefaction potential index (IL) given by the following equation (Iwasaki et al., 1982):

$$IL = \int_0^{20} F(z)w(z)dz \quad (10)$$

Where,
F(z)= (1- FL); for FL ≤1.0
F(z)= 0; for FL >1.0
W (z)=(10-0.5z); for z≤20 m
W(z)= 0 ; for z>20m

The value of liquefaction potential, IL indicates that a soil mass is susceptible to liquefaction if IL >0 If the value of IL is large, the soil is very susceptible for liquefaction. Severity of liquefaction is then expressed as shown below:

IL =0; No liquefaction
=0-5; Low liquefaction
=5-15; Moderate liquefaction
= >15; High liquefaction

IL has been used to express the measure of liquefaction potential for a particular location and for further zonation of the area based on a particular range of this index. Table 2 shows the interpretation of liquefaction potential in terms of intensity and ground susceptibility.

Table 2 Summary of the liquefaction potential index (after Iwasaki et al., 1986)

| Liquefaction Potential | Criteria | Explanation |
|---|---|---|
| High | 15< IL | Ground Improvement is indispensable |
| Moderate | 5< IL≤ 15 | Ground Improvement is required. Investigation of important structure is indispensable |
| Low | 0< IL≤ 5 | Investigation of Important structure is required. |
| Very low | IL=0 | No measure is required. |

Liquefaction resistance factor, FL, for the top 20 m of soil, and the resulting liquefaction potential IL for the 26 sites was calculated. The flow chart of liquefaction analysis used in this study and the result of Liquefaction potential was provided in tabulated form. The computed results from the liquefaction potential analysis were exported to a GIS environment and plotted on the Cox's Bazar district map dividing the study area into different zones according to the ranges of liquefaction potential index values (Table 2). Thus microzonation maps were developed for liquefaction potential as shown in Figure 8.

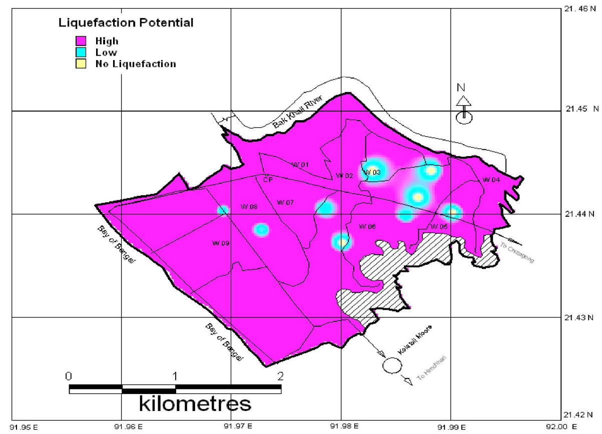



Figure 8 Microzonation map based on regional distribution of liquefied areas

## 9. LANDSLIDE POTENTIAL ANALYSIS

The overall stability failure mechanism is development of slip circles resulting in deep sliding surface which is a conventional soil mechanics stability problem. Preexisting slip planes within the soil, cracker material can have a significant effect on slope stability. Stability analysis is carried out to evaluate the factor of safety against bearing capacity failure. The program used for stability analysis is XSTABL which is a fully integrated slope stability analysis program. The landslide potential was categorized as 'high' and 'low" for Factor of Safety being greater than or equal to 1.2 and less than 1.2 consecutively. The corresponding Factor of Safety values have been exported to GIS and plotted on the Cox's Bazar municipality range. Thus the microzonation map based on landslide potential was developed as shown in Figure 9.

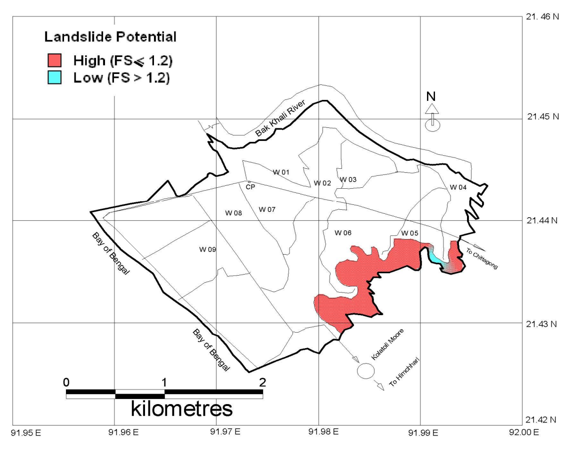



Figure 9 Microzonation map based on landslide potential in Cox's Bazar Municipality area

## 10. SEISMIC HAZARD INTEGRATION

The most important endeavor of this study was the estimation of seismic hazards linked with the local site attributes of soil amplification, liquefaction, and landslide and then integrating them in such a manner so that a reflection of probable actual disaster consequences can be represented. It is not feasible to resolve how much of the potential hazard is discretely attributed by each local site effect; consequently the ultimate regional seismic hazard distribution is established on a weighted average combination of the hazards related with each effect.

The rules for combining the various hazards were based on expert opinion (Stephanie and Kiremidjian, 1994) about the relative accuracy of the hazard information and the behavior of the local geology. It was assumed that the final combined seismic hazard would be quantified in terms of Modified Mercalli Intensity (MMI). At the end, different possible hazards were integrated to investigate the combined effects of more than one hazard. The results of the combined hazard analysis were summarized in Table 3.

Table 3 Final Combined Intensity and affected areas for different hazard combinations

| Combined Intensity (MMIF) | Combination of Possible Hazards | Area (%) |
|---|---|---|
| X | 2.0 times Amplification + High Liquefaction | 43.12 |
| | 2.5 times Amplification + High Liquefaction | 35.40 |
| | 3.0times Amplification + High Liquefaction | 7.72 |
| | 2.0 times Amplification + High Landslide | 1.65 |
| | 2.5 times Amplification + High Landslide | 6.25 |
| IX | 2.5 times Amplification + Low Liquefaction | 0.93 |
| | 3.0 times Amplification + Low Liquefaction | 2.75 |
| | 2.5 times Amplification + Low landslide | 0.23 |
| VIII | 2.0 times Amplification + Low Liquefaction | 1.95 |

## 11. CONCLUSION

This study proposed a methodology for seismic hazard assessment for Cox's Bazar, Bangladesh. In this study, seismic microzonation maps were developed on the basis of potential of earthquake occurrences and ground susceptibility to earthquake. SPT data from 26 boreholes were used to study site amplification as well as soil liquefaction potential characteristics. Using historical seismicity records and attenuation laws of Peak Ground Acceleration (PGA), the bedrock PGA was estimated as 0.18g for magnitude 7.5 earthquake with 200 years return period. The surface PGA was calculated as 0.41g and 0.31g adopting on First Peak Amplification and Average Horizontal Spectral Amplification, respectively. The liquefaction potential of the boreholes points were assessed by including these PGAs. Landslide potential was assessed using a slope stability program. The results obtained from these three analyses, were developed in GIS environment and were presented in the form of microzonation maps. The final combined hazard ($MMI_F$) is computed as a weighted sum of those three hazards.

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