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OFFICE FOR URBAN SAFETY

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INSTITUTE OF INDUSTRIAL SCIENCE
THE UNIVERSITY OF TOKYO

# BNUS ANNUAL REPORT - 2009

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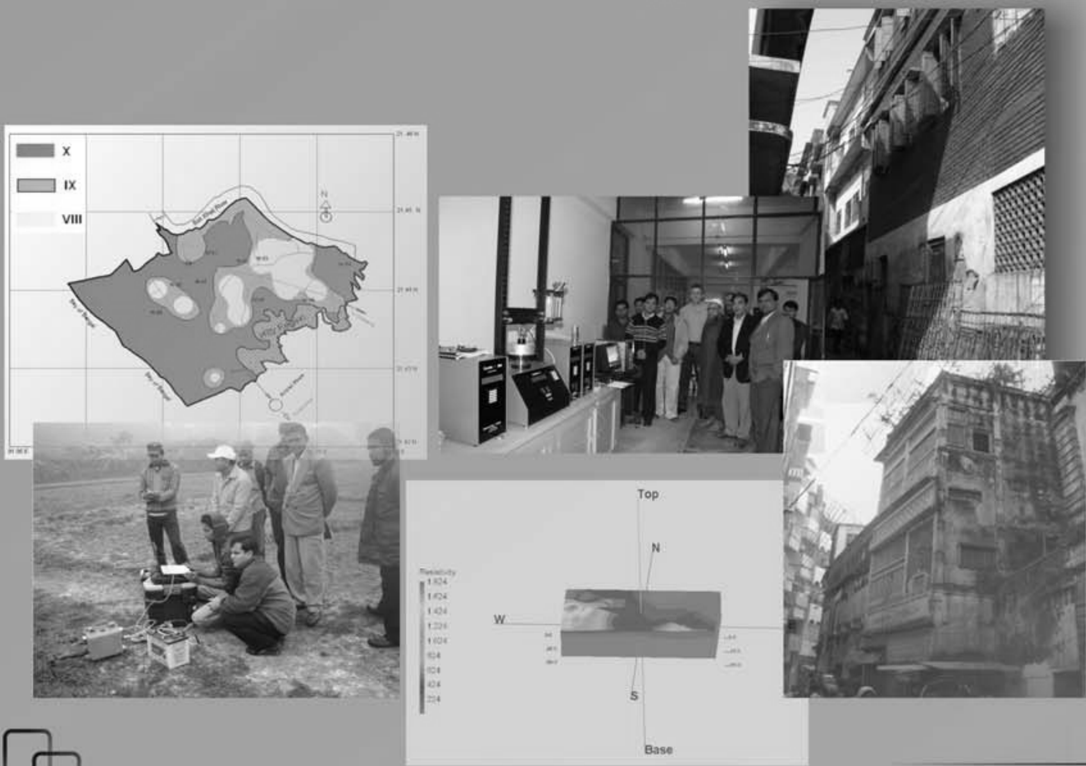
# BNUS Annual Report-2009

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# PART-I

# SEISMIC MICROZONATION OF COX'S BAZAR MUNICIPAL AREA

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# ABSTRACT

The purpose of this study is to develop geotechnical microzonation maps using Geographical Information Systems (GIS). Cox's Bazar Municipal Area, located in the Southeastern region of Bangladesh, beside the Bay of Bengal, has been chosen as the study area. The model inputs include site amplification, liquefaction potential study and slope stability analyses. It is now well known, and widely accepted amongst the earthquake engineering community, that the effects of surface geology on seismic motion exist and can be large. Nearly all recent destructive earthquakes have brought additional evidence of the dramatic importance of site effects. Accounting for such "site effects" in seismic regulations, land use planning or design of critical facilities thus has become one goal of earthquake hazard reduction programs.

Cox's Bazar area, having been a great tourist resort, has experienced a rapid urbanization in the last few decades including various establishments, construction of significant number of buildings and other structures in an unregulated manner and without seismic design considerations. Landslide and related casualties have also become very common in the hilly areas of the locality. In order to assess seismic vulnerability based on ground susceptibility and adopt mitigation strategies for urban areas, seismic microzonation is considered to be the first step. This study deals with the microzonation of the Cox's Bazar Municipal Area using geographic information system (GIS) where reflection of ground shaking and the site attributes of soil amplification, liquefaction and landslide are the salient features. The probable earthquake hazard and expected ground motion for this area were assessed using probabilistic approach. The liquefaction potential was estimated from Standard Penetration Test (SPT) following the methods suggested by Seed and Idriss combined with Japanese Code of Bridge Design. SHAKE analysis was performed for estimation of 1D site amplification. Slope stability analyses were performed for samples from the hilly regions of the area using the program XSTABL. The results obtained for site amplification, liquefaction and landslide potential were exported in GIS environment and presented as microzonation maps.

The findings of the study show that the rock level Peak Ground Acceleration (PGA) of the area is 0.18g for a 7.5 magnitude earthquake having a return period of 200 years. The surface PGA could be as high as 0.41g for an average 2.3 times amplification factor if extreme or most severe condition is considered. For this, ground shaking amplified by 2, 2.5 and 3 times

can affect 47%, 42% and 11% of the municipal area respectively. 87% of the study area is highly susceptible to liquefaction and approximately 8% of the municipality consists of hilly region whose 97% is very unsafe regarding natural slope stability. On the other hand, surface PGA will be 0.31g for an average amplification factor of 1.7 if a refined hazard condition is assumed based on average horizontal spectral acceleration technique. 89% area will be affected by 1.7 times amplification of ground shaking and 58% area will be prone to high liquefaction potential. 96% of the hilly region will become vulnerable if high landslide associates with only 1.7 times amplification of ground shaking.

### 1.1 Background

Bangladesh runs a high risk of experiencing earthquakes due to her geological and tectonic structures. The northern region of Bangladesh lies above the seam of the Indian and Eurasian tectonic plates and the eastern part is above the joint of the Burmese and Indian plates. The Indian plate is edging north-east while the Burmese plate is moving north-west. The country's position adjacent to the very active Himalayan front and ongoing deformation in nearby parts of south-east Asia expose it to strong shaking. In the recent past, a good number of tremors of moderate to severe intensity had already taken place in and around Bangladesh. Cox's Bazar, located in the southeastern part of Bangladesh, is a strategically and economically important area of the country. The district is exposed to the most devastating natural disasters of the country. In the seismic zoning map of Bangladesh, provided in BNBC (Bangladesh National Building Code 1993), Cox's Bazar has been shown under Zone II with design Peak Ground Acceleration (PGA) value of 0.15g (Z=0.15). This level of acceleration may be considered as more or less equivalent to a seismic intensity between VII and VIII. Historical information reveals that earthquakes of magnitude between 6 and 7 have occurred around the area in the past. Thus Cox's Bazar and the nearby area are considered to fall in the High Risk Zone for earthquakes. The frequent earthquakes in and around the country, particularly Chittagong and Cox's Bazar regions, also point toward the potential of such intensity earthquakes, even much higher than that projected. Therefore, it is essential to assess the earthquake hazard and related secondary effects for the region in order to aid the earthquake risk mitigation efforts.

Cox's Bazar, having been a great tourist resort, a rapid urbanization has occurred in the last few decades including various establishments, construction of significant number of buildings and other structures in an unregulated manner and without seismic design considerations. The consequences of moderate to strong earthquake event can be catastrophic if such a densely populated urban area is affected and may have very severe long-term consequences for the entire country.

One of the major concerns during an earthquake is the presence of vulnerable soil near the ground surface. In order to assess seismic vulnerability based on ground susceptibility, seismic microzonation is considered to be the first step towards a seismic risk analysis and mitigation strategy for urban areas. Therefore this study deals with the microzonation of the Cox's Bazar Municipal Area based on liquefaction potential, site amplification and land slide potential. Figure 1.1 shows the location map of Cox's Bazar Municipal area.

Liquefaction phenomena can affect buildings, bridges, buried pipelines, lifelines and other constructed facilities in many different ways. Cox's Bazar is mostly a hilly region consisting of alluvial flood plain and sandy sea shore area. The area bottom of the hill can liquefy if the intensity of shaking is high, which may cause land slide in the hilly region. On the other hand floodplains and sea shore areas consisting of fine sand and silt deposit with shallow water table in most of the places may liquefy during a strong earthquake.

Site Amplification is an important basis of microzonation. The basic intention of amplification assessment is to estimate the effect of local site conditions through the site response analysis. This factor is highly dependent on the local soil conditions and on the expected earthquakes. Local soil effects can amplify the ground motion and thus lead to intensity greater than the projected ones in certain areas causing more damage. In the urbanization process it has become a common practice to fill up many low lying lands or shallow water bodies in the town area for construction. The filled soils in many cases are not properly compacted or consolidated. Furthermore, the low lying lands may also possess soft soils. These soft soil sites may cause amplification and modification of ground motion, producing larger seismic forces in buildings. Cox's Bazar area is also characterized by a significant amount of sediment and landfill, which may greatly amplify seismic waves and is another issue of concern for studying the site effects.

Landslide has become very common in the hilly areas of southeastern Bangladesh, especially in Bandarban, Rangamati, Khagrachhari and Cox's Bazar. Illegal hill-cutting due to rampant building has left some 70,000 (IRIN, 2008) people at risk of landslides in 18 sub-districts of the hill districts, as well as the city of Chittagong, warned specialists. Every year especially in the rainy season landslides take place in both natural and man-induced slopes. Considerable number of buildings, roads and other infrastructures are damaged and valuable lives are lost in these incidents. The loss of lives and properties due to landslide events in Cox's Bazar is also very significant. Now time has come to find out the cause of such events in the area and to take necessary preventions to avoid repeated casualties. Therefore assessment of landslide potential of Cox's Bazar has become very essential. Indiscriminate Hill cutting is one of the major causes of landslide. Landslide may be caused by earthquake in steep hill and loose land of steep periphery. Gentle angle or slope is mostly absent in the hills of Cox's Bazar due to human activities. Rock strata in this area are mostly found as soft or brittle sedimentary rocks which may easily be broken or slide. Since Cox's Bazar is on the threat of probable earthquake events, the hill-tops loosened by any means can cause massive destruction if a moderate to major tremor takes place.

Seismic hazard due to local site effects such as soil amplification, liquefaction, and landslide can be estimated by combining the available soil parameter data with the current hazard status of the region. Moreover, for accomplishing comprehensive regional hazard assessment, geographic information system (GIS) provides a perfect environment. Therefore this study deals with the microzonation of the Cox's Bazar Municipal Area using geographic information system where reflection of ground shaking and the site attributes of soil amplification, liquefaction and landslide are the salient features. Microzonation maps can be used for planning locations and construction of future facilities. 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. Microzonation maps presented on a GIS platform provides the results of a regional seismic hazard and risk analysis that serve as an effective means of transferring information from the scientific community to the professional community of decision makers involved in hazard and risk mitigation. Hence these zonation maps will add value in planning of the coastal town Cox's Bazar by helping in finalizing design of many important structures and saving construction time and cost.

### 1.2 Objectives of the Study

The goal of the study is to develop maps showing local site effects such as the liquefaction potential, site amplification and landslide potential for Cox's Bazar Municipal area in Bangladesh. The following are the specific objectives of the research:

1. To compile a subsoil investigation database for different locations of Cox's Bazar Municipal area
2. To determine the Site Amplification of the Area based on 1D-SHAKE analysis
3. To determine the Liquefaction Potential of the Area based on Geology, standard penetration test (SPT) and laboratory test results.
4. To demarcate the regions susceptible to Landslides due to natural slope instability
5. To determine the combined effects of the aforementioned hazards to ground shaking.
6. To present the results of the study in GIS based Maps.

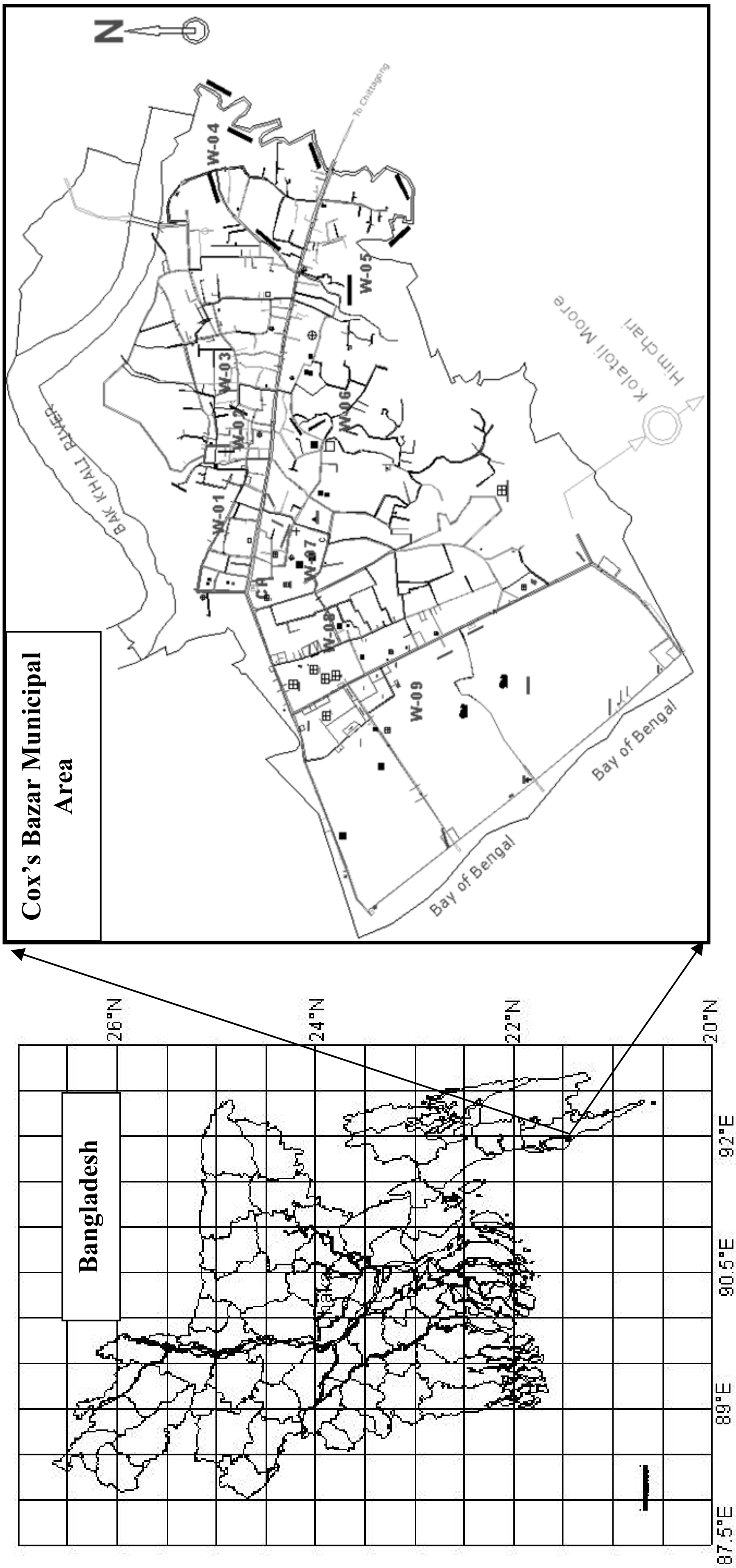



Figure 1.1: Location map of study area

### 1.3 Methodology of the Study

Bore-hole soil data, geophysical measurements, historical data, reports and published papers have been used to identify the vulnerable locations and estimate necessary soil parameters. Standard analytical methods have been used to develop site amplification scenarios, liquefaction potential and landslide potential of Cox's Bazar district. Figure 1.2 shows the methodology adopted for this study.

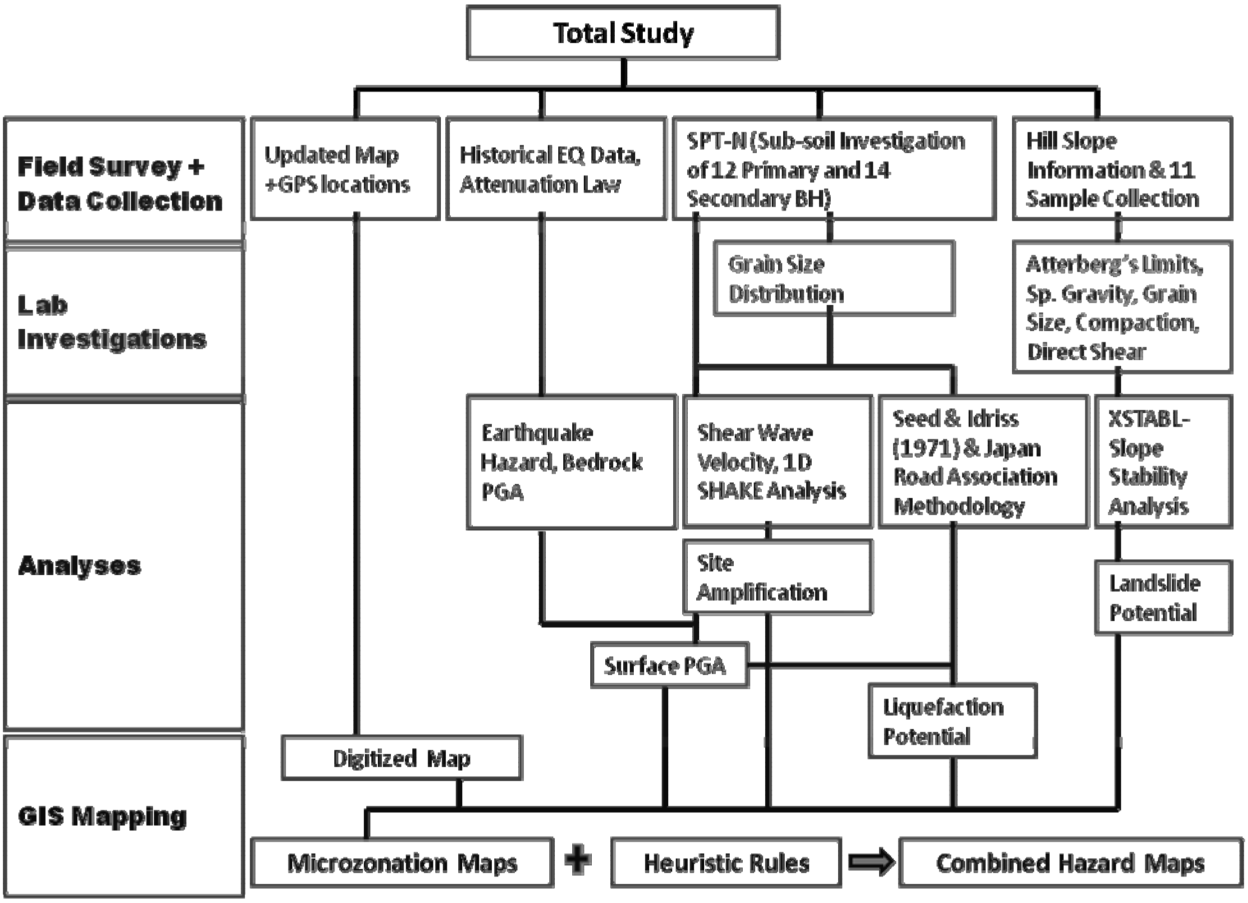



Figure 1.2: Methodology of the study

### 2.1 Overview of the Study Area

Cox's Bazar is a town; a fishing port and a district headquarter in Bangladesh. It is known for its wide sandy beach which is claimed to be the longest natural sandy sea beach in the world. It is located along the Bay of Bengal in Southeastern Bangladesh and 150 km south of Chittagong. Cox's Bazar derives its name from Captain Cox, an officer serving in British India. Cox's Bazar thana was first established in 1854 and the municipality was constituted in

1869 (Banglapedia, 2004). In 1959 the municipality was turned into a town committee. The town committee was replaced by municipality in 1972 and it was elevated to B grade in 1989.

Cox's Bazar municipality covers an area of 6.85 sq km with 27 mahallas and 9 wards, is located at 21.58333°N 92.01667°E and bounded by Bakkhali River on the North and East, Bay of Bengal in the West, and Jhilwanja Union in the South. Population of the area is 51918 (BBS, 2001). As one of the most beautiful and famous tourist spots of Bangladesh, the major source of economy of Cox's Bazar is tourism. Millions of foreigners and Bangladeshi natives visit this coastal town every year. Therefore, a number of hotels, guest houses, and motels have been built in the town and coastal region.

### 2.2.1 Geomorphology of Cox's Bazar District

The district of Cox's Bazar is bounded on the west and south by the Bay of Bengal, on the east by the hill ranges of elevation around 100-200 m. Basin of Matamuhuri River and Bakkhali river form the morphological pattern on the North of the district. The landmass of the district of Cox's Bazar includes two distinct geological settings namely Tertiary folded belt and coastal deposits. The tertiary folded belt extends north-south as part of the Indo-Burmese mobile belt, which is characterized by long narrow folds (Alam et al., 1990). Flood plain and coastal deposit of Holocene age overlies late Tertiary formations at places presenting the surface form. The present day morphology of the area are believed to be influenced by the Holocene sea level rise, tidal and fluvial discharges and very special type of physical set up of the plain around Tertiary Hills (Huq and Ahmed, 1997).

Alam et al. (1999) present the morphology of Cox's Bazar coastal plain as shown in Figure 2.2. The schematic cross-section shows that the plain is elevated landward and gradually slope toward the sea. The elevation of the marginal part of the plain is of the order of 2 to 3 m above mean sea level. The characteristics of different landforms are shown in Table 2.1. Table shows that sediment of the plain varies from very fine silt to medium sand with finer particles at the flood plain and largest grain size for tidal creeks.

Table 2.1: Landform Characteristics of the Cox's Bazar Coastal Plain (after Alam et al., 1999)

| Feature | Height | Slope | Processes | Width | Mean Grain Size |
|---|---|---|---|---|---|
| Flood Plain | 5 | <1° | Mainly fluvial origin, flash flood and occasional marine wash over, minor rills are common | <5->3 km | Very fine sand to silt |
| Dunes | 3-4 | >10° | Undulating, develops parallel to the flood plain | highly variable | Fine Sand |
| Beach | 2-3 | 4°-6° | Wave and wind actions are predominant with occasional storm surge induced flooding | <200m to >500m | Medium to Fine sand |
| Mudflat | ≤1 | <1° | Subject to erosion and accretion through regular tidal action and periodically submerged | 50-200m | Clay to silty clay with very fine sand intercalations |
| Spit | 1-2 | Most cases steep, varies from 2°->4° | Exposed to wave and wind action and submerged to high spring tide | <50m from the ridge | Fine sand to silty clay |
| Tidal creek | 0.5-1.5 | Slopes gently down sea-ward | Limited wave action and exposed to regular tidal exchange | <10 m to 150m | Medium sand with occasional clay intercalation |

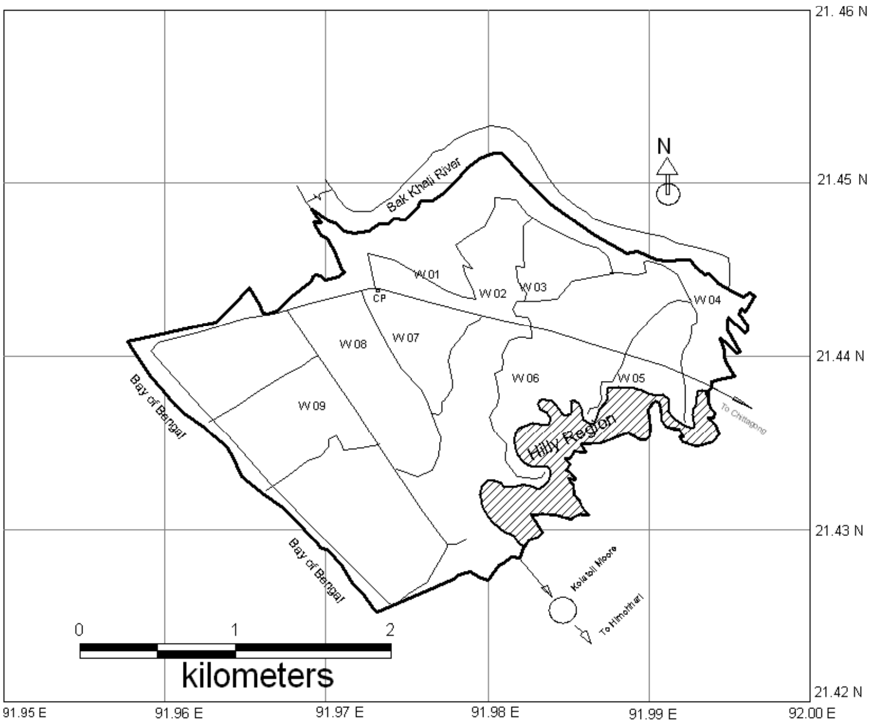



Figure 2.1: Map showing 9 wards in Cox's Bazar Municpal Area

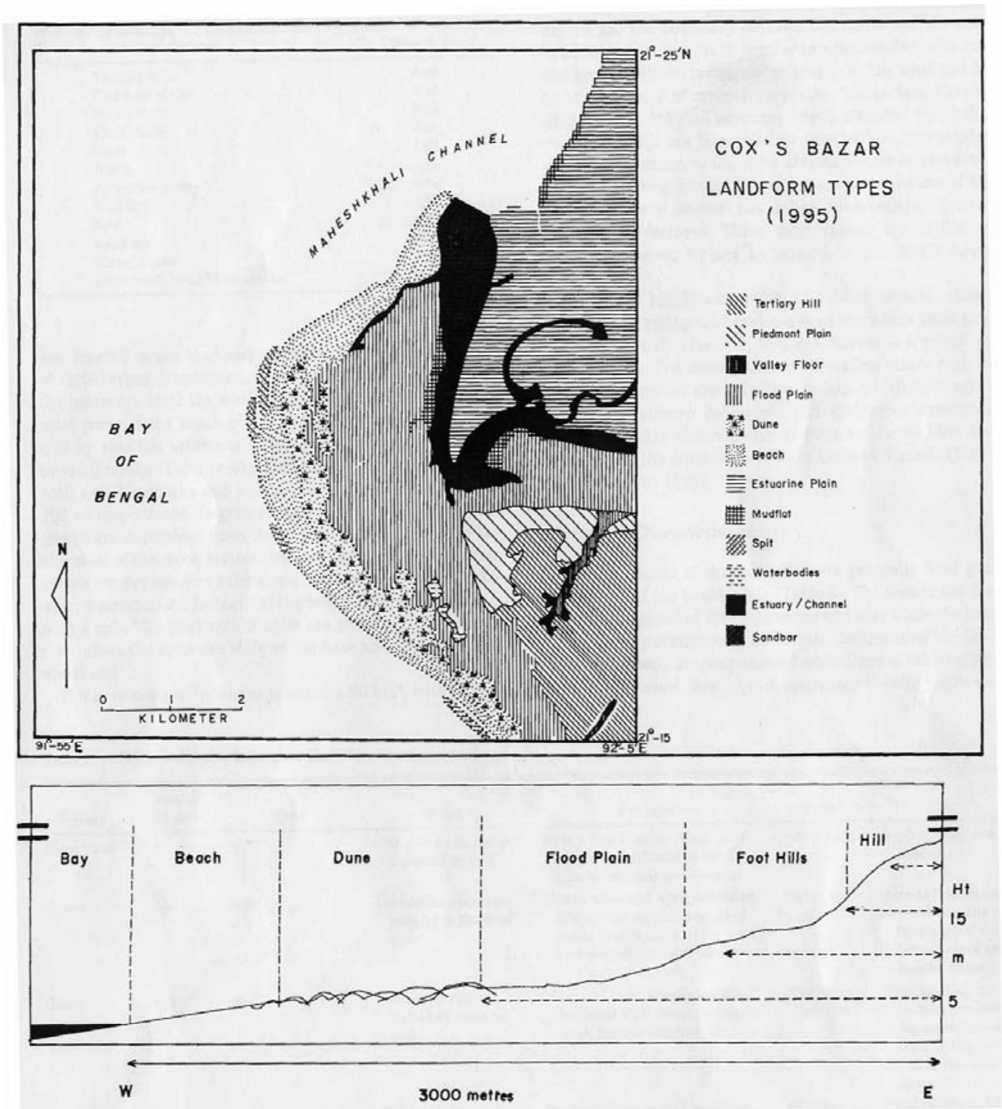



Figure 2.2: Morphology of Cox's Bazar Sadar (Alam et al., 1999)

### 2.2.2 Geology of Cox's Bazar Municipal 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 2.3 shows the Surface Geology of Cox's Bazar Municipal area according to the Geological Map of Bangladesh (after Alam et al., 1990). The Western Figure reveals that the area around the Cox's Bazar municipality predominantly composed of Valley Alluvium and Colluvium and Dihing Formation of Pliocene-Pleistocene age. Rocks of the Pliestocene, 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. This is a narrow zone of Coastal Deposit along the western edge of the tectonically active Fold Belt. Beach and Dune Sand are characterized as light to whitish grey sand being medium to fine, well sorted, subrounded; containing concretion, shell fragments, heavy minerals, and rare clasts. It also includes small mud-flat deposits. This formation uncomfortably overlies Late Tertiary formations.

To the East of Beach and Sandstone, there lies another narrow zone of **Boka Bil Formation** of Neogene age. It is greenish to bluish-grey and yellowish grey shale, siltstone and sandstone. Sandstone is very fine to medium grained; flaser bedding and starved ripple marks are found to be very common. In the upper and lower parts of the formation, shale commonly dominates and is interbedded with siltstone and sandstone; middle part is dominated by massive, hard, locally calcerous, conglomeratic sandstone. Middle and lower parts contain calcareous lenses and concretions. It locally contains some fossiliferous beds as well.

A slight narrow zone **Tipam Sandstone** of Neogene age forms the Eastern side of Boka Bil zone. The layer is light yellow to yellowish grey, grey, brownish-grey, and orange, fine to medium-grained pebby sandstone, sub angular to sub rounded; siltstone, and shale; massive to thin-bedded, containing intraformational clasts and ferruginous concretions; soft and friable. It locally contains silicified wood and lignite. Upper and lower parts of the formation are predominantly sandstone; middle part is predominantly shale, silty shale and siltstone. The Neogene rock units represent sediments derived from the Himalayan and Shilong Plateau of India and derived from the Arakan-Yoma Mountains of Myanmar. These formations are probably time transgressive to the south and to the west; their lithology varies vertically and horizontally with distance from the source.

Along the East of Tipam Sandstone zone, another formation of Bedrock from Tipam Group that is **Girujan Clay** of Pleistocene and Neogene age lies. This zone is composed of Grey to greenish grey, red mottled, silty shale, shale and claystone and interbedded with subordinate thin-bedded siltstone and crossbedded sandstone. This formation contains calcareous claystone nodules, ferruginous sandy concretions, clay galls, quartzite pebbles, thin lignite beds, silicified wood and leaf impressions.

The North Eastern boundary of the town consists of Alluvial Deposits of **Valley Alluvium and Colluvium**. This formation consists of medium to dark-grey or light-brown silt, clayey silt, and fine to medium sand; locally contains coarse debris derived from local bedrock and organic matter. Colluvium is flushed into narrow valleys and reworked by alluvial processes. This unit is susceptoble to mass-movement processes such as landslides, earth slump and mud flows.

The south eastern part of the town has basically **Dihing Formation** Bedrock which is characterized by yellow to yellowish-grey, massive, fine to medium grained poorly consolidated sandstone and clayey sandstone. Mottled clay and pebble beds occur locally. In Fold Belt, pebbles are quartzite. It is highly weathered and contains silicified wood; ferruginous crust is present locally. 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 town. **Dupi Tila** is characterized as yellow to ochre, pink, light-brown, light-grey to grayish-white or bluish grey sandstone, siltstone and conglomerate. It is massive to thin bedded, containing quartz and shale pebbles, clay galls and pellets, silicified wood and lignite fragments. Upper part of the formation is dominated by fine to medium grained sandstone, subordinate thin beds of siltstone and claystone, intraformational siltstone breccias at top. Lower part is dominated by sandstone and the zone is locally crossbeded.

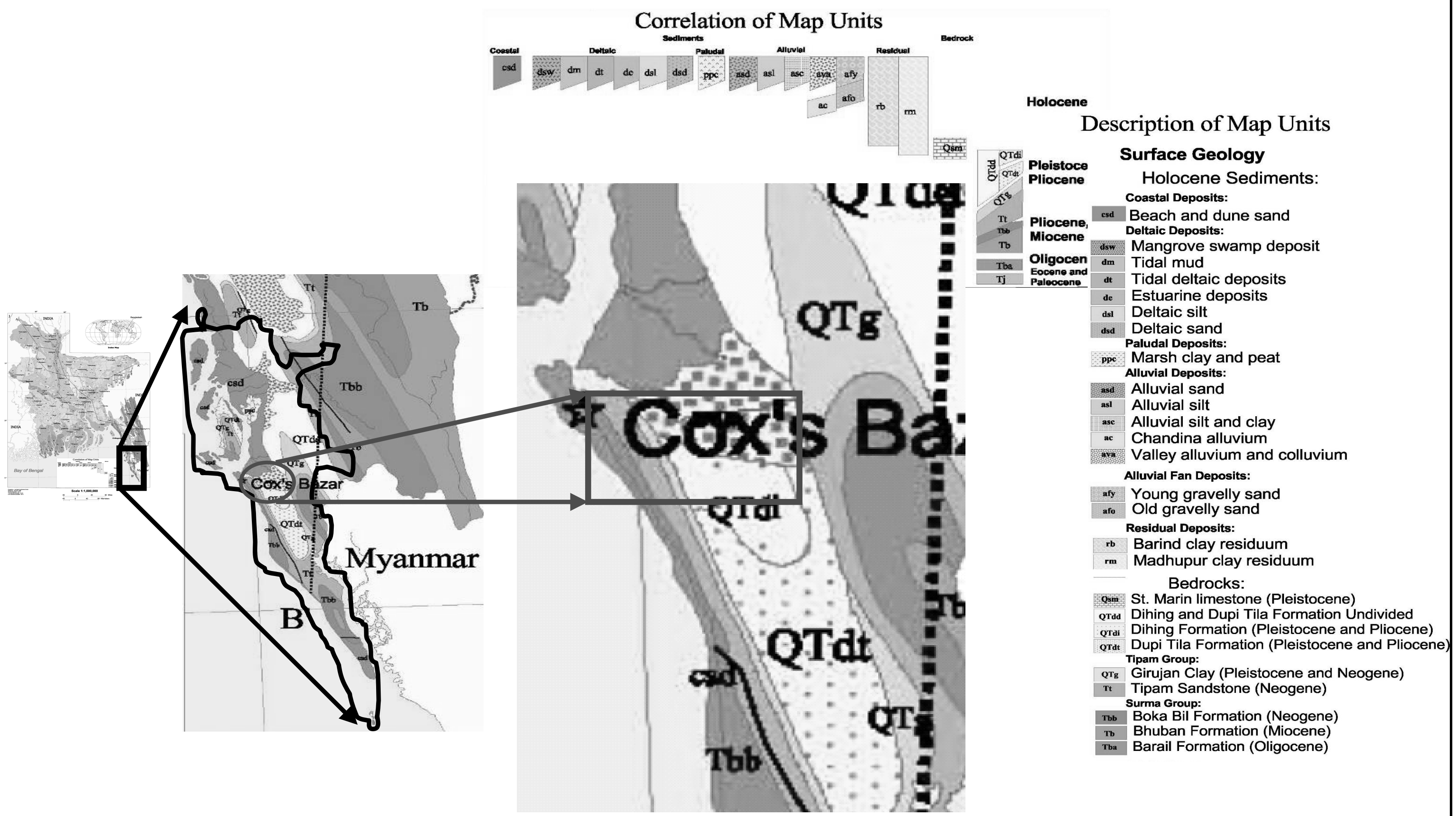



Figure 2.3: Geology of Cox's Bazar Municipal (Alam et al, 1990)

### 2.3 Status of Earthquakes in Bangladesh

Bangladesh is a country located in south Asia. Figure 2.4 shows the seismicity of southern Asia according to British Geological Survey. It shows that Bangladesh is covered by many points indicating earthquake events. It is obvious that Bangladesh is surrounded by the regions of high seismicity, which include the Himalayan Arc and Shillong Platue in the north, the Burmese Arc, Arakan Yoma anticlinorium in the east and complex Naga-Disang-Jaflong thrust zones in the northeast (Rahman 2008, Sarker et al. 2004). It is also the site of the Dauki Fault system along with numerous subsurface active faults and a flexure zone called Hinge Zone. These weak regions are believed to provide the necessary zones for movements within the basin area.

Earthquake catalogue for Bangladesh and surrounding area (Sharfuddin, 2001) shows that 1200 earthquakes with magnitude 4.0 have occurred between 1865 to 1999. During the last 150 years, seven major earthquakes with magnitude 7.0 have affected Bangladesh. Two of them had their epicentres within Bangladesh and caused considerable damage locally. The 1897 Great Indian earthquake (M=8.7) in Shillong, considered to be one of the strongest earthquakes of the world, had its epicentre only 230 km away from Dhaka and caused extensive damage to brick masonry structures in Bangladesh including Dhaka. Figure 2.5 reveals earthquakes of different magnitudes in and around Bangladesh. It shows that the earthquakes of the greater magnitude occurred in the northern part of the country. From the figure it can be seen that Chittagong and Cox's Bazar area also fall under moderate earthquake zone having magnitude of 6 to 7 in Richter scale.

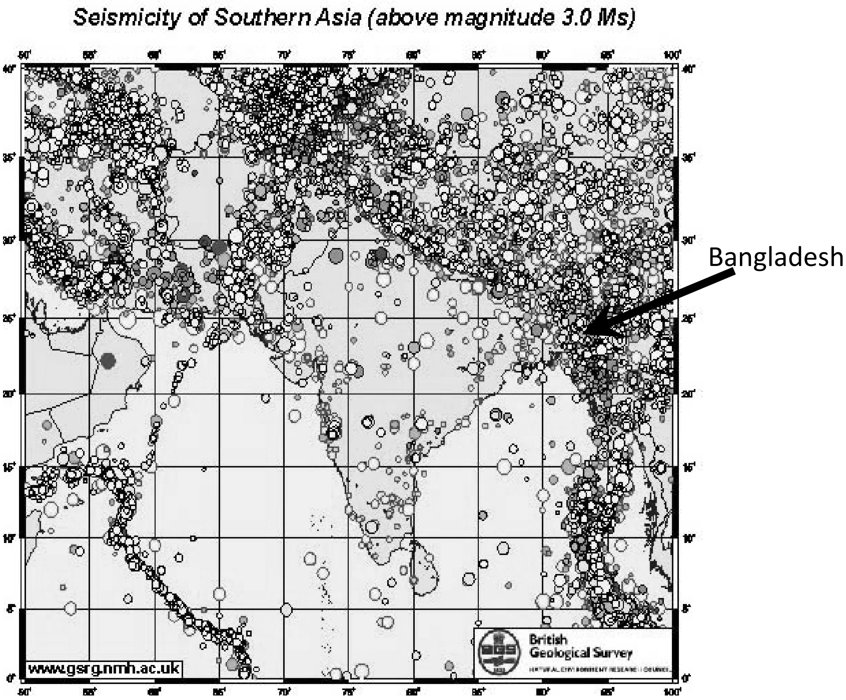



Figure 2.4: Seismicity of Southern Asia (The Tsunami Page, 2005)

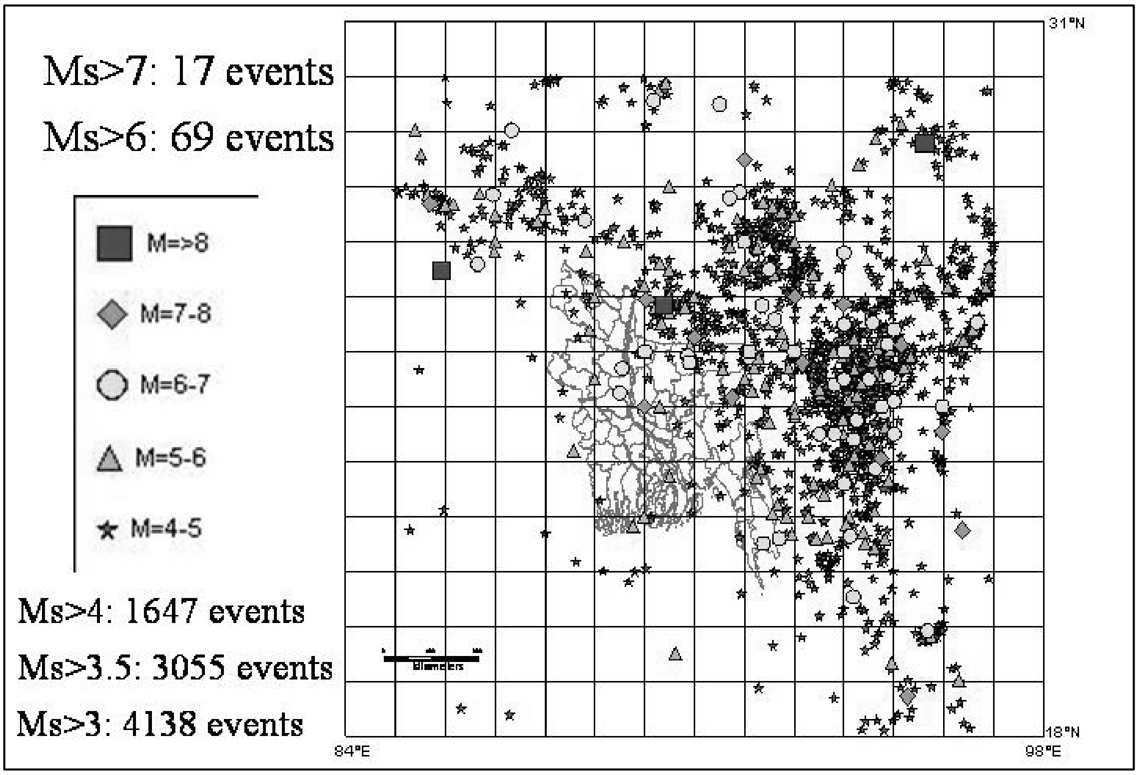



Figure 2.5: Earthquake in and around Bangladesh (1865-1995)

(after Ansary, 2009)

### 2.4 Historical Earthquakes in Bangladesh

Accurate historical information on earthquakes is very important in evaluating the seismicity of Bangladesh. Information on earthquakes in and around Bangladesh is available for the last 250 years. Appendix A provides a list of the historic earthquakes recorded in and around Bangladesh according to Scribd, 2008. The earthquake record suggests that since 1900 more than 100 moderate to large earthquakes occurred in Bangladesh, out of which more than 65 events occurred after 1960. This brings to light an increased frequency of earthquakes in the last 30 years. This increase in earthquake activity is an indication of fresh tectonic activity or propagation of fractures from the adjacent seismic zones. The Meteorological Department of Bangladesh established a seismic observatory at Chittagong in 1954 which is the only observatory in the country.

The major earthquakes that have affected Bangladesh since the middle of the last century are presented in Table 2.2.

Table 2.2: Great historical earthquakes in and around Bangladesh

| Date | Name | Epicentre | Magnitude (M) |
|---|---|---|---|
| 10-01-1869 | Cachar Earthquake | Jantia Hill, Assam | 7.5 |
| 14-07-1885 | Bengal Earthquake | Sirajgonj, Bangladesh | 7.0 |
| 12-06-1897 | Great Indian Earthquake | Shillong Plateau | 8.7* |
| 18-07-1918 | Srimangal Earthquake | Srimangal, Sylhet | 7.6 |
| 02-07-1930 | Dhubri Earthquake | Dhubri, Assam | 7.1 |
| 15-01-1934 | Bihar-Nepal Earthquake | Bihar, India | 8.3 |

* Recently modified as 8.1(M) (Ambraseys, 2000)

### 2.5 Major Seismic Sources

The seismic hazard is typically determined using a combination of seismological, morphological, geological and geotechnical investigations, combined with the history of earthquake in the region. Figure 2.6 shows the tectonic features of Bangladesh and adjoining areas. Figure 2.7 shows the distribution of faults and lineaments in Bangladesh.

Bolt (1987) analyzed different seismic sources in and around Bangladesh and arrived at conclusions related to maximum likely earthquake magnitude (Bolt, 1987). Bolt identified the following four major sources:

(i) Assam fault zone

(ii) Tripura fault zone

(iii) Sylhet fault zone

(iv) Bogra fault zone

Recently, Whitney (2004) has added two major possible source zones, namely Shahzibazar Fault and Tanor Fault. Figure 2.8 shows seismotectonic lineaments and faults capable of producing damaging earthquakes in Bangladesh. The magnitudes of earthquake suggested by Bolt is shown in Table 2.3 are the maximum magnitude generated in these blocks as recorded in the historical seismic catalogue. The historical seismic catalogue of the region covers approximately 250 years of (starting 1762) earthquake data. For example, the Assam and Tripura fault zones contain significant faults capable of producing magnitude 8.6 and 8.0 earthquakes respectively in future. Similarly maximum magnitude of 7.5 in Sub-Dauki fault zone and Bogra fault zones are not unlikely events.

Table 2.3: Significant seismic sources and maximum likely earthquake magnitude in Bangladesh (after Bolt, 1987)

| Location | Maximum likely earthquake magnitude |
|---|---|
| Assam fault zone | 8.0 |
| Tripura fault zone | 7.0 |
| Sylhet fault zone | 7.3 |
| Bogra fault zone | 7.0 |

After a thorough review of available data, Ali and Choudhury (1992) recommended magnitudes of Operational Basis Earthquakes and Maximum Credible Earthquakes as shown in Table 2.4.

Table 2.4: Operational basis earthquake, maximum credible Earthquake and depth of focus of earthquakes for different seismic sources (after Ali and Chowdhury, 1992)

| Location | Operational basis earthquakes (Richter) | Maximum Credible earthquakes | Depth of focus (km) |
|---|---|---|---|
| Assam fault zone | 8.0 | 8.7 | 0-70 |
| Tripura fault zone | 7.0 | 8.0 | 0-70 |

| | | | |
|---|---|---|---|
| Sylhet fault zone | 7.3 | 7.5 | 0-70 |
| Bogra fault zone | 7.0 | 7.5 | 0-70 |

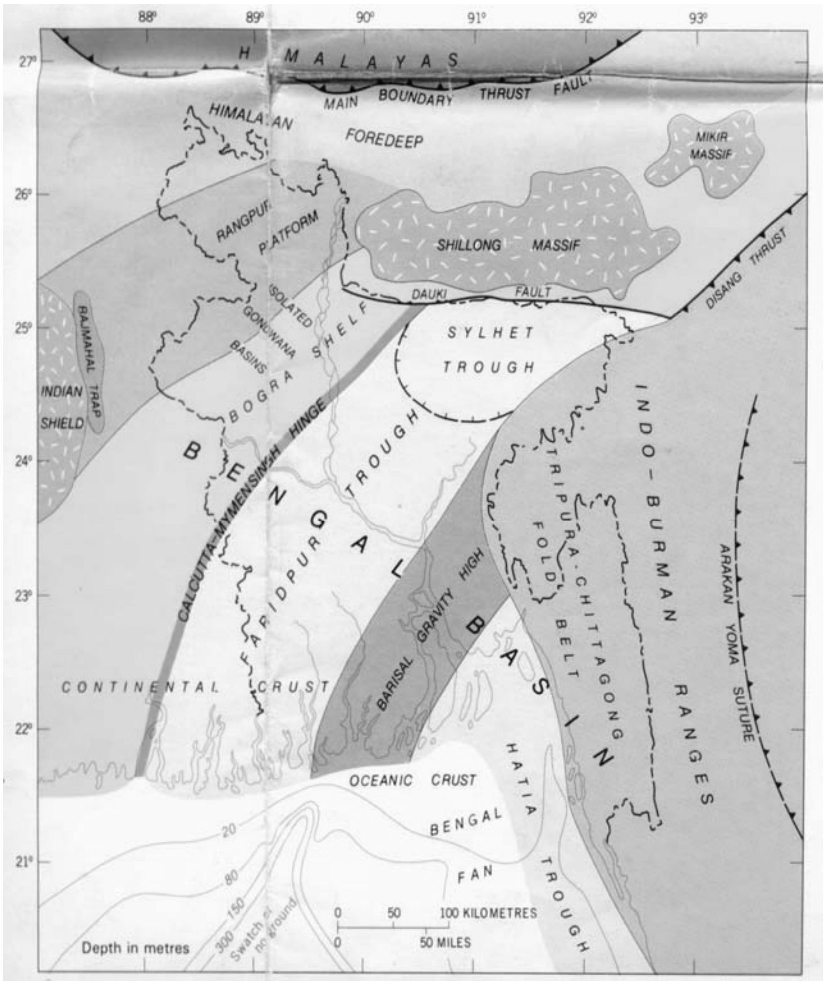



Figure 2.6: Generalized tectonic map of Bangladesh and adjoining areas

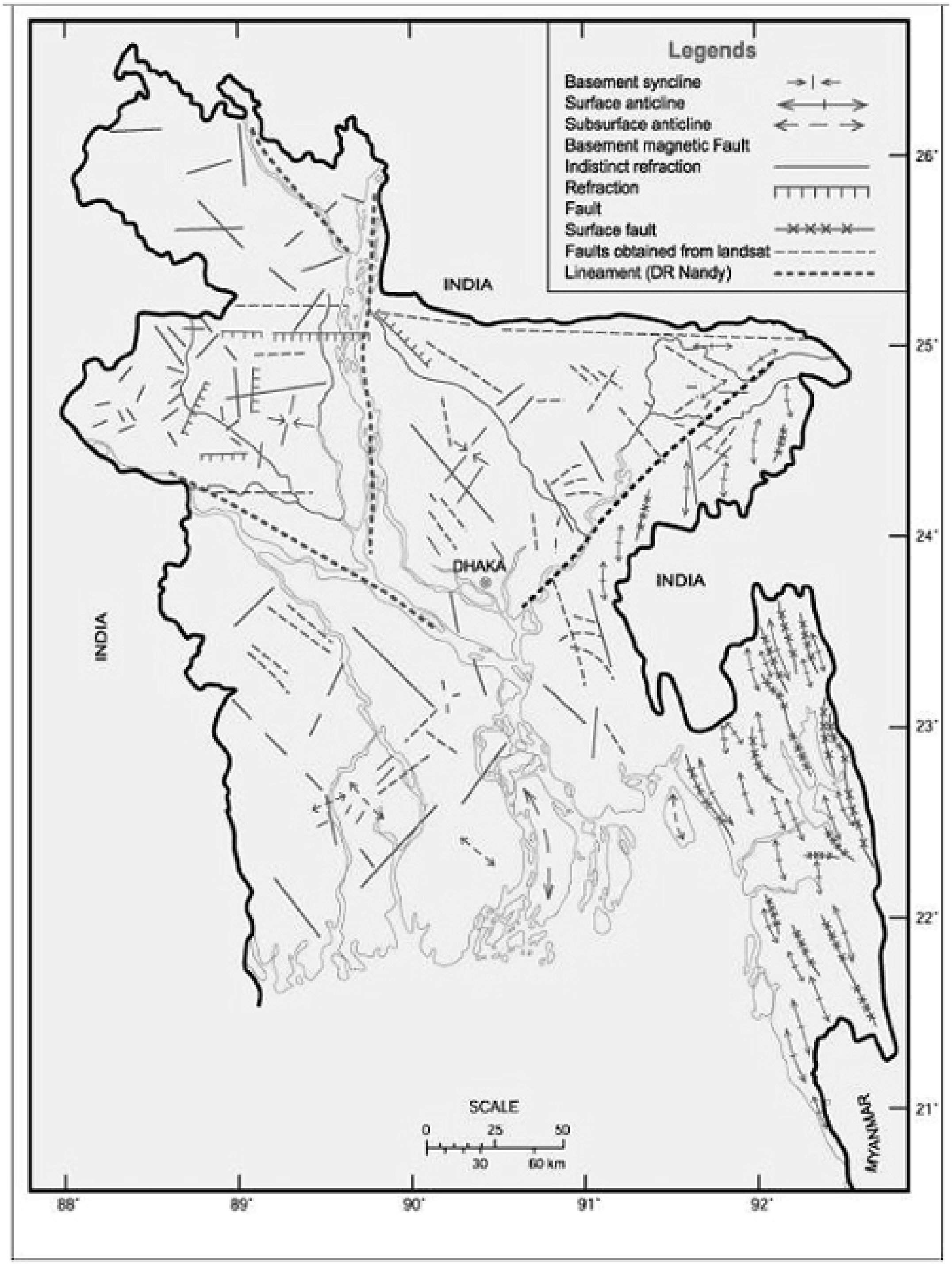



Figure 2.7: Distribution of faults and lineaments in Bangladesh (Banglapedia, 2004)

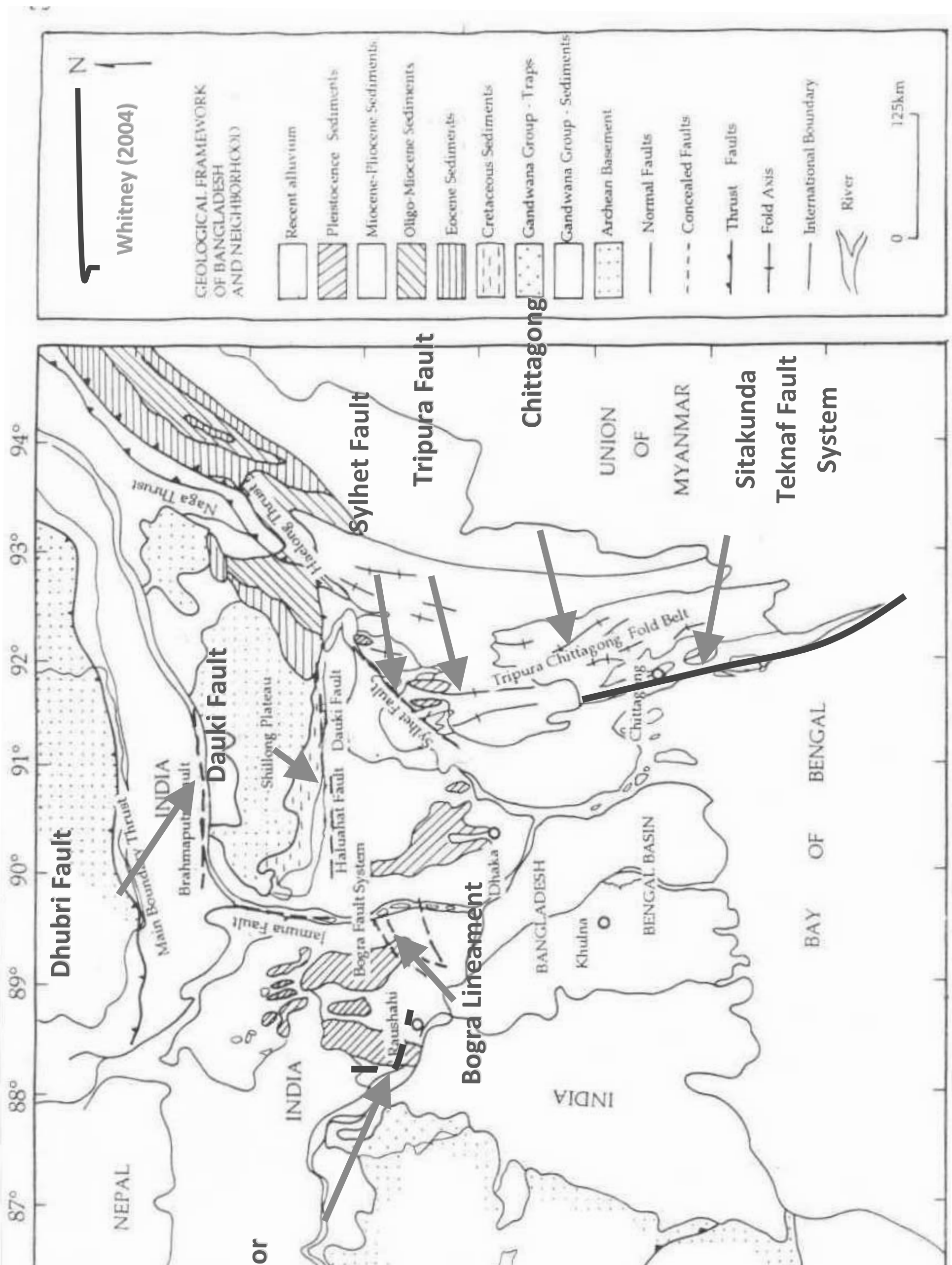



Figure 2.8: Seismo–tectonic lineaments and fault capable of producing

## 2.6 Historical Earthquakes in and around Cox's Bazar

In recent years, earthquakes have occurred quite frequently in Bangladesh and have caused alarm especially in Chittagong and Moheshkhali causing structural damage and casualties.

### 2.6.1 Chittagong Earthquake of 1762

Historical documents mention the occurrence of a large earthquake on April 2, 1762 (Rastogi et al., 2006) near Chittagong in the south-east which caused sea flooding, river waves inland, land mass changes etc. It is among the earliest known large earthquakes in South Asia. The earthquake, a major one (possibly M>7.0), was centred 40 km SE of Chittagong and 257 km SE of Dhaka, 61 km north of Cox's Bazar district. Chittagong suffered very severely; great explosion heard at first; earth opened in many places; quantities of water gushed out, great chasms remained unclosed and filled with water. Water spouted out like a fountain together with fine sand or mud, evidence of liquefaction. The great earthquake of April 2 raised the coast of some islands by several metres and also caused a permanent submergence of 155.40 sq km near Chittagong. At Dollazari houses fell. Near Luckipore, a circuit of land, about 15 miles in circumference, was swallowed up, and all the inhabitants and cattle perished. The earthquake also agitated the rivers and lakes of the country causing deaths inside the country.

### 2.6.2 Chittagong Earthquake of 1997

In November 21, 1997 another damaging earthquakes of body-wave magnitude 6.0 have occurred in Bangladesh (Sharfuddin, 2001). During this earthquake, 23 people were killed after collapse of an under-construction building in Chittagong. In Chittagong many low to middle rise buildings have suffered minor cracks although major damage has not been observed. The epicentral area (22.225N, 92.743E) is close to Ruma in Bandarban district of Chittagong Hill Tracts region. Many houses were damaged and old trees were uprooted in the epicentral region. Partial collapse of a long earthen dam (Prantik lake) has been observed.

### 2.6.3 Moheskhali Earthquake of 1999

On July 22, 1999, at 4:42 pm (local time), an intense earthquake shook the island of Moheskhali causing damage to several houses and some buildings, killing 6 people and injuring 200 people. The main damage has been reported to be in Shaplapur and Huanok Unions. Dineshpur and Kaidabad under Shaplapur Union were reported to have heavy damages. Cracking and spalling in reinforced concrete columns at the beam-column joint occurred in a cyclone shelter at Dineshpur. Several rural houses with mud walls and thatched or tin roof construction were severely damaged. At Kaidabad EU cyclone shelter was also badly damaged. Severe cracking was formed in many mudwall houses at Bara Maheshkhali and Huanok Union. Some landslides were also observed which could have been triggered by the earthquake.

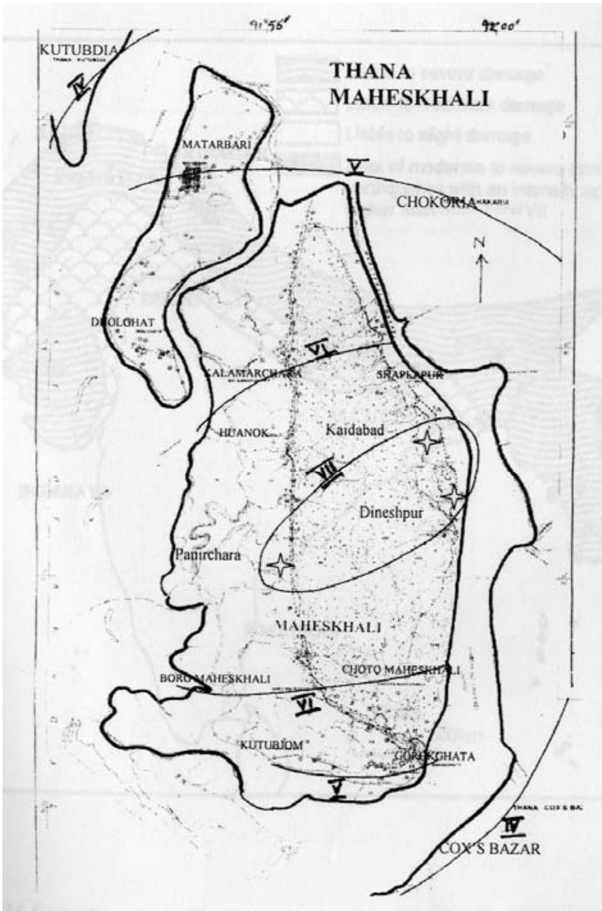



Figure 2.9: Isoseismal of Maheshkhali Earthquake of 1999 (Ansary et al., 1999)

The hypocentre of the earthquake was initially estimated to be at 21.47$^{o}$N, 91.90$^{o}$E (focal depth = 10 km, origin time 16:42:12) (Sharfuddin, 2001). The focal depth of this earthquake was quite shallow. The location of the hypocenter was later corrected as at 21.54$^{o}$N, 91.88$^{o}$E. The magnitude of the main shock was 5.1 on bodywave magnitude scale. Three more aftershocks of smaller intensity occurred in the same island on the following night. Figure 2.9 shows the seismic intensity map based on the observed damage and questionnaire survey (Ansary et al., 2001).

### 2.6.4 Database of Earthquakes in and around Cox's Bazar

Historical data (1923-2008) for seismic activity affecting Cox's Bazar and surrounding area show that the area has undergone through frequent earthquakes of magnitude ranging from 5 to 6 in Richter scale. Epicenters of these earthquakes (Appendix B) with reference to the 250 km radius of the municipality reveal that the earthquake with the highest magnitude (6.5 in Richter scale) occurred in this region in 1955. Again, considering 450 km radius around the study area, it is observed that the highest magnitude earthquakes experienced occurred in 1664, 1858, 1912 with magnitudes 7.8, 7.66, 7.9 consecutively (Ansary, 2009). Figure 2.10 shows the plot of frequency of the earthquakes occurring from 1919 to 2008 over the decades. The figure depicts that earthquakes having magnitude higher than 5.0 are recurring in almost every decade in this region. Again the frequency of earthquakes with magnitude varied from 4.0 to 5.0 has increased markedly over the last four decades. These historical records and observations indicate the probable occurrence of moderate to high intensity earthquakes in the upcoming years in and around Cox's Bazar.

## 2.7 Seismic Zoning Maps

In the Bangladesh National Building Code (BNBC) published in 1993, a new seismic zoning map for Bangladesh has been presented. The pattern of ground surface acceleration contours having 200 year return period forms the basis of this seismic zoning map. The 1993 BNBC zoning map is shown in Figure 2.11. In this zoning map the country has been divided into three generalized seismic zones: zone-I, zone-II and zone-III.

Zone-I comprising the Northern and Eastern regions of Bangladesh with the presence of the Dauki Fault system of Eastern Sylhet and the deep seated Sylhet Fault, and proximity to the highly disturbed southeastern Assam region with the Jaflong thrust, Naga thrust and Disang thrust, is a zone of high seismic risk with a basic seismic zoning co-efficient of 0.25 (Rahman 2008, Sarker et al. 2004). Northern Bangladesh comprising greater Rangpur and Dinajpur districts is also a region of high seismicity because of the presence of the Jamuna Fault and the proximity to the active east-west running fault and the Main Boundary Fault to the north in India (Rahman 2008, Sarker et al. 2004). The Chittagong-Tripura Folded Belt experiences frequent earthquakes, as just to its east is the Burmese Arc where a large number of shallow depth earthquakes originate.

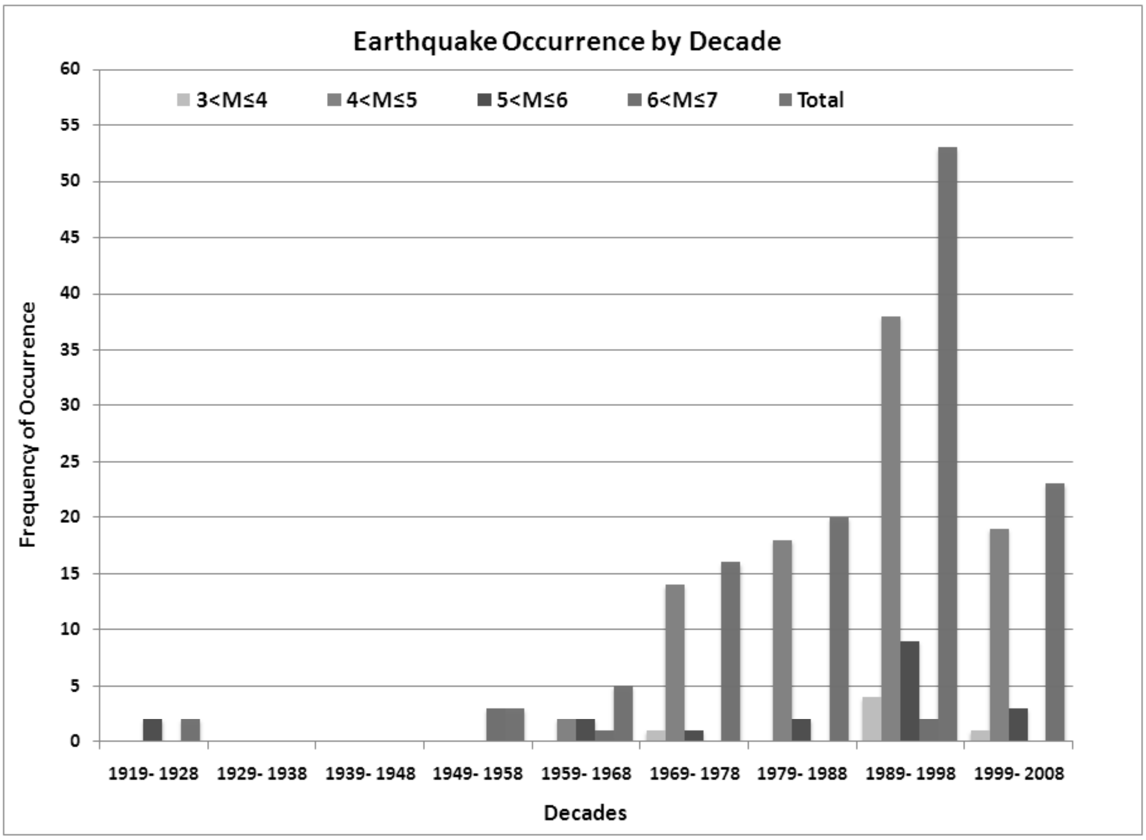



Figure 2.10: Earthquake Occurrences in and around Cox's Bazar municipal area (1919-2008) (after Ansary, 2009)

Zone-II comprising the central part of Bangladesh represents the regions of recent uplifted Pleistocene blocks of the Barind and Madhupur Tracts, and the western extension of the folded belt. The zone extends to the south covering Chittagong and Cox's Bazar. Seismic zoning coefficient for Zone II is 0.15.

The Zone-III comprising the southwestern part of Bangladesh is seismically quiet, with an estimated basic seismic zoning co-efficient of 0.075.

Bangladesh National Building Code (BNBC, 1993) placed Cox's Bazar in Seismic zone 2. The zoning map has recently been updated (Sharfuddin, 2001) and shown as Figure 2.12. The zoning in this updated map was based on consistent ground motion criterion such as equal peak ground acceleration levels. According to this map, Cox's Bazar falls in Zone 3. Based on the philosophy behind this seismic zoning and experience from recent earthquakes, it can reasonably be assumed that a major earthquake event in Cox's Bazar and surrounding region is liable to higher damage than that assumed in the existing zoning map (BNBC 1993).

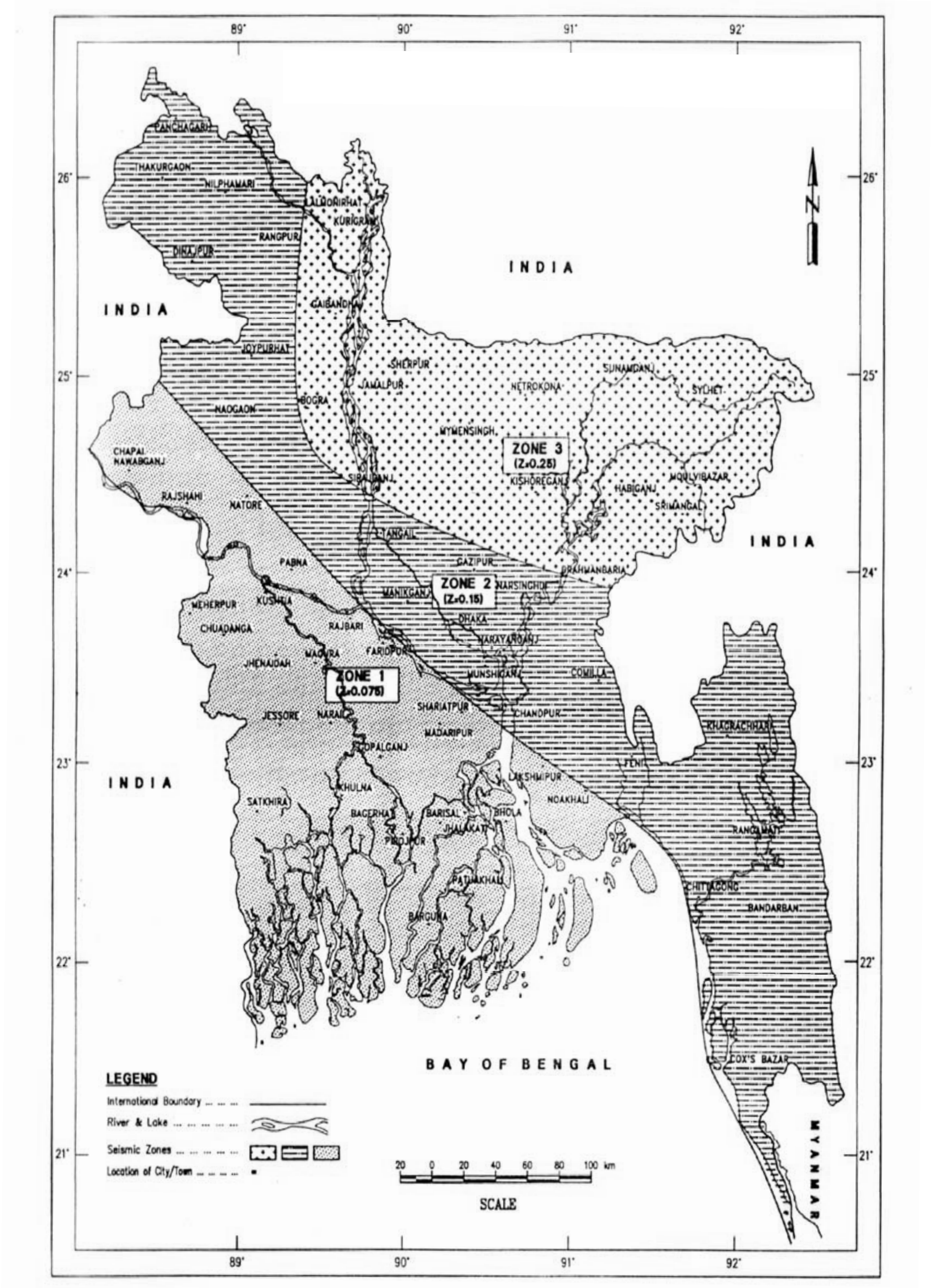



Figure 2.11: Seismic Zoning Map of Bangladesh
(BNBC, 1993)

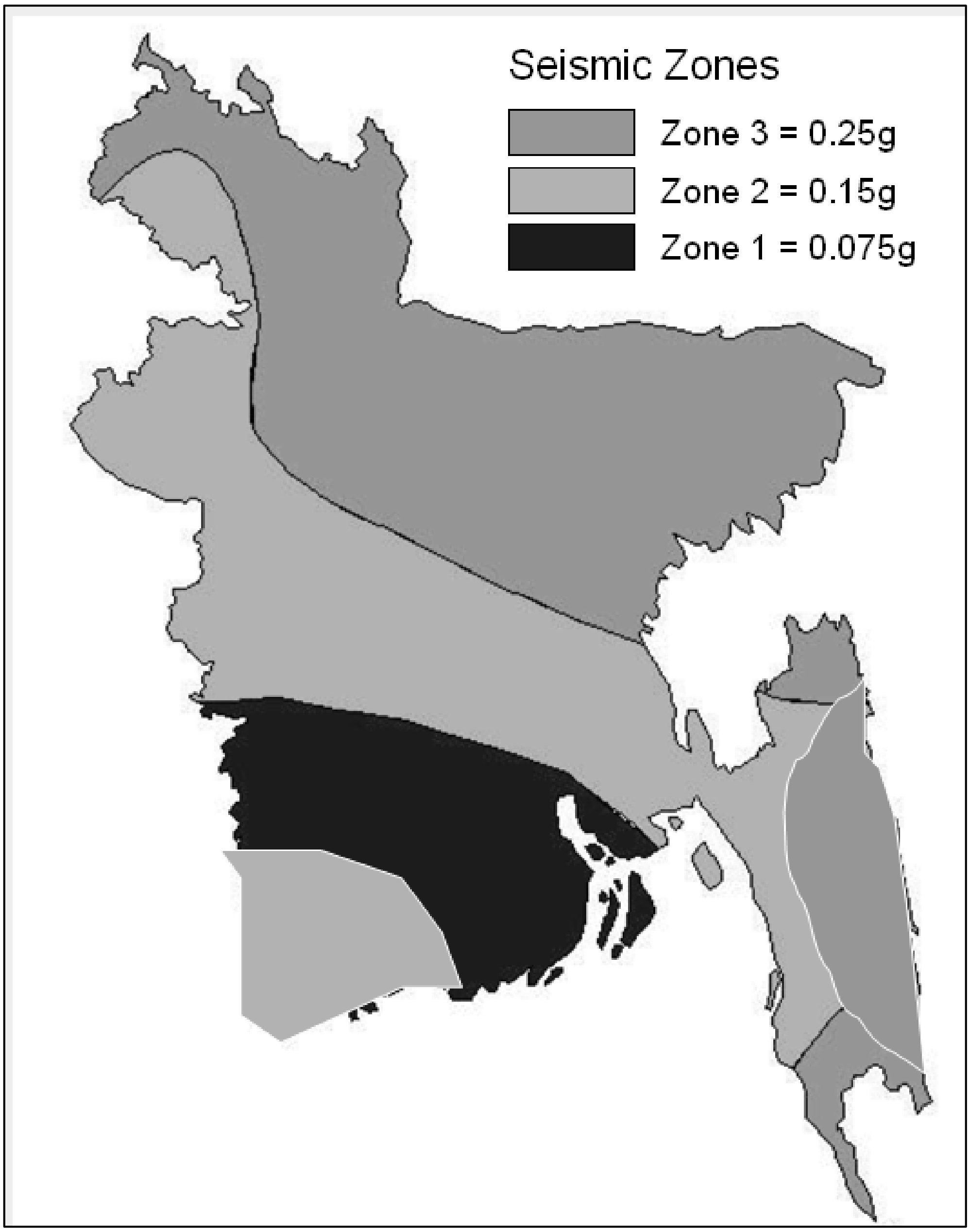



Figure 2.12: Updated Seismic Zoning Map of Bangladesh
(Ansary, 2009)

## 2.8 Seismic Microzonation

Seismic microzonation can be defined as the subdivision of a region into zones that have relatively similar exposure to various earthquake related effects. It is the mapping of seismic hazard at local scales to incorporate the effects of local soil conditions. The earthquake damages are controlled basically by three interacting factor groups; earthquake source and path characteristics, local geological and geotechnical site conditions, structural design and construction features. Seismic microzonation can be considered as the assessment of the first two groups of factors. In general terms, it is the process for estimating the response of soil layers under earthquake excitations and thus the variation of earthquake characteristics on the ground surface. Seismic microzonation is the initial phase of earthquake risk mitigation and requires multidisciplinary approach with major contributions from geology, seismology, geotechnical and structural engineering. The final output contains recommendations suitable for application by local administrators, urban planners and engineers.

The national seismic zoning maps are generally prepared in small scales such as 1:1,000,000 or less neglecting numerous source and site factors that are important in assessing ground motion characteristics. Seismic microzonation maps are prepared based on larger scales for a particular region taking into consideration both earthquake source and regional geological and geotechnical site conditions in order to be used for urban and landuse planning. A Seismic microzonation study consists of four stages: (1) estimation of the regional seismic hazard that is asessment of the expected input motion, (2) determination of the local geological and geotechnical site conditions (3) assessment of the probable ground response and ground motion parameters on the ground surface (4) finally, preparation of microzonation maps.

### 2.8.1 Function of GIS in Microzonation

The regional earthquake hazard analysis requires a map of the region that identifies the potential seismic sources. This procedure typically requires several geologic and geographic maps of the region. The bedrock motion in the region resulting from the seismic event must first be determined. This is often done by applying one of the attenuation functions within the GIS or by linking the function as an external executable program. The GIS-based procedure for estimating regional bedrock motion is straight-forward. Quantifying and integrating the seismic hazard due to local site effects (soil amplification, liquefaction, and landslide) is the main areas of development presented in this dissertation. The procedure involves developing models for each of the effects, assembling the necessary geologic and geographic maps and databases, applying the models either within the GIS or as linked external programs and then overlaying and combining the resulting hazard maps.

The results obtained from the analysis are microzonation maps for the study area. These maps typically require a detailed layout for the region, a quantification of the regional seismic hazard and accounts of susceptibility due to the expected hazards. The spatial database structure of a GIS environment is ideal for this procedure. In this study "MapInfo Professional 7.0" software has been used for developing maps.

**2.9 Attenuation Law of Peak Ground Acceleration**

The quantitative assessment of seismic hazard at any particular site within a region requires an attenuation law for the Peak Ground Acceleration (PGA). This describes the transfer of ground motions from the source to a particular site as a function of magnitude, distance and soil conditions. The maximum ground motion to be expected in the site constitutes a crucial problem in earthquake engineering. For Bangladesh, as in many other parts of the world, no PGA attenuation law has been developed, due mainly to the shortage of strong motion data. However, in order to assess the seismic hazard in this region, an attenuation law needs to be adopted from the literature. PGA attenuation relationships, predicting strong ground motions in terms of magnitudes, distance, site geology, and in some cases other factors, using various models and data sets are established for different parts of the world. Reviews of these laws are presented in Campbell (1997) and Joyner and Boore (1988). Some of the published attenuation functions are presented in Table 2.5. Attenuation relationships of ground motions are of the form:

$$log(y) = b_1 + b_2 (Ms) - b_3 \log(r) - b_4 (r)) + \sigma P \qquad (2.1)$$

where y is the ground motion parameter in consideration, M is earthquake magnitude, $b_{1,2,3,4}$ are constants determined for the ground motion parameter, σ is the standard deviation representing the scatter of data in the attenuation relationship and P is a parameter which takes the value of 0 (zero) when the predicted value represents the mean and P equals one when the predicted value represents the mean plus one standard deviation. 'r' is a distance parameter, usually of the form $r = \sqrt{(d^2 + h^2)}$.

Table 2.5: Published attenuation function (after Islam, 2005)

| Author | Law |
|---|---|
| Duggal (1989) | $y=227x10^{0.308M}(d+30)^{-1.2}$ |
| McGuire (1978) | $y=0.0306e^{0.89M}r^{-1.17}e^{-0.2S}$ ; Where S=0 for rock and S=1 for alluvium |
| Katayama (1974) | $\log y=2.308-1\ 637\log(r+30)+0.411M$ |
| Sadigh, et al. (1986) | $\ln y = -1.406 + 1.1\ M - 2.051\ (R + 1.353\ e^{0.406M})$; Where M > 6.5 |
| Joyner and Boore (1988) | $\log y = 0.43 + 0.23\ (M - 6) - \log (r^2 + h^2)^{1/2} - 0.0027(r^2 + h^2)^{1/2}$; for rock |
| Ambraseys (1995) | $\log y=-1.43+0.245Ms-0.001r-0.786\log r$; here, $r=(d^2+2.7^2)^{1/2}$ |
| Boore et al. (1997) | $\ln y = -0.2424 + 0.527(M-6) - 0.778\ \ln r - 0.371\ \ln V_s / 1.396$<br>where, $r = (r_b^2 + 5.57^2)^{1/2}$, $r_b$ = epicentral distance in km,<br>$V_s$ = average shear wave velocity of surface 30 m |
| Joynner and Boore (1981) | $y = 0.0955\ e^{(.573M)}\ d^{(-1)} * e^{(-0.00587D)}$, $d= (r2+h^2)^{0.5}$, for rock |

Where, y=PGA; M= surface magnitude; d=epicentral distance; r=hypocentral distance; h=focal depth

## 2.10 Seismic Hazard Assessment

The first step in microzonation is the estimation of seismic hazard. This involves the assessment of expected ground motion using the deterministic or probabilistic seismic hazard analysis. Numerous methods for earthquake hazard assessment in a given site are available today. Lomnitz and Epstein (1966) employed the Poisson process for the occurrence of large earthquakes which is still used. Cornell (1968) and Esteva (1968) derived the general basis for the most complete analysis of the whole seismic hazard problem with the inclusion of the propagation mechanism of the ground motion. Shah and Vagliente (1972) used the Markov model of earthquake prediction in seismic hazard analysis. A methodology for seismic hazard estimation based on historical earthquake occurrences is presented in detail in Tomatsu and Katayama (1988) and Molas and Yamazaki (1994). In Japan, the seismic risk method proposed by Kawasumi (1951) is still popular while in the United States, the basic method proposed by Cornell (1968) is often used

### 2.10.1 Deterministic Seismic Hazard Analysis

Krinitzsky (2005) highlights that a Deterministic Seismic Hazard Analysis (DSHA) uses geology and seismic history to identify earthquake sources and to interpret the strongest earthquake each source is capable of producing regardless of time. Those are the Maximum Credible Earthquakes (MCEs), the largest earthquake that appears possible along a recognized fault under the presently known or presumed tectonic activity which will cause the most severe consequences to the site.

The methodology followed for Deterministic Seismic Hazard Analysis is described as followed:

1. Source characterization, that includes identification and characterization of all earthquake sources which may cause significant ground motion in the study area. Here historic data of the earthquakes as well as the availability of the source of earthquake such as faults are used to determine the potential of the earthquake occurrence.
2. Selection of the shortest distance between the source and site of interest.
3. Selection of controlling earthquake, that is, the earthquake that is expected to produce the strongest level of shaking. Controlling earthquake has been evaluated based on historic data and assumed subsurface fault rupture length.
4. Defining the hazard at the site formally in terms of the ground motion produced at the site by the controlling earthquakes.

### 2.10.2 Probabilistic Seismic Hazard Analysis

PSHA is the most commonly used approach to evaluate the seismic design load for the important engineering projects. PSHA method was initially developed by Cornell (1968) and its computer form was developed by McGuire (1978). Site ground motions are estimated for selected values of the probability of ground motion exceedance in a design period of the structures or for selected values of annual frequency or return period for ground motion exceedance. The probabilistic approach offers a rational framework for risk management by taking account of the frequency or probability of exceedance of the ground motion against which a structure or facility is designed. The occurrence of earthquakes in a seismic source is assumed as the Poisson distribution. The probability distribution is defined in terms of the annual rate of exceeding the ground motion level z at the site under consideration, due to all possible pairs (M, R) of the magnitude and epicentral distance of the earthquake event expected around the site, considering its random nature. This procedure can be described in the following four steps:

1. Identification of earthquake sources such as active faults, which may affect the study area. Characterize the probability distribution of potential rupture locations within the source.
2. Characterization of the seismicity of each source zone using a recurrence relationship, which specifies the average rate at which an earthquake of some size will be exceeded.
3. Estimation of the ground motion produced at the site by earthquakes of any possible size occurring at any possible point in each source zone using predictive relationships.
4. Obtaining the probability that the ground motion parameter will be exceeded during a particular time period.

### 2.11 Local Site effects and Site Response Study

Site response analysis aims at determining the response of a soil deposit to the motion of the bedrock immediately beneath it. The overburden stress plays a very important role in determining the characteristics of the ground surface motion thus emphasizing the need for ground response analysis. A number of techniques have been developed for ground response analysis. These techniques can be grouped as one-, two-, and three-dimensional analyses according to the dimensionality of the problems they can address. A one-dimensional method can be used if the soil structure is essentially horizontal.

#### 2.11.1 Assessment of Site Amplification

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

Many results for this case have been presented, and a discrete model with lumped masses and springs, based on a finite difference formulation, has enjoyed great popularity among practicing engineers. The continuous and the discrete formulations are equivalent. This part of the report describes the use of a one-dimensional wave propagation program to develop a microzonation map of Cox's Bazar District.

When P and S wave reach the ground surface, most of their energy is reflected back in to the crust, so that surface is affected simultaneously by upward and downward moving waves. For this reason considerable amplification of shaking typically occurs near the surface and enhances the shaking damages at the surface. Different types of ground affected by the same earthquake waves may vary in their severity of ground shaking and consequent destructiveness by one or more degrees of intensity.

Certain building types are more vulnerable to different frequencies of ground motion vibration than others. Seismic micro zoning can show the frequency content of vibration due to different local ground condition. It can be used to ensure that a match does not occur between buildings vulnerable to certain frequencies of vibration and ground conditions that are likely to vibrate in that frequency range and thus avoiding building being damaged by 'resonance effect' in zones where the ground is likely to vibrate in certain frequency ranges. Buildings should be designed either to have frequencies of natural vibration well outside the critical range or to be designed for the much higher seismic forces they are likely to experience. The frequency map could be used to impose restrictions on the types of building structures that may have similar frequency.

### 2.11.2 Methodology Review

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

The analytical procedure generally involves the following steps:

- **Determination of the characteristics of the motions likely to develop in the rock formation underlying the site, and selection of an accelerogram with these characteristics for use in the analysis:** The maximum acceleration, predominant period, and effective duration are the most important parameters of an earthquake motion. Empirical relationships between these parameters and the distance from the causative fault to the site have been established for different magnitude of earthquakes (Gutenberg and Richter, 1954, Seed et al., 1969, Schnable et al., 1972). A design motion with the desired characteristics can be selected from the strong motion accelerograms that have been recorded during previous earthquakes (Seed and Idriss, 1969) or from artificially generated accelerograms (Housner and Jennings, 1964).

- **Determination of the dynamic properties of the soil Deposit:** Average relationships between the dynamic shear moduli and damping ratios of soils, as functions of shear strain and static properties; have been established for various soil types (Hardin and Drnevich, 1970, Seed and Idriss, 1970). Thus a relatively simple testing program to obtain the static properties for use in these relationships will often serve to establish the dynamic properties with a sufficient degree of accuracy. However, more elaborate dynamic testing procedures are required for special problems and for cases involving soil types for which empirical relationships with static properties have not been established.
- **Computation of the response of the soil deposit to the base rock motion:** A one dimensional method of analysis can be used if the soil structure is essentially horizontal. Programs developed for performing this analysis are in general based on either the solution to the wave equation (Kanai, 1951) or on a lumped mass simulation (Idriss and Seed, 1968). More irregular soil deposits may require a finite element analysis.

### 2.11.3 Method for Amplification Anlysis

One dimensional method of ground response analysis is widely used in earthquake geotechnical engineering A number of different techniques are available for one-dimensional response analysis, which can be broadly categorized as linear analysis, equivalent linear analysis and nonlinear analysis. The most popular method used in professional practice is the "equivalent linear" approach which is incorporated in the computer program SHAKE. The program 'SHAKE' is capable of computing the responses for a known motion given anywhere in a system. It requires three input parameters such as bedrock motion, dynamic material properties and site specific soil properties The peak surface acceleration, ground response spectrum and period of soil column are obtained as output from this analysis. The accelerograms measured on a known soil deposit can be used to predict underlying rock motions using 'SHAKE', which, in turn, can be used to obtain the surface motion for other soil deposits as shown in Fig. 2.13 (after Schnable et al., 1971). The rock motion is assumed not to vary within a region. The program incorporates non-linear soil behavior, the effect of the elasticity of the base rock and systems with variable damping.

a. **Theory to the Program:** The theory (behind SHAKE) considers the responses associated with vertical propagation of shear waves through the linear visco-elastic system shown in Figure 2.14. The system consists of N horizontal layers which extend to infinity in the horizontal direction and has a half space as the bottom layer. Each layer is homogeneous and isotropic, and is characterized by the thickness, h, mass density, ρ, shear modulus, G, and damping factor, β.

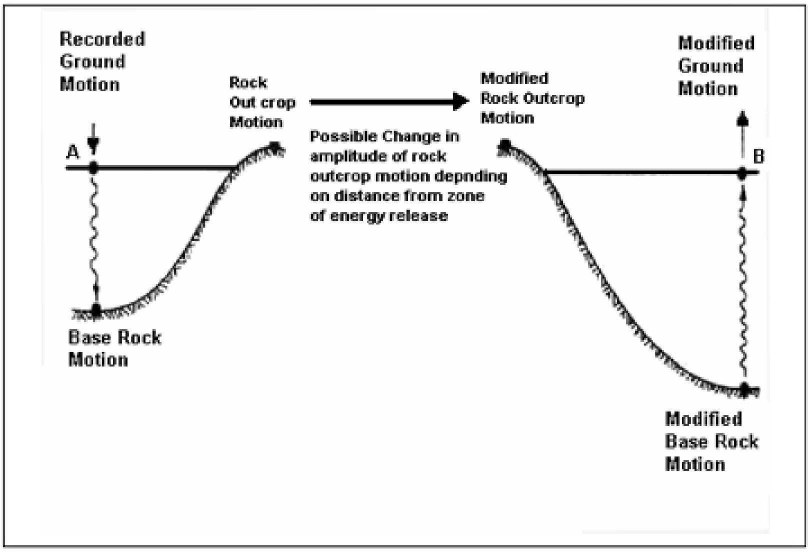



Figure 2.13: Schematic representation of procedure for computing effects of local soil conditions on ground motions (Schanbel et al., 1971)

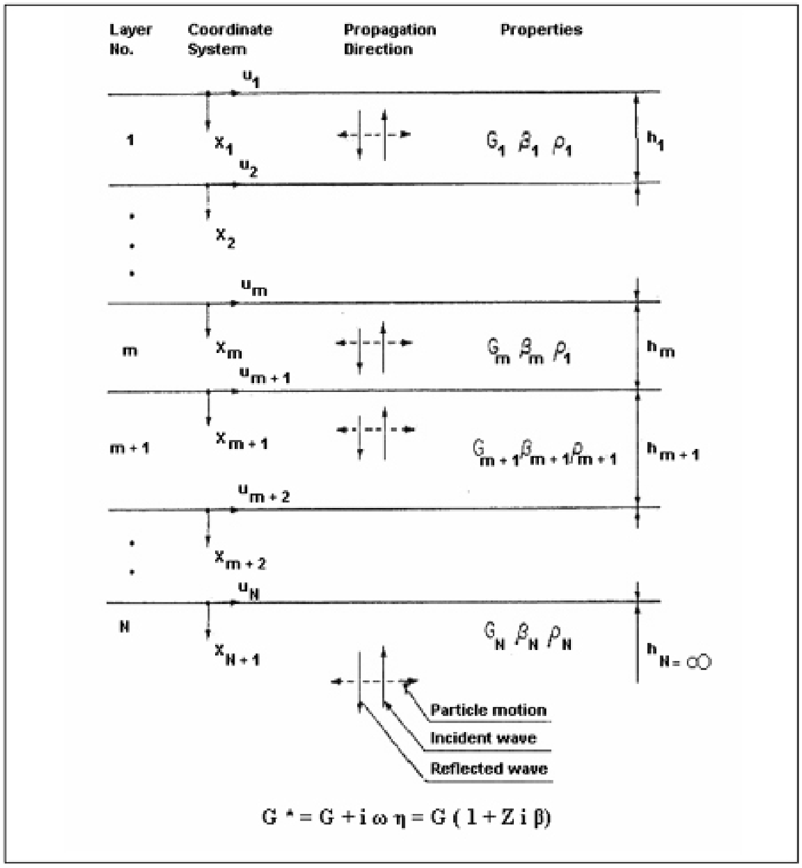



Figure 2.14: One dimensional wave propagation system (Schanbel et al., 1971)

### 2.11.4 Description of the Program SHAKE

Program SHAKE computes the responses in a system of homogeneous, visco-elastic layers of infinite horizontal extent subjected to vertically travelling shear waves. The system is shown in Figure 2.14**.** The program is based on the continuous solution to the wave- equation adapted for use with transient motions through the fast Fourier transform algorithm. The nonlinearity of the shear modulus and damping is accounted for by the use of equivalent linear soil properties using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer. The following assumptions are implied in the analysis:

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

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

- Read the input motion, find the maximum acceleration, scale the values up or down, and compute the predominant period.
- Read data for the soil deposit and compute the fundamental period of the deposit.
- Compute the maximum stresses and strains in the middle of each sub-layer and obtain new values for modulus and damping compatible with a specified percentage of the maximum strain.
- Compute new motions at the top of any sub-layer inside the system or outcropping from the system.

### 2.11.5 Use of SPT-value for Shear Wave Velocity

There are several empirical relations correlating the SPT-N value and Shear Wave Velocity (Vs) as Shown in Table 2.6. The Standard Penetration Test (SPT) has been widely used to investigate soil deposit for identifying subsurface soil profiles. The empirical relationships presented here can be used to convert SPT-N value into Shear Wave Velocity which is needed as one of the input parameters for the program SHAKE.

Table 2.6: Empirical Relations Correlating SPT-N value and Shear Wave Velocity (After TC4, 1993)

| **Researchers** | **Equation** |
|---|---|
| Imai and Yoshimura (1970) | $Vs = 76\ N^{0.33}$ |
| Ohba and Toriumi (1970) | $Vs = 84\ N^{0.31}$ |
| Ohta and Goto (1978) | $Vs = 69\ N^{0.17}\ D^{0.2}\ F_1\ F_2$<br>Where<br>$F_1$ = 1.0 (H); $F_2$ = 1.00 (clay)<br>= 1.3 (P); = 1.09 (f. sand)<br>= 1.07 (m. sand)<br>= 1.14 (c. sand)<br>= 1.15 (g. sand)<br>= 1.45 (gravel) |
| Imai (1977) | $Vs = a\ N^b$<br>Where<br>a = 102; b = 0.29 (H. clay)<br>= 81; = 0.33 (H. sand)<br>= 114 = 0.29 (P. clay)<br>= 97 = 0.32 (P. sand) |
| Okamoto et al. (1989) | $Vs = 125\ N^{0.3}$ (P. clay) |
| Tamura and Yamazaki (2002) | $Vs = 105\ N^{0.187}\ D^{0.179}$ |

Here,

Vs = Shear Wave Velocity (m/s); N = Corrected SPT blow count

D = Depth (m); H = Holocene; P = Pleistocene

f = Fine; m = Medium; c = Coarse; g = Gravel

### 2.12 Liquefaction Analysis

Soil liquefaction is a phenomenon in which a soil below the ground water table loses a substantial amount of strength due to pore pressure generation from strong earthquake ground shaking. Earthquake shaking induces shear stresses in the soil that cause the saturated cohesion less granular soil particles to rearrange and excess pore pressures to build up. Liquefaction can occur in moderate to major earthquakes resulting in severe damages to structures. It can have a significant and sometimes devastating effect on buildings supported on the upper soil layers constructed without consideration of its consequences of liquefaction. The damaging effects of soil liquefaction have been well recognized since the Niigata and Alaska earthquakes of the early 1960s. The types of failures associated with liquefaction include:

(i). Sinking or overturning of the structures,

(ii). Excessive differential settlement of the structures,

(iii). Sand boils; and

(iv). Surface lateral spreading.

#### 2.12.1 Causes of Soil Liquefaction

The general trend on understanding about the basic causes of liquefaction of sands is a quite qualitative measure. If a loose saturated sand deposit is subjected to ground vibrations, it tends to compact and decrease in volume. The effective stress in the sand deposit is equal to the difference between the overburden pressure and the pore water pressure. If drainage is unable to occur, the tendency to decrease in volume results in an increase in pore water pressure. So, with increasing oscillation, the pore water pressure will be equal to the overburden pressure causing the effective stress to become zero. Since the shear strength of a cohesionless soil is directly proportional to the effective stress, the sand loses its strength completely and develops a liquefied state.

In more quantitative terms, it is now generally believed that the basic cause of liquefaction in saturated cohesionless soil during earthquake is the buildup of excess hydrostatic pressure due to the application of cyclic shear stress induced by the ground motions. These stresses are generally considered to be due primarily to upward propagation of shear waves in a soil deposit; although other forms of wave motions are also expected to occur. Thus, soil elements can be considered to undergo a series of cyclic stress conditions, the stress series being somewhat random in pattern but nevertheless cyclic in nature.

There are several factors that influence liquefaction such as the geologic history of the deposit, the depth of ground water table, the grain size distribution, the density of soil, duration of earthquake, amplitude and frequency of shaking, distance from epicenter, cohesion of the soil and permeability of the layer and ground slope. The liquefaction hazards are commonly associated with saturated sandy and silty soils having low plasticity and density.

### 2.12.2 Methodology for Liquefaction Analysis

Liquefaction susceptibility is a measure of a soil's inherent resistance to liquefaction, and can range from not susceptible, regardless of seismic loading, to highly susceptible, which means that very little seismic energy is required to induce liquefaction. There are a number of different methods by which the potential for liquefaction of a soil can be evaluated. The types of methods can be classified into four categories:

Category-1: Evaluation of liquefaction potential roughly based on topographical and geological information

Category-2: Evaluation of liquefaction potential from N-value and grain size distribution data, and estimates of peak surface acceleration.

Category-3: Evaluation of liquefaction potential from laboratory cyclic shear testing of undisturbed samples, in light of dynamic response analysis.

Category-4: Evaluation of liquefaction potential by conducting in-situ cyclic or blasting tests, or laboratory shaking table tests.

Because of their simplicity, methods that fall in the first and second category are generally useful for formulating microzonation maps of liquefaction potential for wide areas. Methods in the last two categories provide a more rigorous examination of liquefaction at a single site, but are too tedious and costly for survey-type applications. In this study, the second procedure was adopted to formulate microzonation map of liquefaction potential.

The second procedure involves a more direct use of geotechnical data, such as SPT-N value and means particle diameter, and estimates of peak surface acceleration (Seed and Idriss, 1971). A liquefaction resistance factor FL, is calculated which is used to evaluate the liquefaction potential index, IL. The method is briefly explained below.

### 2.12.3 Liquefaction Potential Based On SPT N-Values

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). This method has been used here to evaluate the Liquefaction Resistance Factor, $F_L$ which can also be termed as Factor of Safety. It is the most common and traditional method that uses correlations between the liquefaction characteristics of soils and the Standard penetration Tests or N-value along with other parameters such as grain size distribution curves of soils, overburden pressure, and estimated peak surface acceleration. The assessment of the liquefaction resistance factor at any depth involves comparison of the predicted cyclic stress ratio ($t/б'_0$) that would be induced by a given design earthquake (L) with the cyclic stress ratio required to induce liquefaction (R). For this method, $F_L$ is calculated for a given depth of soil layer by the following formula.

$$F_L = \frac{R}{L} \tag{2.1}$$

Liquefaction is assumed to occur at that depth if FL is less than 1.0. Here, R is the in-situ capacity of soil to resist liquefaction expressed by Cyclic Resistance Ratio (CRR) for earthquake of magnitude 7.5 and L is the earthquake load induced by a seismic motion expressed by Cyclic Stress Ratio (CSR). Cyclic Resistance Ratio for earthquake of magnitude 7.5 is determined based on corrected SPT and mean soil particle size (Seed et al. 1983).

Table 2.7: Magnitude Scaling Factor after Seed and Idriss (1983)

| Earthquake Magnitude | MSF |
|---|---|
| 6 | 1.32 |
| 6.75 | 1.13 |
| 7.5 | 1.00 |
| 8.5 | 0.89 |

Magnitude Scaling Factor (MSF), obtained from Table 2.7, is used to determine the Factor of Safety against Liquefaction for earthquakes other than that of magnitude 7.5 and calculated as

$$FS = F_L = \frac{CRR_{7.5}}{CSR} MSF \qquad (2.2)$$

The shear stresses developed at any point in a soil deposit during an earthquake appear to be due primarily to the vertical propagation of shear waves in the deposit. If the soil column above a soil element at depth "h" behaved as a rigid body, the maximum stresses on the soil element would be

$$(\tau_{max})_r = \frac{\gamma h}{g} \alpha_{smax} = \frac{\sigma_0}{g} \alpha_{smax} \qquad (2.3)$$

where

$\sigma_o$ = total overburden pressure

$\alpha_{Smax}$ = estimated peak surface acceleration (in percentage of g)

$\gamma$ = Unit weight of the soil

g = acceleration due to gravity;

Figure 2.15 illustrates the procedure for determining cyclic shear stress on a soil element during ground shaking and Figure 2.16 illustrates the procedure for determining maximum shear stress.

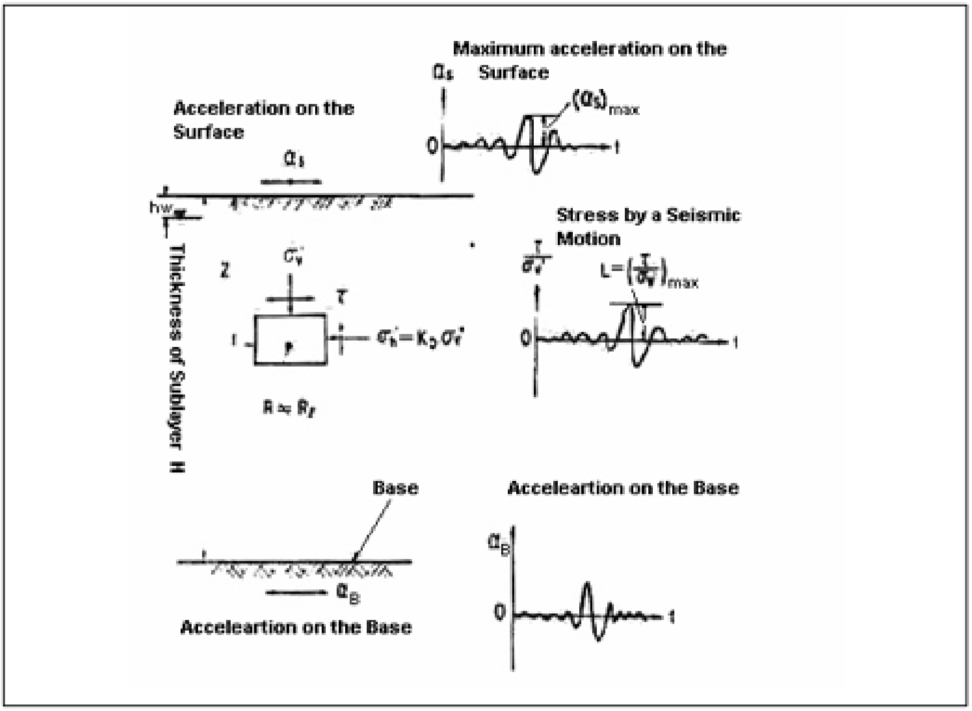



Figure 2.15: Cyclic shear stresses on a soil element during ground shaking

(Iwasaki, 1982)

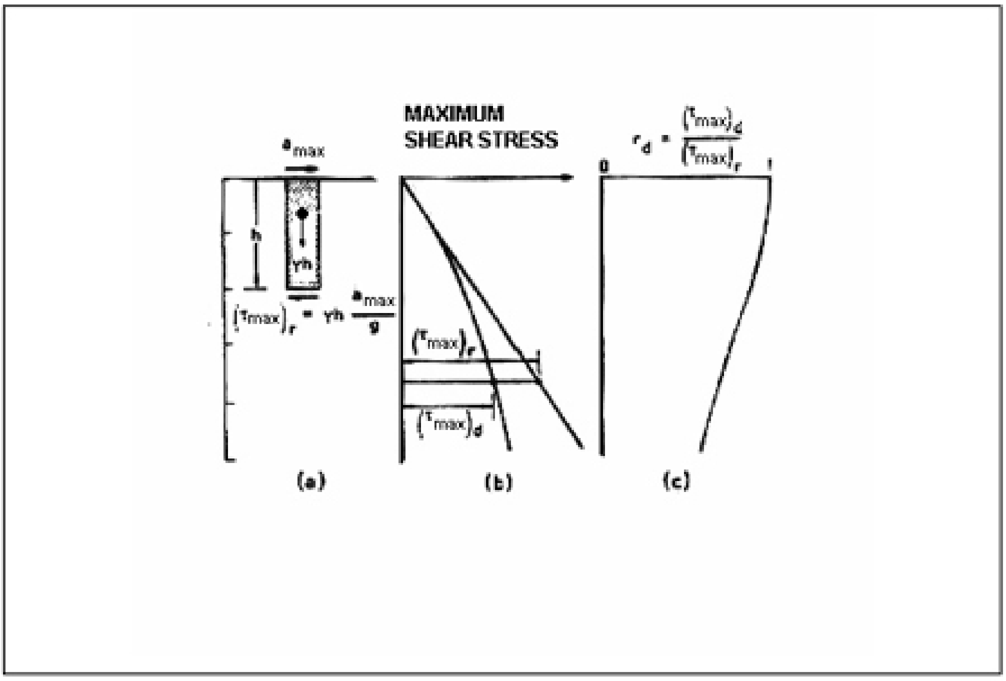



Figure 2.16: Procedure for determining maximum shear stress

(Seed et al. 1983)

Because the soil column behaves as a deformable body, the actual shear stress at depth h, $(\tau_{max})_d$, as determined by the ground response analysis will be less than $(\tau_{max})_r$ and might be expressed by

$(\tau_{max})_d = r_d\ (\tau_{max})_r$ (2.4)

Where

$r_d$ = a stress reduction factor with a value less than 1 given by (1- 0.015z) in which

z = depth of ground surface in meters.

Computations of the value of $r_d$ for a wide variety of earthquake motions and soil conditions having sand in the upper 50 ft. have shown that $r_d$ generally falls within the range of values shown in Figure 2.17. It may be seen that in the upper 30 or 40 ft., the scatter of the results is not so great and, for any of the deposits, the error involved in using the average values shown by the dashed line would generally be less than about 5%. Thus to a depth of about 40 ft., a reasonably accurate assessment of the maximum shear stress developed during an earthquake can be made for the relationship given in equation (3.3) by using values of $r_d$ to be taken from the dashed line in Figure 2.17.

The actual time history of shear stress at any depth in a soil deposit during an earthquake will have an irregular form such as that shown in Figure 2.18. From such relationships it is necessary to determine the equivalent uniform average shear stress. By appropriate weighting of the individual stress cycles, based on laboratory test data, this determination can readily be made. However, after making these determinations for a number of different cases it has been found that with a reasonable degree of accuracy, the average equivalent uniform shear stress, $\tau_{av}$, is about 65% of the maximum shear stress, $\tau_{max}$. Combining this result with the above expression for $\tau_{max}$, the average cyclic stress ratio ($\tau_{av}$ / $\sigma'_0$) induced by an earthquake is given by the expression (Seed et al., 1983)

$$CSR = L = \frac{\tau_{av}}{\sigma'_0} = 0.65\left(\frac{\alpha_{s\max}}{g}\right)\left(\frac{\sigma_0}{\sigma'_0}\right)r_d \qquad (2.5)$$

Where,

$\sigma'_0$ = effective overburden pressure

The cyclic stress ratio required to cause liquefaction has been evaluated using empirical relationship between cyclic stress ratio and N values. This curve is presented in Figure 2.19.

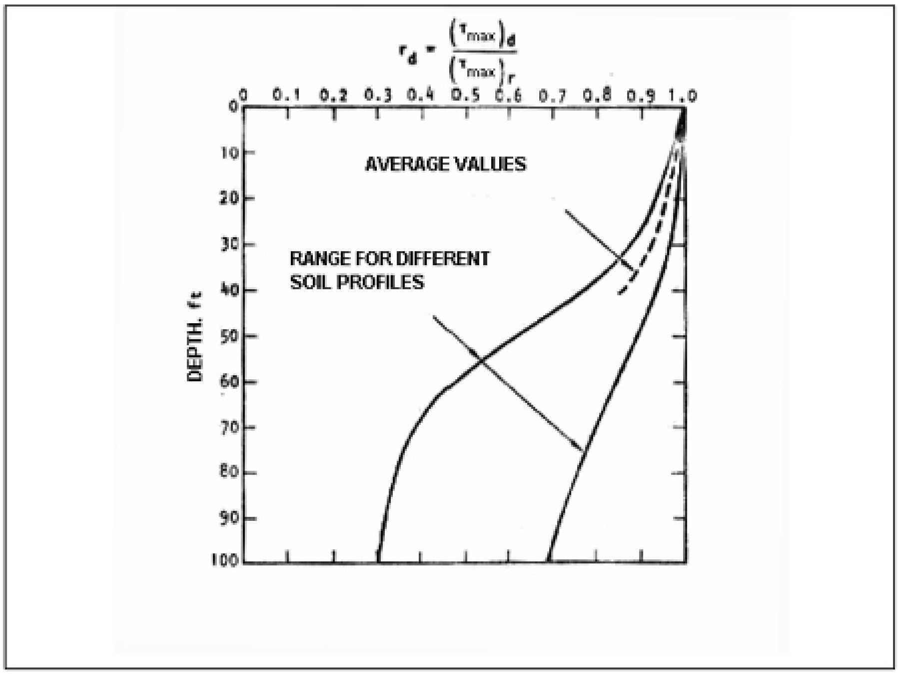



Figure 2.17: Range of Values of rd for different soil profiles (Seed et al., 1983)

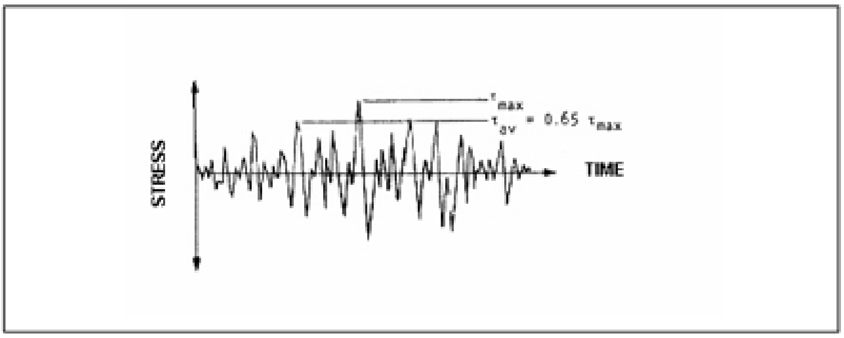



Figure 2.18: Time history of shear stresses during earthquake (Seed et al., 1983)

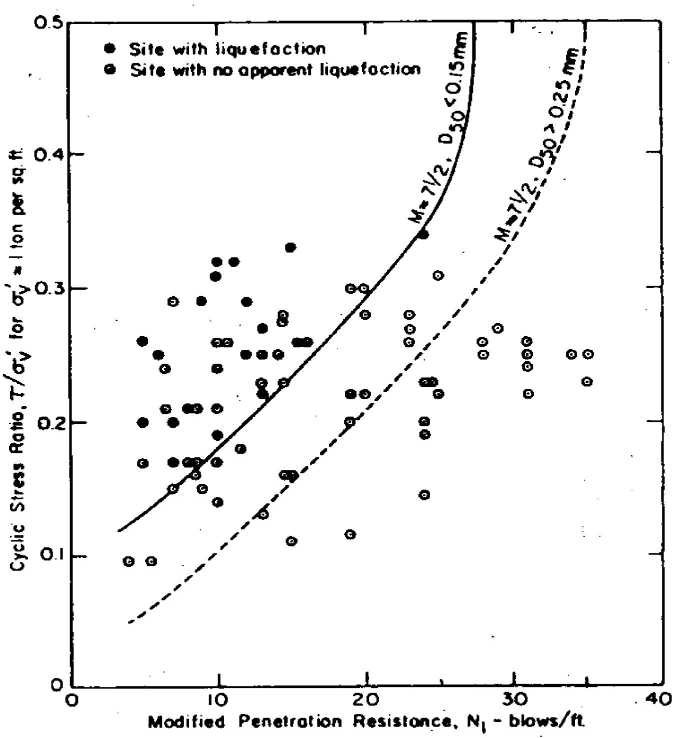



Figure 2.19: Correlation between field liquefaction behavior of Silty sands under level ground conditions and standard penetration resistance (after Seed et al., 1983)

Since the standard penetration resistance, N, measured in the field actually reflects the influence of the soil properties and the effective confining pressure, it has been found desirable to eliminate the influence of confining pressure by using a normalized penetration resistance $N_1$, where N is the measured penetration resistance of the soil under an effective overburden pressure of 1 ton per sq. ft. Thus, before using the graph in Figure 2.20, normalized to the field SPT-N value is estimated as follows:

$$N_1 = C_N \cdot N \tag{2.6}$$

Where,

$N_1$ = modified N values

$C_N$ = a correction factor

The correction factor, $C_N$ was provided by Murthy (1991) and presented here as Figure 2.20.

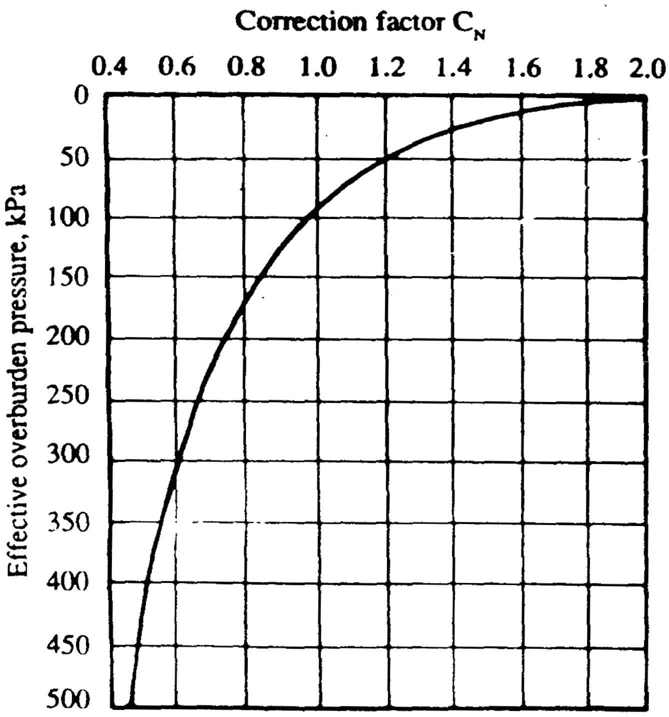



Figure 2.20: Recommended Curves for Correction Factor from Effective Overburden Pressure (after Murthy, 1991)

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 $F_L$. Generally speaking, liquefaction under the following condition tends to be severe:

1. The liquefied layer is thick

2. The liquefied layer is shallow

3. The $F_L$ of the liquefied layer is far less than 1.00

In order to account for these effects, the Japanese Bridge Code (Japanese Road Association, 1991) recommended a modification to the procedure suggested in Seed et al (1983). In this method the factor of safety values, $F_L$ (Seed and Idriss, 1971) against resistance to liquefaction have been computed up to top 20 meters depth for all the bore holes and these values have been subsequently converted into liquefaction potential index ($I_L$) given by the following equation (Iwasaki et al., 1982):

$$I_L = \int_0^{20} F(z)w(z)dz \qquad (2.7)$$

Where,

F (z) = $(1\text{-}F_L)$ for $F_L \leq 1.0$

F (z) = 0 for $F_L > 1.0$

W (z) = (10 – 0.5 Z) for $z \leq 20$ m

W (z) = 0 for z >20 m

The value of liquefaction potential, $I_L$ indicates that a soil mass is susceptible to liquefaction if $I_L$>0. If the value of $I_L$ is large, the soil is very susceptible for liquefaction.

Severity of liquefaction is then expressed as shown below:

$I_L$ = 0, No Liquefaction
= 0-5, Low Liquefaction
= 5-15, Moderate Liquefaction
= >15, High Liquefaction

$I_L$ 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 2.8 shows the interpretation of liquefaction potential in terms of intensity and ground susceptibility.

Table 2.8: Summary of the Liquefaction Potential Index (Iwasaki et al., 1986)

| Liquefaction Potential | Criteria | Explanation |
|---|---|---|
| High | $15 < I_L$ | Ground Improvement is indispensable |
| Moderate | $5 < I_L \leq 15$ | Ground Improvement is required. `Investigation of important structures is indispensable |
| Low | $0 < I_L \leq 5$ | Investigation of important structures is required |
| Very low | $I_L$=0 | No measure is required |

## 2.15 Landslide

A landslide is a geological phenomenon which includes a wide range of ground movement, such as rock falls, deep failure of slopes and shallow debris flows. Although the action of gravity on an over-steepened slope is the primary reason for a landslide, there are other contributing factors affecting the original slope stability. Typically, pre-conditional factors build up specific sub-surface conditions that make the area/slope prone to failure, whereas the actual landslide often requires a trigger before being released.

Landslides and other gravity-stimulated mass movements are a continual source of concern for geotechnical engineers and engineering geologists throughout the world, particularly in geologically active regions. They occur worldwide and are described as sudden, short-lived geomorphic events that involve the rapid to slow descent of soil or rock in sloping terrains. They can occur on any terrain give the right conditions of soil, moisture and the angle of slope. Risks of landslides are enhanced in the tropics, where thick, loose residual soil, the result of deep weathering, can be easily eroded.

### 2.15.1 Types of Landslides

The term "landslide" describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing. Figure 2.21 shows a graphic illustration of a landslide, with the commonly accepted terminology describing its features.

The various types of landslides can be differentiated by the kinds of material involved and the mode of movement. A classification system based on these parameters is shown in Table 2.9.

Table 2.9: Types of landslides, Abbreviated version of Varnes', 1978 classification of slope movements (National Atlas, 2008)

<table>
<tr><th colspan="2" rowspan="3">Type of Movement</th><th colspan="3">Type of Material</th></tr>
<tr><th rowspan="2">Bedrock</th><th colspan="2">Engineering Soils</th></tr>
<tr><th>Predominantly Coarse</th><th>Predominantly Fine</th></tr>
<tr><td rowspan="2"></td><td>FALLS</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td>TOPPLES</td><td>Rock topple</td><td>Debris slide</td><td>Earth slide</td></tr>
<tr><td rowspan="2">SLIDES</td><td>ROTATIONAL</td><td rowspan="2">Rock slide</td><td rowspan="2">Debris slide</td><td rowspan="2">Earth slide</td></tr>
<tr><td>TRANSLATIONAL</td></tr>
<tr><td rowspan="4"></td><td>LATERAL SPREADS</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td rowspan="2">FLOWS</td><td rowspan="2">Rock flow<br><br>(deep creep)</td><td>Debris flow</td><td>Earth flow</td></tr>
<tr><td colspan="2">(soil creep)</td></tr>
<tr><td>COMPLEX</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

The most common types of landslides are described as follows and are illustrated in Figure 2.22.

**Slides:** The term Slide refers to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides are rotational slides and translational slides.

Rotational slide is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide (Figure 2.22A).

In Translational slide, the landslide mass moves along a roughly planar surface with little rotation or backward tilting (Figure 2.22B).

A block slide is a translational slide in which the moving mass consists of a single unit or a few closely related units that move downslope as a relatively coherent mass (Figure 2.22C).

**Falls:** Falls are abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs (Figure 2.22 D).

**Topples:** Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks (Figure 2.22 E).

**Flows:** There are five basic categories of flows that differ from one another in fundamental ways.

a. Debris flow: A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope (Figure 2.22 F). Debris flows include <50% fines. Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt, that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. Debris-flow source areas are often associated with steep gullies, and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies. Fires that denude slopes of vegetation intensify the susceptibility of slopes to debris flows.

b. Debris avalanche: This is a variety of very rapid to extremely rapid debris flow (Figure 2.22 G).

c. Earthflow: Earthflows have a characteristic "hourglass" shape (Figure 2.22 H). The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.

d. Mudflow: A mudflow is an earthflow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles. In some instances, for example in many newspaper reports, mudflows and debris flows are commonly referred to as "mudslides."

e. Creep: Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. There are generally three types of creep: (1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature; (2) continuous, where shear stress continuously exceeds the strength of the material; and (3) progressive, where slopes are reaching the point of failure as other types of mass movements. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges (Figure 2.22 I).

**Lateral spreads:** Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain (Figure 2.22 J). The dominant mode of movement is lateral extension accompanied by shear or tensile fractures. The failure is caused by liquefaction, the process whereby saturated, loose, cohesionless sediments (usually sands and silts) are transformed from a solid into a liquefied state. Failure is usually triggered by rapid ground motion, such as that experienced during an earthquake, but can also be artificially induced. When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Often the initial failure is a slump, but in some materials movement occurs for no apparent reason. Combination of two or more of the above types is known as a complex landslide.

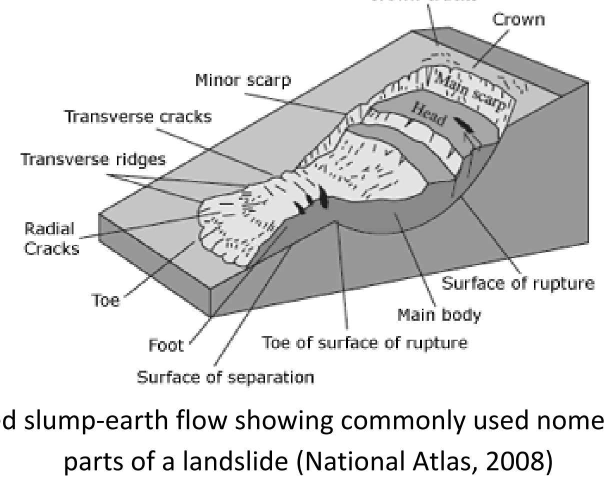



Figure 2.21: An idealized slump-earth flow showing commonly used nomenclature for labeling the parts of a landslide (National Atlas, 2008)

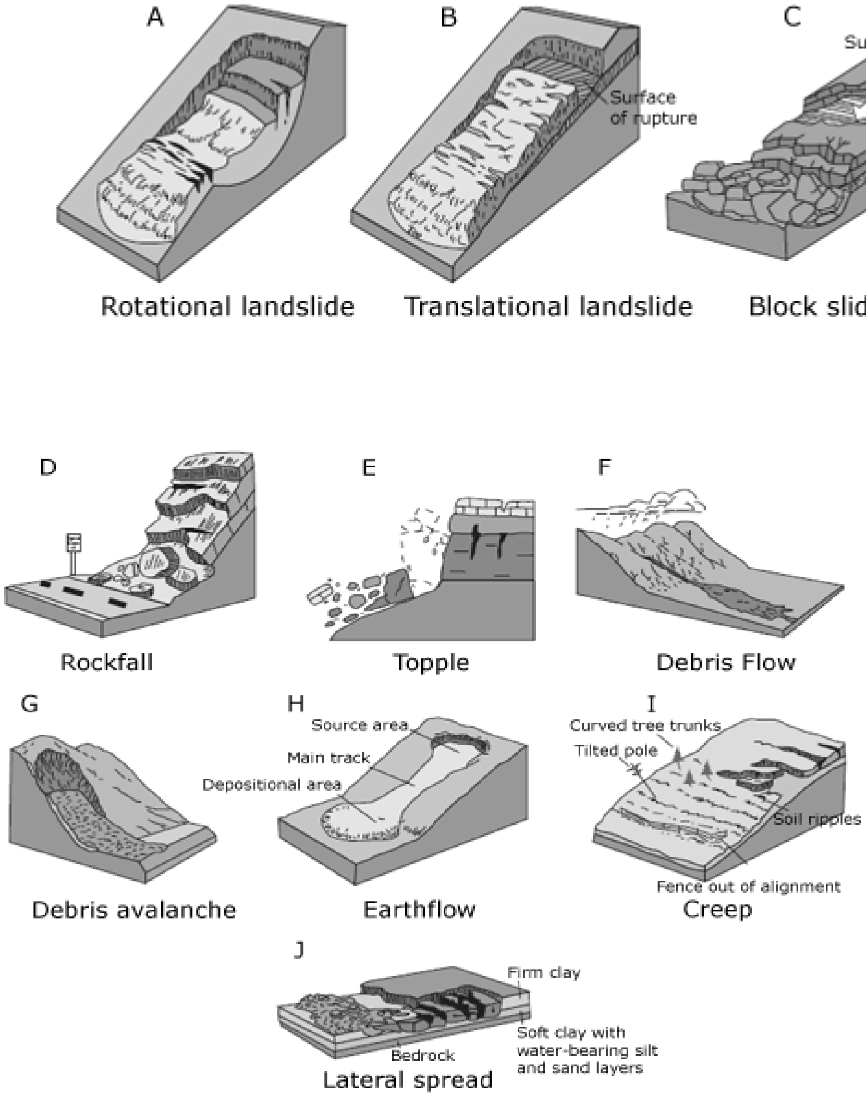



Figure 2.22: Schematics illustrating the major types of landslide movements (National Atlas, 2008)

### 2.15.2 Landslide in the South Eastern Bangladesh

Landslide is a regular geologic hazard in Bangladesh, especially in the South-Eastern part of the country. The steepness of a hill is the main factor for the movement of the materials that flow down towards the foot of the hill. Steep slope push down debris or mud converting gravitational energy into kinetic energy. A natural hill is a stable surface of the earth system having a balance of its components. Every natural hill is maintaining its stability by natural condition of the system that sometimes disturbed by improper interactions of human being.

Landslide induced by human activities has become very common in the hilly areas of southeastern Bangladesh, especially in Bandarban, Rangamati, Khagrachhari and Cox's Bazar. Illegal hill-cutting due to rampant building has left some 70,000 (IRIN, 2008) people at risk of landslides in 18 sub-districts of the hill districts, as well as the city of Chittagong, warned specialists. Every year especially in the rainy season landslides take place in both natural and man-induced slopes. Considerable number of buildings, roads and other infrastructures are damaged and valuable lives are lost in these incidents. The loss of lives and properties due to Landslide events in Cox's Bazar is also very significant. In 15th June of 2003 (International Landslide Centre, 2006) total 6 casualties were reported at Cox's Bazar due to Landslides caused by heavy rain. The earthquake of July 30, 2003(Natural Hazards, 2007) with a magnitude of 5.9 hit the Chittagong area causing casualties of six persons in Cox's Bazar by landslide. In September 2006 landslide triggered by heavy rain killed two children and injured six people in the village Rajarkol. Nineteen people died in landslides in Cox's Bazar district in the first half of July 2008 (International Herald Tribune, 2006) alone. On 14 July two people died under a mudslide at Himchhari. On August 11, 2008 three members of a family were buried alive as their mud-hut collapsed in Cox's Bazar. Very recently, on July 31, 2009, ten people were killed in Bandarban due to landslide (South Asian Media Net, 2009).

Types, major nature and processes that cause landslides in Bangladesh are 1) removal of lateral support: a) erosion by rivers, b) previous slope movements such as slumps that create new slopes, c) human modifications of slopes such as cuts, pits, and canals; 2) addition of weight to the slope: a) accumulation of rain, b) increase in vegetation, c) construction of fill, d) weight of buildings and other structures, e) weight of water from leaking pipelines, sewers, canals, and reservoirs; 3) earthquakes; 4) regional tilting; 5) removal of underlying support: a) undercutting by rivers and waves; b) swelling of clays; 6) anthropogenic activities as jhum cultivation

Since Cox's Bazar, the study area for this dissertation, is one of the most landslide prone areas of the country, assessment of landslide potential of Cox's Bazar has become very essential. Indiscriminate Hill cutting is one of the major causes of landslide in this area. Land slide may also be caused by earthquake in steep hill and loose land of steep periphery. Gentle angle or slope is mostly absent in the hills of Cox's Bazar. Rock strata in this area are mostly found as soft or brittle sedimentary rocks which may easily be broken or slide. Since Cox's Bazar is on the threat of probable earthquake events, the hill-tops loosened by any means can cause massive destruction if a moderate to major tremor takes place.

The southern part of the municipal area is mostly hilly which consists of Dupi Tila Formation (Figure 2.3). Lower hill of the area are mainly underlain by little-consolidated sands and shales of the Dupi Tila formation, which may be from late-Miocence age (Brammer, 1996). These hills are mainly composed by unconsolidated or little-consolidated beds of sandstones, siltstones and shales, together with minor beds of limestone and conglomerates. Nature of parent materials strongly determines the texture of the soils. Shale results heavy silt loam or silty clay loam subsoil. Soils developed on sandstone have dominant textural class of sandy loams with occasional loamy sand or loam texture

There also exist hills of Tipam and Bokabil Formation, sparsely in the area. Previous studies on erosional hazards of Chittagong City (Banglapedia, 2006) disclose that the hills formed of Dupi Tila Formation is prone to three types of landslides and slope failures which are lateral spreading movement, rotational and translational movements. Planar or block movement have been observed to occur in Bokabil Formation and rotational, translational and planar or block failures occur in Tipam Formation.

The major landslide occurrences in and around Cox's Bazar municipal area have been listed in Appendix C (Banglapedia, 2006).

### 2.15.3 Landslide Hazard Analysis Method

The effects of earthquake-induced landslide have received much less research attention than the seismic effects of soil amplification and liquefaction. Landslide hazard is typically very difficult to quantify because landslide come in many forms and are caused by a variety of processes. The local site factors that affect landslides generally include slope stability, geology, slope angle, hydrological conditions, vegetation, land use, and severity of the earthquake. Most of these factors are necessary for the investigation of an individual slope, but for seismically induced landslide analysis on a broad regional basis, magnitude of the seismic event, and distance from the seismic source (Hansen and Franks, 1991).

As with liquefaction, regional landslide hazard has traditionally been analyzed in a qualitative manner utilizing expert opinion, although recently more quantitative geotechnical methods have been proposed. The qualitative methods typically produce microzone maps indicating the relative susceptibility of various regions to landslides with no investigation into the possible triggering mechanisms for the land movement. The maps often result from an expert analysis of regional factors such as previous landslide locations, geologic deposits, and topography.

The complicated nature of the landslide process has made regional estimates of this local site effect very difficult to define quantitatively. Most of the recent research in this field has focused on determining the critical level of a given ground motion parameter that will trigger landslide in various geologic deposits. Wieczorek, et al. (1985) models a landslide as a translational failure in an infinite slope with a depth of 3 meters. They define three classes of geological units, assign shear strength parameters for each class, and then perform stability analyses using dry and saturated conditions to obtain the static factor of safety (FS) for each class. Based on the static FS, the critical acceleration to begin the process of slope failure, $a_c$, is computed as

$$a_c = (FS-1)\ g \sin\theta \tag{2.8}$$

Where, $\theta$ = slope angle

FS = factor of safety determined from a static slope stability analysis

G = acceleration of gravity

These $a_c$ values are compared to the regional estimates of surface peak ground acceleration to give a prediction for the occurrence of damaging earthquake-induced landslides in the area. There have been very few implementations of quantitative landslide hazard models in the GIS environment instead, a qualitative approach utilizing regional maps showing relative susceptibility of landslides in various geologic deposits will be used to describe earthquake-induced landslide hazard.

### 2.15.4 Slope Stability Analysis

The evolution of slope stability analyses in geotechnical engineering has followed closely the developments in soil and rock mechanics as a whole. Slopes either occur naturally or are engineered by humans. Slope stability problems have been faced throughout history when human or nature has disrupted the delicate balance of natural soil slopes. An understanding of geology, hydrology, and soil properties is central to applying slope stability principles properly. Analyses must be based upon a model that accurately represents site subsurface conditions, ground behavior, and applied loads. Judgments regarding acceptable risk or safety factors must be made to assess the results of analyses.

Civil engineers often are expected to make calculations to check the safety of natural slopes, slopes of excavations and compacted embankments. This check involves determining the shear stress developed along most likely rupture surface and comparing it with the shear strength of the soil. This process is called slope stability analysis. The most likely rupture surface is the critical surface that has the minimum factor of safety.

The stability analysis of a slope is difficult to perform. Evaluations of variables such as soil stratification and its in-place shear strength parameters may prove be a formidable task. Seepage through the slope and the choice of a potential slip surface add to the complexity of the problem. The forces of gravity tends to move soil from high levels to low levels and the forces that resists this action are on account of shear strength of soil. Presence of water increases weight reduces strength and decreases stability. The factor of safety is therefore chosen as a ratio of the available shear strength to that required to keep the slope stable.

**2.15.5 Common Features of Slope Stability Analysis Methods**

Sliding surfaces in landslides are commonly bowl- or dish-shaped in three dimensions. The widths of the slides are often the same order of magnitude as the down slope length, and stresses parallel to the strike of the ground surface are thought to influence the failure to only a limited extent. It is common to examine the stability of a series of two-dimensional sections in the dip direction and to calculate weights, forces and moments for unit width in the strike direction, Lodalen, Norway (Sevaldson, 1956). A section through the deepest part of the slide mass usually gives a conservative estimate of the stability. Averaging techniques (Lambe and Whitman, 1969) are available. Analysis of slides in jointed rock masses must often formally consider three-dimensional limiting equilibrium.

Various techniques of slope stability analysis include three broad categories Limit Equilibrium Methods, Limit Analysis Solutions and Probabilistic Methods. However, Limit Equilibrium Methods are more commonly used in practice. The basic assumptions of Limit Equilibrium Methods approach is that Coulomb's failure criterion is satisfied along an assumed failure surface, which can be a straight line, an arc of a circle, a logarithmic spiral or any other irregular surface.

Common Features of Slope Stability Analysis Methods include:

1. Safety Factor: $F = S/S_m$ where S = shear strength and $S_m$ = mobilized shear resistance. F = 1: failure, F > 1: safety
2. Shape and location of failure is not known a priori but assumed (trial and error to find minimum F)
3. Static equilibrium (equilibrium of forces and moments on a sliding mass)
4. Two-dimensional analysis

*Most Critical Failure Surface:* In homogeneous soils relatively unaffected by faults or bedding, deep seated shear failure surfaces tend to form in a circular, rotational manner. The stability analysis aims to find the most dangerous, ie., the most critical surface, and using the assumption above, this surface can be found using "trial circles". This provides a basis for several methods used to assess the stability of slopes.

The method is as follows:-

1. A series of slip circles of different radii but the same centre of rotation is considered (Figure 2.23). The Factor of Safety (FoS) for each of these circles against radius is plotted (Figure 2.24), and the minimum FoS is found out.
2. This should be repeated for several circles, each investigated from an array of centres. The simplest way to do this is to form a rectangular grid from the centres (Figure 2.25).
3. Each centre will have a minimum FoS, and the overall lowest FoS from all the centres shows tha FoS for the whole slope. This assumes that enough circles, with a large spread of radii, and a large grid of centres have been investigated. Then an overall failure, surface, with smaller individual ones is also found out. (Figure 2.26).
4. Submerged Slopes: When an external water load is applied to a slope (Figure 2.27), the pressure it exerts tends to have a stabilising effect on the slope. The vertical and horizontal forces due to the water must be taken into account in our analysis of the slope.

*Assumptions in Limit Equilibrium: C*ertain assumptions are needed to be made in analysing slopes using limit equilibrium:-

1. Assuming a Failure Mechanism: The shape and location of a failure surface rather are assumed then determining it by analysis.

2. Assuming Plane-Strain (2-D): 3-D effects (although of course in reality slopes are in three dimensions) are ignored. By neglecting these effects the analysis becomes conservative, ie. higher FoS is achieved by taking them into account.
3. Assuming Rigid Block Movement: The soil mass is assumed to be moved as a rigid block, with the movement only taking place on the failure surface itself.
4. Assuming Uniform Localisation of Shear Stresses: The shear stresses are not usually uniformly mobilised over the whole length of the failure surface but for the purpose of the analysis, it assumed that they are.

*Factor of Safety:* In slope design, and in fact generally in the area of geotechnical engineering, the factor which is very often in doubt is the shear strength of the soil. The loading is known more accurately because usually it merely consists of the self-weight of the slope. The FoS is therefore chosen as a ratio of the available shear strength to that required to keep the slope stable. A factor of safety is calculated by dividing the forces resisting movement by the forces driving movement. If the forces available to resist movement are greater than the forces driving movement, the slope is considered stable. When performing stability analyses usually more interest is put in the stability of the un-failed soil, and in determining a factor of safety, F, for the un-failed soil. To determine the factor of safety it is assumed that only some part of the frictional and cohesive forces have been mobilized, so that on the assumed failure plane the soil is not at a state of failure. Guidelines for limit equilibrium of a slope are given as table 2.10.

Table 2.10: Guidelines for limit equilibrium of a slope (Connolly, 1997)

| Factor of Safety | Details Of Slope |
|---|---|
| <1.0 | Unsafe |
| 1.0-1.25 | Questionable safety |
| 1.25-1.4 | Satisfactory for routine cuts and fills,<br>Questionable for dams, or where failure would be catastrophic |
| >1.4 | Satisfactory for dams |

For highly unlikely loading conditions, factors of safety can be as low as 1.2-1.25, even for dams. e.g. situations based on seismic effects, or where there is rapid drawdown of the water level in a reservoir.

### 2.15.6 Methodology Review for Slope Stability Analysis

This section aims at presenting the methods of slope stability analysis, which are commonly available. The methods of analysis can be categorized as follows:

**A.** Granular Soils:

The C'=0 Method

**B.** Cohesive Soils:

Circular Failure Surface

- Method of Slices
- Fellenius' Method
- Bishop's Method

Non-Circular Failure Surface

- Janbu's Method
- Infinite Slope Method
- Stability Charts

Few of the methods are summarized in the following paragraphs.

*Method of Slices:* The method of slices is a method for analyzing the stability of a slope in two dimensions. The sliding mass above the failure surface is divided into a number of slices. The forces acting (Figure 2.28) on each slice are obtained by considering the mechanical equilibrium for the slices. It is assumed that the arc is circular, radius R, centre is O. The soil mass above a trial failure surface is divided into slices by vertical planes. Each slice is taken as having a straight line base. The Factor of Safety of each slice is assumed to be the same, implying mutual support between the slices, ie., there must be forces acting between the slices. To go about finding the FoS, the problem is now statically indeterminate and some assumptions are needed to be made about the interslice forces. This part is better performed by Fellenius Method.

*Fellenius Method:* This is a modified version of the Method of Slices.

Here it is assumed that E1 =E2 = X1 =X2 (Figure 2.29)

Then, N = W cosα and S = 1/F [c′l +( Wcosα – ul) tanϕ]

Using Moment Equilibrium,

∑Wx =∑SR

∑WR sinα = ∑SR (Figure 2.39)

∑S = ∑W sinα = ∑1/F [c′l +( Wcosα – ul) tanϕ]

So, F = $\dfrac{\sum 1/F\,[c'l + (W\cos\alpha - ul)\tan\phi]}{\sum W \sin\alpha}$ (2.8)

*Bishop's Method:* The Modified (or Simplified) Bishop's Method is a method for calculating the stability of slopes. It is an extension of the Method of Slices. By making some simplifying assumptions, the problem becomes statically determinate and suitable for hand calculations. It is assumed that the forces on the sides of each slice are horizontal.

The method has been shown to produce factor of safety values within a few percent of the "correct" values.

$$F = \frac{\sum[\frac{c'+((W/b)-u)\tan\phi'}{\psi}]}{\sum[(W/b)\sin\alpha]} \qquad (2.9)$$

where

$$\psi = \cos\alpha + \frac{\sin\alpha\tan\phi}{F} \qquad (2.10)$$

Here, c' is the effective cohesion

ϕ' is the effective internal angle of internal friction

b is the width of each slice, assuming that all slices have the same width

W is the weight of each slice

u is the water pressure at the base of each slice

As F is on both sides of the equation, it is solved iteratively. An initial value of F is obtained by carrying the "Fellenious Method" and multiplying the solution by 1.2. This value is inserted into the right hand side of the equation, and the left hand side value of F is calculated. This new value is then inserted into the Right hand side and the process is repeated until the Right hand side = Left hand side.

*Janbu's Method:* The difficulty in analysing a non-circular failure surface is that it is difficult to find a single point through which many of the force components act. So, the moment equilibrium method used for circular surfaces is no longer the most appropriate. Janbu chose instead to use the force equilibrium method in the analysis. The equation of Factor of Safety here is followed as Bishop's Method. After discovering a certain amount of inaccuracy in this formula, Janbu decided on a correction factor $f_0$, which should be applied after iteration has taken place (in Bishop's Method):

$F_{corrected} = f_0 * F_{iterative}$

The value of $f_0$ is found from the limiting graphs (Figure 2.30). For this method, it is necessary to use narrow slices.

*Infinite Slope Analysis:* The simplest form of sliding surface is a plane parallel to the ground surface (Figure 2.31). This may be observed in the field as large flake or planar slides in natural hillsides, which are often initiated by softening and weathering processes extending downwards from the ground surface; by high groundwater pressures; or by toe unloading (Skempton, 1964). The term infinite slope is used to designate a uniform slope of an extent large enough that a typical element can be considered representative of the slope as a whole and irregularities at the toe and the crest of the slide can be ignored. The soil properties and porewater pressure at any given distance below the ground surface are assumed constant. The analysis is simple and direct.

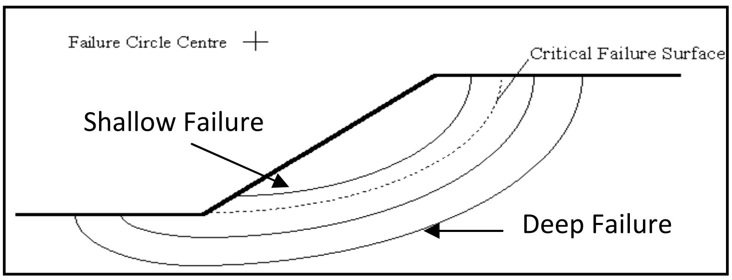



Figure 2.23: Variety of Slope Failure Circles Analysed at Varying Radii from a Single circle Center (Connolly, 1997)

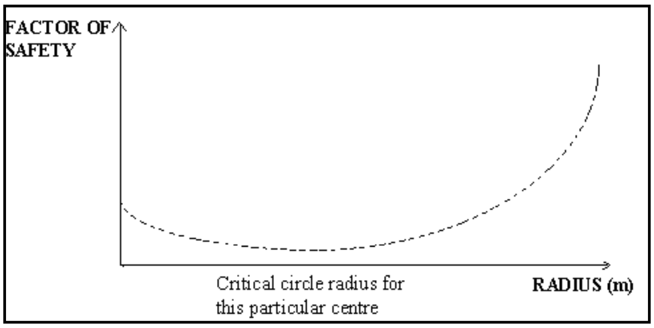



Figure 2.24: Graph Showing Factor of safety against Radius (Connolly, 1997)

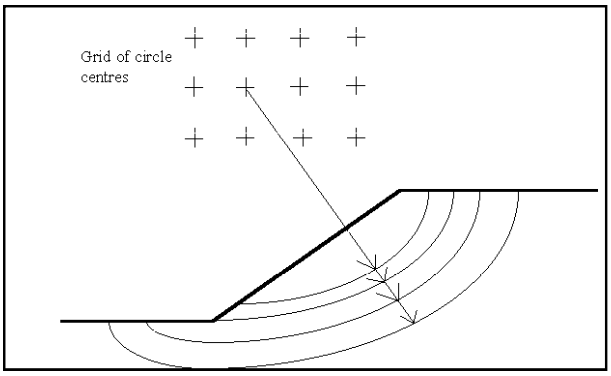
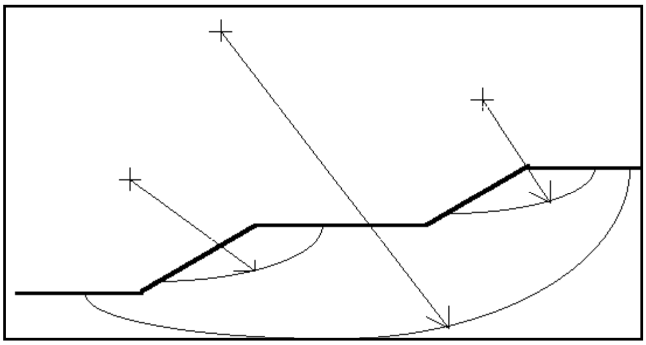



Figure 2.25: Failure Surface Analyzed from a Variety of circle Centers (Connolly, 1997)



2.26: Slope Showing Overall Failure Surface and Smaller Individual ones (Connolly, 1997)

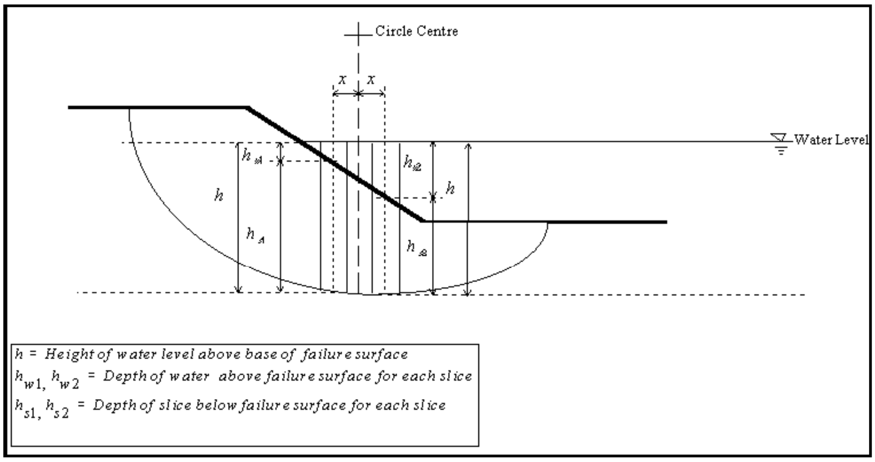



Figure 2.27: Analysing the Effect of External Water Load on a Slope (Connolly, 1997)

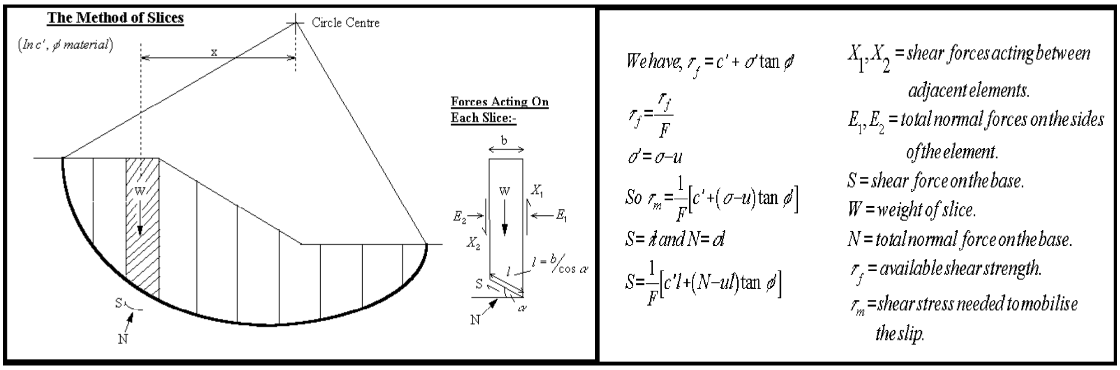



Figure 2.28: The Method of Slices (Connolly, 1997)

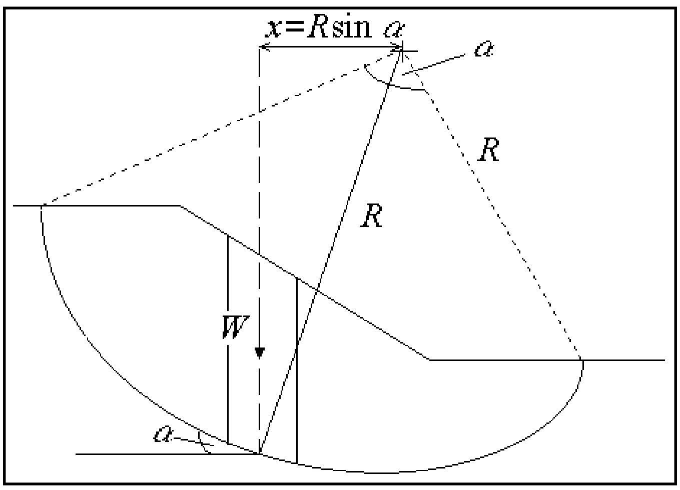



Figure 2.29: Fellenius Method (Connolly, 1997)

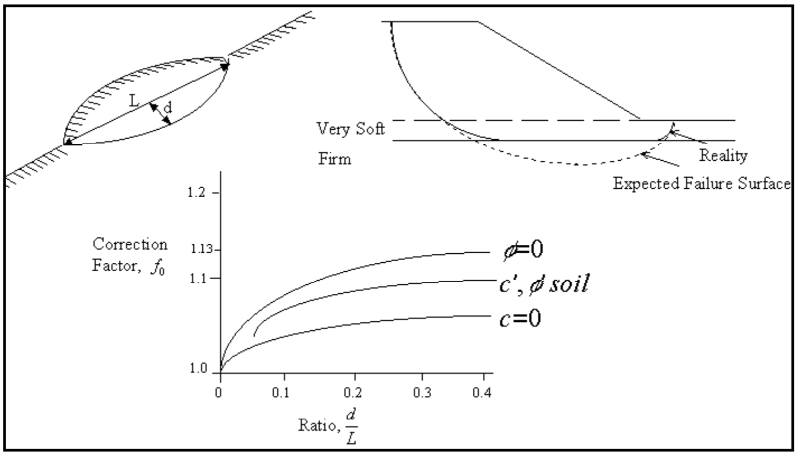



Figure 2.30: Limiting Graphs for Values of $f_0$ (Connolly, 1997)

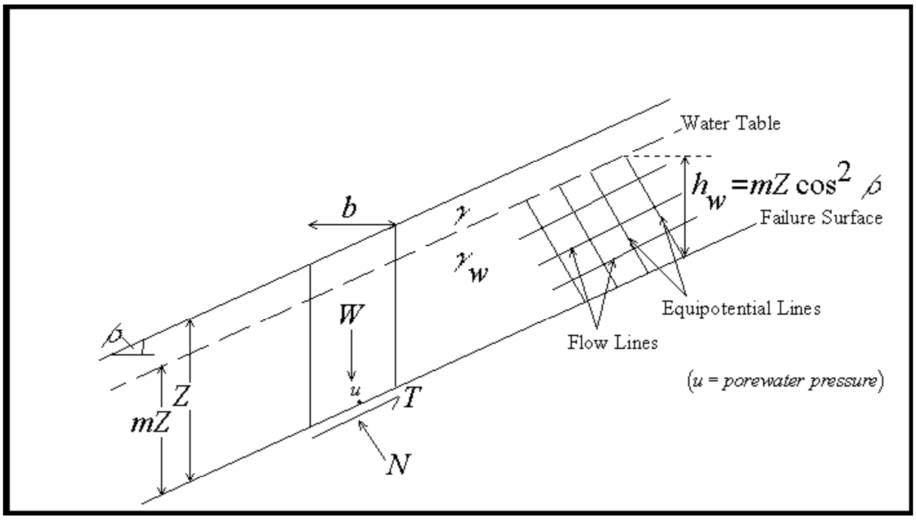



Figure 2.31: Infinite Slope Analysis (Connolly, 1997)

### 2.15.7 Computer Based Slope Stability Analysis

The calculations involved in slope stability analysis are repitetive and laborious. Thus the most problems in practice are now solved with the aid of computers. Details vary from program to program, but essentially the methods consist of reading the profile into the computer in the form of a series of straight lines and associated soil types, then superimposing on this profile a family of trial sliding surfaces which can be analysed to find the lowest safety factor for the slope. A good program eill permit specification of an irregular slope with variable soil properties expressed eithr in total or effective- stress terms. It will accommodate external water, line and earthquake loads, and can accept porewater pressures described by either a constant soil parameter $r_u = \mu/(\gamma H)$ or by a phreatic surface. It may also permit selection of the method of solution (for example, by Bishop's Method, Spencer's method etc.), and of the shape of the slide surface, whether cicular or non-circular (Fredlund, 1978).

The software XSTABL is such a program that provides an integrated environment for performing slope stability analyses running MS-DOS. There are many factors such as slope geometry and its surface conditions, roughness, weather and environmental conditions which influence stability of a slope. Considering the fact that it would be impossible to relate the stability to all these factors within the time and scope of this study, deep circle and shallow circle were considered for stability analyses using a computer code XSTABL.

*Analytical Features of the Program XSTABL*

XSTABL is a fully integrated slope stability analysis program. The Generalized Limit Equilibrium (GLE) method has been implemented in XSTABL. This method allows factors of safety to be calculated for force and moment equilibrium or for force equilibrium only, using different interslice force angle distributions. With this approach, the user can readily calculate the factor of safety according to Spencer's, Morgenstern-Price, or one of the methods proposed by the Corps of Engineers. If an analysis requires a search for the most critical failure surface, the simplified Bishop and Janbu methods of analysis are selected due to their relative ease of use. The program may be used to either search for the most critical circular, noncircular, or block-shaped surface, or alternatively, to analyze a single circular or non-circular surface. The critical surface is identified by automatically generating and analyzing failure surfaces between defined initiation/termination ranges or by connecting points randomly located within search boxes specified by the user. This aproach minimizes the required input parameters and can be effectively used to confine the surface generation within a narrow, well-defined zone. The soil strength along the failure surface may be described as either conventional (i.e., C, ø), undrained or non-linear Mohr Coulomb and can be either isotropic or anisotropic. The undrained strengths are assigned as a function of the vertical effective stress.

XSTABL is programmed to handle:

1. Heterogenous soil system
2. Anisotropic soil strength properties
3. Pore water pressure for effective stress analysis may be simulated by specifying
   a) A Peizometric surface
   b) Multiple Phreatic surfaces
   c) Pore pressure grid
   d) Pore pressure parameter, $R_u$
   e) Constant pore water pressure
4. Pseudo-static earthquake loading
5. Surcharge boundary loads.
6. Automatic generation and analysis of an unlimited number of circular, noncircular and block shaped failure surfaces.

*Parameters Used in XSTABL*

XSTABL uses a soil unit number to uniquely identify the different soils in the slope. The spatial distribution of the soils is then assigned by specifying the appropriate soil unit number corresponding to the soil beneath each boundary segment The parameters for each soil unit are assigned for isotropic and/or anisotropic soils using one of the options available under "SOIL" category.

A. Isotropic Soils

   XSTABL can include soils that exhibit isotropic or anisotropic strength properties. For each soil unit, the following properties are required:

   1. Moist Unit Weight: Used to calculate the weight of each portion of the discretized slice above the ground water level
   2. Saturated Unit Weight: used to calculate the weight of each portion of the discretized slice below the ground water level
   3. C- Value: Represents the intercept on the Mohr-Coulomb envelop for the strength parameters of the soil
   4. Φ- Value: Represents the slope of the Mohr-Coulomb envelop for the strength parameters of the soil
   5. $R_u$ Factor: Used to model the pore water pressures as a fraction of Ru of the total vertical earth pressure within the slope.

6. Constant Pore Pressure: This option allows the users to specify a constant pore water pressure for all points within a soil layer.
7. Water Surface Index: Defines a phreatic or piezometric surface that influences the soil layer if a soil unit is not affected by a water surface, a water surface index of 0 (zero) should be specified in the soil property data table.

B. Anisotropic Soils

Soils anisotropic strength properties are described by assigning the Mohr-Coulomb strength parameters (i.e. c and Φ) to discrete angular ranges between -90° to +90°, measured counterclockwise from the horizontal. Then, depending on the angle of the base of each discretized slice, the appropriate c and Φ values are selected from one of the specified ranges for the computing the factor of safety.

*Assumptions Used in XSTABL*

Water surfaces, associated with soil units, may be used to represent phreatic or piezometric surfaces for calculating pore water pressure at points within the soil mass if a water surface is not defined across the failure surface zone. In general the phreatic surface approach is more realistic and will calculate a higher effective strength. However, if piezometers have been installed, and pore water pressure data is available for a potential failure surface, the piezometric surface approach should be used for the analysis.

A. Phreatic Surface: These represent the free ground water level within the slope. In most slopes this groundwater level will be inclined, indicating ground water flow. Such conditions require that the pore water pressure calculations account for the seepage losses This requires the determination of the equipotential line passing through the center of the slice base. The equipotential line is assumed to be a vertical line. The inclination o the phreatic surface and the magnitude of the vertical distance between the phreatic surfaces is located above the ground surface, hydrostatic pressures are assumed to act upon the ground surface boundary.
B. Piezometric Surface: This presents the actual pressure head relative to a surface within the slopes. This relative surface, in two dimensions, will correspond to a line such as a potential failure surface. This option should only be used to examine the stability of single surfaces, or for a back analysis of an actual slope failure. Pore

pressures are calculated according to the vertical distance between the base of the slice and piezometric surface corresponding to the appropriate soil unit.

### 3.1 Data Collection

The goal of this study is to produce microzonation maps in GIS environment by incorporating the hazard analyses results. GIS is considered to be the most valuable and powerful software for spatial data compilation, integration, analysis and graphical and non-graphical representation. Thus an updated administrative boundary map of the study area is essential to represent the outcomes of the research. For geotechnical data collection field and laboratory investigations were used from the study of Imtiaz (2009).

### 3.2 Updated Administrative Boundary of Municipal Area

An important issue in developing a seismic microzonation map is the selection of an appropriate geographical reference, or geo-code, which will generally be driven by the availability of input data regarding soils conditions. Municipal areas are divided into wards and wards are divided into Mahallahs. For this study, Municipal administrative boundary incorporating locations of Wards was adopted as geographical reference (geo-code) for the microzonation. Recently Cox's Bazar municipality has been expanded and the administrative map has not been finalized yet. For this study the proposed map as of January 2009, was collected from Municipal Office where total area is divided in to 9 wards. The map is shown in Figure 3.1. GPS values of different core sites of the study area were collected. The existing municipal map was scanned and was converted into digital map. Thus GIS-based updated administrative boundary has been developed for the study area.

### 3.3 Geotechnical Data

Necessary data such as subsoil reports and geology, topography etc, was collected from different relevant sources. A total of 26 borehole SPT data were used to study site amplification as well as soil liquefaction potential characteristics of municipality area.

Twelve borehole data were upto a depth of 15 metres and fourteen boreholes are upto 30 meters. The borings were drilled vertically using the wash boring technique and equipment capable of pushing tube samplers by hydraulic pressure. SPT was carried out in each boring at nominal 1.5 m intervals and the N-values, i.e., number of blows count for each standard penetration was counted. Table 3.1 presents locations of borehole data from different areas of Cox's Bazar Municipal used for this study, where the first twelve locations are the primary sources and the rest are secondary source of Imtiaz, 2009. Figure 3.1(a) shows the borehole locations. To obtain soil parameters such as grain size (soil type and $D_{50}$) Grain Size Analyse data were also used from Imtiaz, 2009. Sample SPT and Grain Size Distribution curves are shown in Figure 3.1 (b) and (c).

Table 3.1: Location of Borehole Data of Cox's Bazar Municipal Area

| Sl No. | Location | Longitude | Latitude |
|---|---|---|---|
| 1 | Cyclone Shelter near Diabetic Hospital | 91.96212 | 21.44223 |
| 2 | Baharchhara High School | 91.96673 | 21.43847 |
| 3 | Shaibal Hotel Water Tank | 91.96683 | 21.43278 |
| 4 | Golf Field Laboni Moore | 91.97415 | 21.43012 |
| 5 | Shamudra Bilash, Middle Saikat Para | 91.98233 | 21.42287 |
| 6 | Baharchhara Gol Chattar Field | 91.97402 | 21.43463 |
| 7 | Cox's Bazar Nursery | 91.97487 | 21.43752 |
| 8 | Cox's Bazar KG & Model High School | 91.97060 | 21.44402 |
| 9 | Fulbagh, Rice Market Road | 91.98188 | 21.44445 |
| 10 | Tekpara, Near Pond | 91.98612 | 21.44283 |
| 11 | Rumaliar Chhra, HSA Road | 91.99183 | 21.44073 |
| 12 | Bibekanondo Bidya Niketon, Ghonarpara | 91.97903 | 21.43757 |
| 13 | 76/A, Kalatoli-3 | 91.97925 | 21.42755 |

| | | | |
|---|---|---|---|
| 14 | Cox's Bazar Press Club | 91.98680 | 21.47290 |
| 15 | Central Govt. PS cum CS | 91.99040 | 21.45380 |
| 16 | Peskarpara Govt. PS cum CS | 91.98630 | 21.45540 |
| 17 | Kosturaghat Govt. PS | 91.98350 | 21.45320 |
| 18 | Kolatoli World Vision MCS | 91.99240 | 21.41800 |
| 19 | Baitus Sharaf Jameya Mosque, South Baharchhara | 91.98050 | 21.43550 |
| 20 | Bangladesh Red Crescent Society, Motel Road | 91.97380 | 21.44230 |
| 21 | Bangladesh Water Development Board | 91.97720 | 21.43980 |
| 22 | Tekpara Govt. PS | 91.98730 | 21.44590 |
| 23 | Ghonarpara, Near Kaderia Non-Govt. PS | 91.98360 | 21.43840 |
| 24 | Mosjid Compound, Ice Factory Road | 91.99240 | 21.44630 |
| 25 | Ramkrisna Shebasram, Baiddorghona | 91.98710 | 21.43980 |
| 26 | Primary Education Officers' Compund | 91.99250 | 21.44010 |

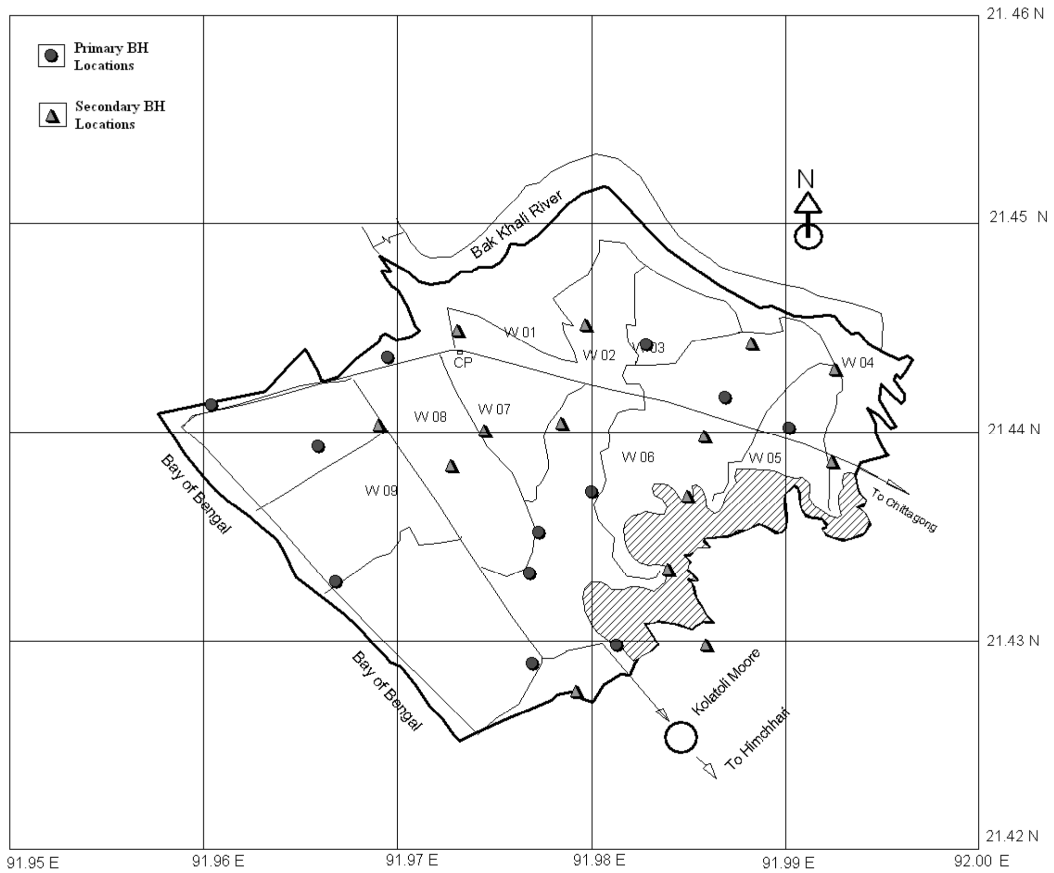



Figure 3.1(a): Cox's Bazar Municipal Area Map Showing Soil Borehole Locations

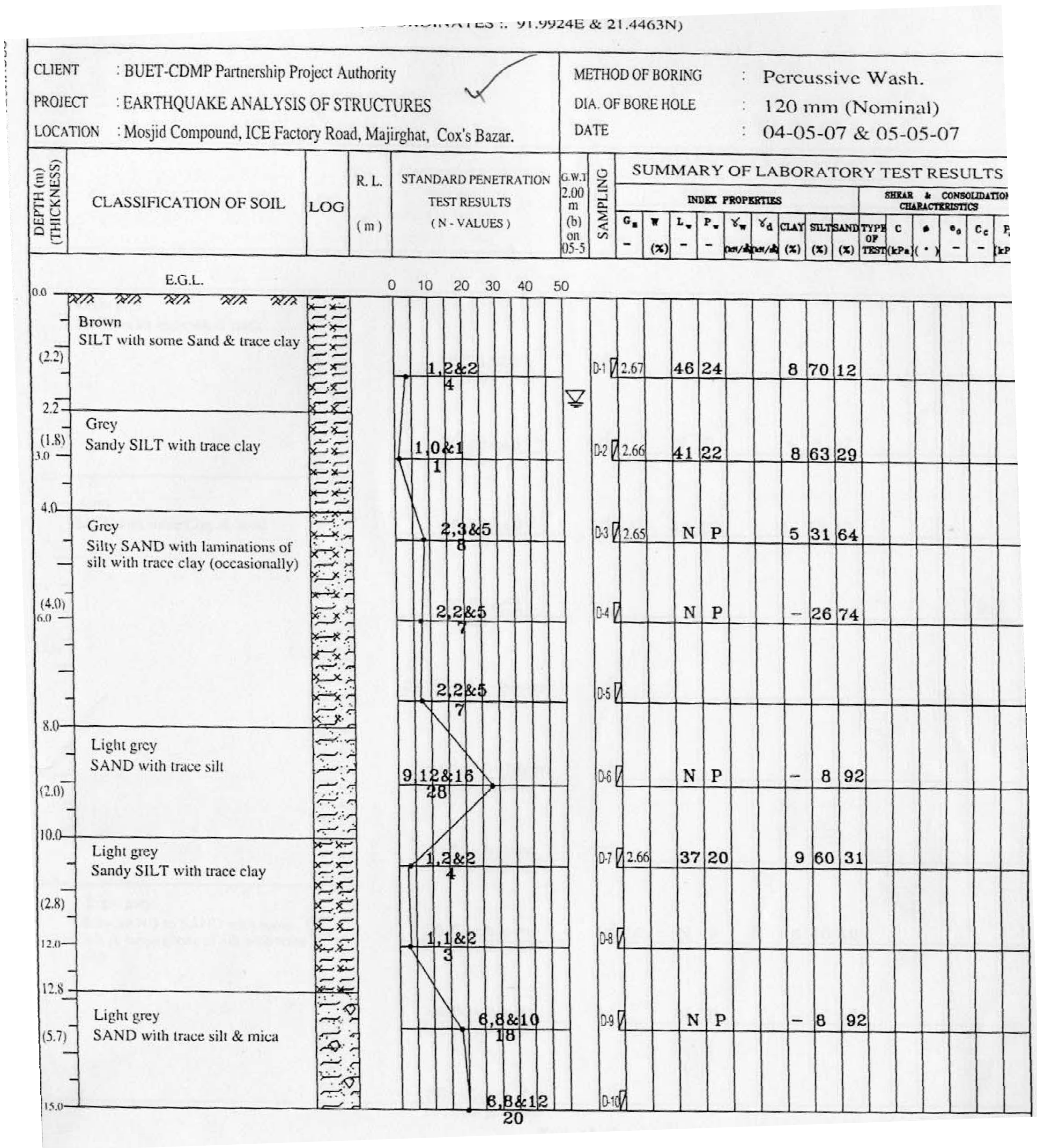
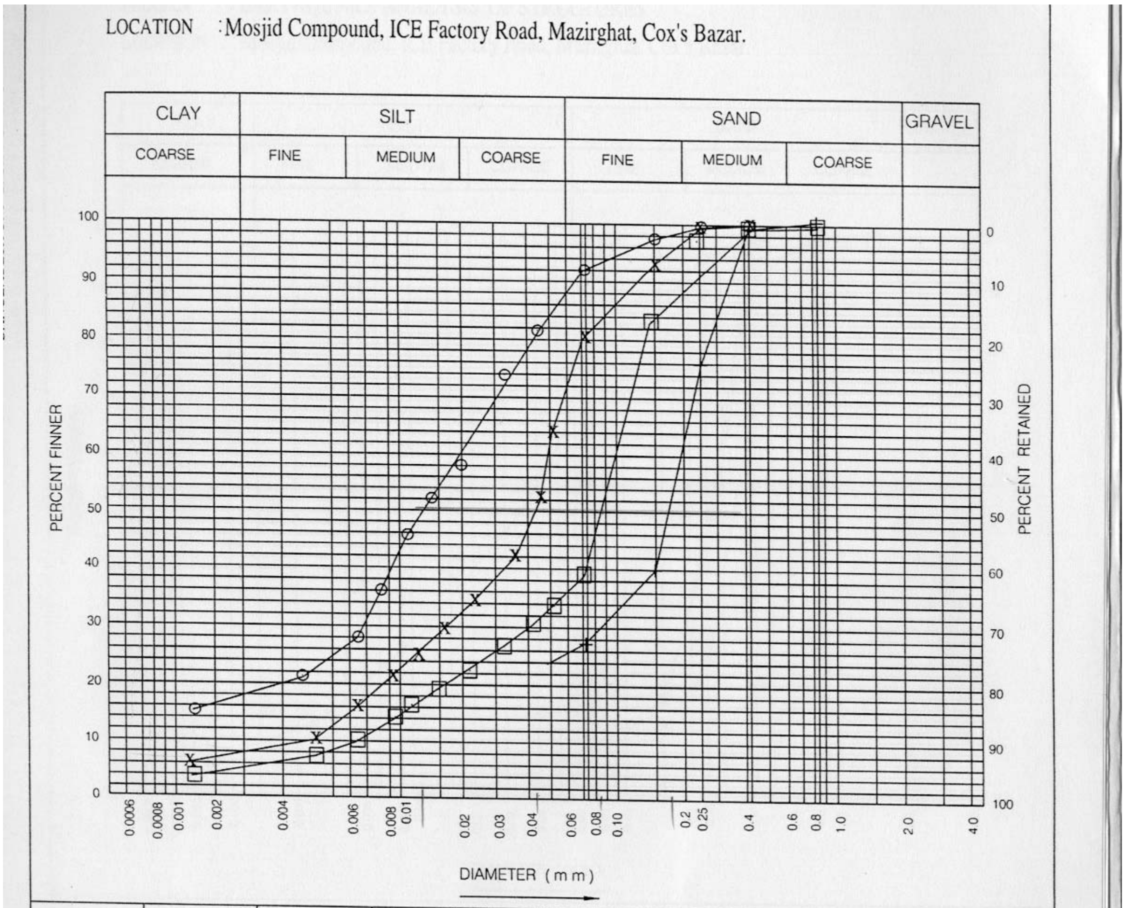



Figure 3.1(b): Sample SPT data sheet




| B.H. NO. | SAMPLE NO. | DEPTH (m) | SYMBOL | CLAY (%) | SILT (%) | SAND (%) | SP. GRAVITY | $D_{60}$ / $D_{10}$ |
|---|---|---|---|---|---|---|---|---|
| 21 | D-1 | 1.05-1.50 | -o-o-o- | 18 | 70 | 12 | 2.67 | |
| | D-2 | 2.55-3.00 | -x-x-x- | 8 | 63 | 29 | 2.66 | |
| | D-3 | 4.05-4.50 | -□-□-□- | 5 | 31 | 64 | 2.65 | |
| | D-4 | 5.55-6.00 | -+-+-+- | – | 26 | 74 | | |

Figure 3.1(c): Sample Grain Size Distribution curves

Hill ranges and hillock mainly appear to the Northern part of the Cox's Bazar town. Baillarpara, Ghonarpara, Baiddorghona, Pahartali, Light House Para, Bus Terminal, Saikat Para, Kolatoli areas of the municipality are mainly consisted of these hillocks. These hills range from 15 meters to 40 meters in height. From the surface elevation map produced by the Geological Survey of Bangladesh (Alam et. al., 1990) it can be observed that the average height of this hilly range is 30 meters.

Hilly regions of this area have been surveyed and location, height, slope and other relevant data have been collected. The slopes of the hills range from 45 degree to almost 90 degrees. All most all the hill ranges contain some eroded slopes with almost vertical positioning. Photographs of some of the prominent hills have been presented in Appendix D. Dense population, houses and even multistoried buildings have been observed on these eroded slopes and at their vicinity.

Eleven disturbed samples from different locations (photographs are provided in Appendix E) 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. Table 3.2 and Figure 3.2 show the locations of the samples.

Table 3.2: Sample locations for estimation of landslide potential

| Sl No. | Location | Longitude | Latitude |
|---|---|---|---|
| 1 | Hill behind PTI School | 91.98433 | 21.43933 |
| 2 | Ghonarpara (Boiddorghona) | 91.98280 | 21.43807 |
| 3 | Light House Hill | 91.97863 | 21.43055 |
| 4 | Kolatoli Bipass | 91.98728 | 21.41703 |
| 5 | Boiddorghona (Behind Mediplus Pharmacy) | 91.98290 | 21.43765 |
| 6 | Kolatoli Sykat Para | 91.98367 | 21.42183 |
| 7 | Bus Terminal | 91.99640 | 21.43642 |
| 8 | Khaja Monjil, Pahartoli | 91.98292 | 21.43498 |
| 9 | Circuit House | 91.97613 | 21.43650 |
| 10 | Ghonerpara Road(M r. Subrata's House) | 91.98102 | 21.43665 |
| 11 | Boillarpara Temple Hill | 91.98950 | 21.43533 |

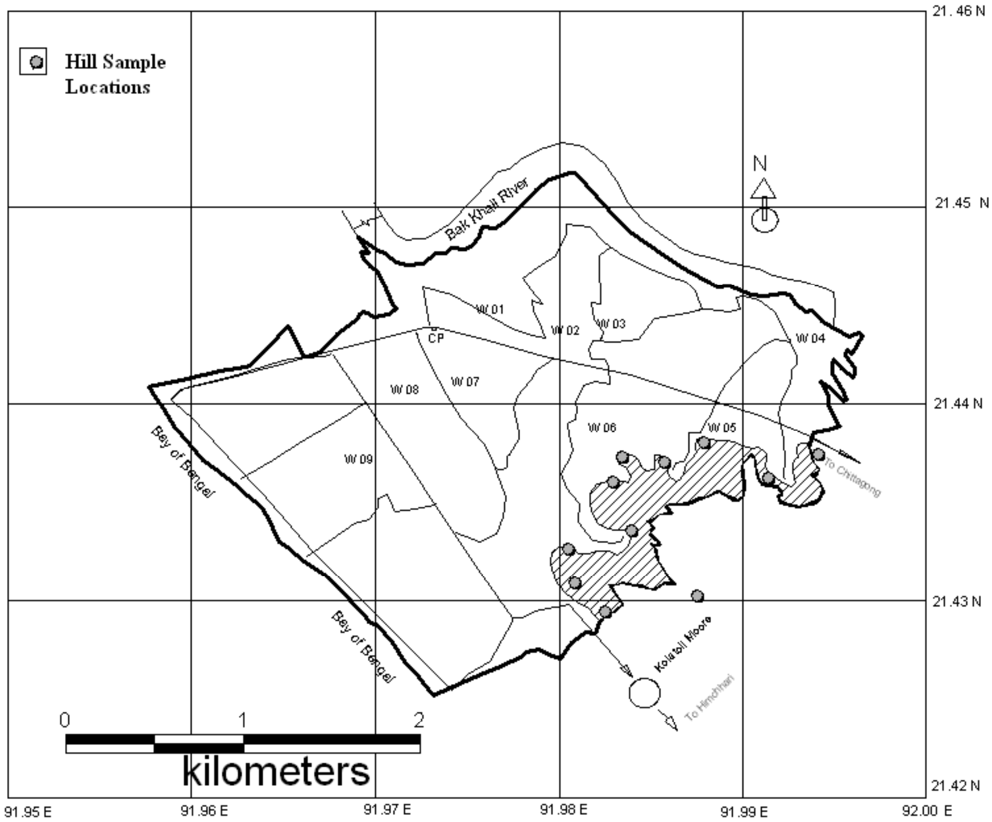



Figure 3.2: Soil sample locations for estimation of landslide potential

### 4.1 Seismic Hazard Analysis

It is well understood that earthquake damage to life and property results primarily from strong-ground shaking and indirect shaking-induced hazards such as liquefaction, landslide etc. Severe earthquakes of the last decade in Armenia, China, India, Indonesia, Mexico, Taiwan, Tehran, Turkey and the United States have reemphasized the importance of local geologic site conditions in estimating the regional damage and consequent losses due to future major earthquakes. Again during land use management, city planning, engineering design and in similar applications, proper evaluation of earthquake hazard is needed. 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.

Seismic hazard analysis involves the quantitative estimation of ground shaking hazards at a particular area. Seismic hazards can be analyzed deterministically as and when a particular earthquake scenario is assumed, or probabilistically, in which uncertainties in earthquake size, location, and time of occurrence are explicitly considered (Kramer, 1996). A critical part of seismic hazard analysis is the determination of Peak Ground Acceleration (PGA) for an area/site.

In this study, seismic hazard is defined as the probability that an event is exceeded for a given time interval and the frequency of occurrence of this event. Thus seismic risk analysis determines the probability of occurrence of a given event or conversely, the identification of the event for a given probability or risk for a given site or area. The event may be any parameter (e.g., PGA, PGV, PGD, Intensity) which is deemed to be representative of the effect which is to be studied. It is important to consider the parameters which will correlate well with the effect to be considered. For analyzing liquefaction potential, it is necessary to use PGA because it directly affects the lateral force imposed on soil. This expected lateral force is then considered in determining the safety factor for a particular soil location.

### 4.2 Methodology

Numerous methods for earthquake hazard assessment in a given site are available today. Lomnitz and Epstein (1966) employed the Poisson process for the occurrence of large earthquakes which is still used. Cornell (1968) and Esteva (1968) derived the general basis for the most complete analysis of the whole seismic hazard problem with the inclusion of the propagation mechanism of the ground motion. Shah and Vagliente (1972) used the Markov model of earthquake prediction in seismic hazard analysis. A methodology for seismic hazard estimation based on historical earthquake occurrences is presented in detail in Tomatsu and Katayama (1988) and Molas and Yamazaki (1994). In Japan, the seismic risk method proposed by Kawasumi (1951) is still popular while in the United States, the basic method proposed by Cornell (1968) is often used.

A methodology for seismic hazard estimation based on historical earthquake occurrences is presented in detail below. The seismic hazard evaluation at a specified site depends upon the definition of the following four models:

(a) *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. Figure 4.1 shows different source models.

(b) *Seismicity model:* The seismicity of each of the modelled 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

$$\log(v)=a+b*M \tag{4.1}$$

$$\log(v) =a+b*\log(y) \tag{4.2}$$

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

$$M=(-\log(T)-a)/b \tag{4.3}$$

$$\log(y)=(-\log(T)-a)/b \tag{4.4}$$

where $T$ (=l/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.

(c) *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

$$\log(y) = b_1 + b_2 (Ms) - b_3 \log (r) - b_4 (r) \tag{4.5}$$

where $r^2 = d^2 + h^2$, $r$ is the hypocentral distance (km), $d$ is the epicentral distance (km), $h$ is 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* for Equation (4.4)

(d) *Recurrence forecasting model*-Various statistical models have been tested in numerous research papers; however, 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. Since hazard analysis defines the occurrence of ground motions equal to or larger than a specified value, the probability of exceedance is used. For a Poisson process this may be expressed as

$$p=1-exp(-vt) \qquad (4.6)$$

where $v$ is the mean annual occurrence rate of events of particular peak ground acceleration over a given time $t$. From equations the value of the peak ground acceleration for $a$ given $b$ and time period $t$ can be calculated as:

$$log(y)=log(-ln(p/t)-a)/b \qquad (4.7)$$

From the assumption of the Poisson process, the relation between the probability of exceedance and the return period of peak ground acceleration, $T$, is given by

$$T=1/v=-t/log(p) \qquad (4.8)$$

## 4.3 Earthquake Analysis

In the regional seismic loss estimation analysis it is needed to determine the bedrock motion in the region. 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. Applying statistical regression analyses to recorded data has developed numerous relationships in the past. Often these relationships are developed with different functional forms and with different definitions of ground motion, magnitude, distance, and site conditions. Figure 4.2 shows the flowchart for earthquake hazard analysis at bedrock level and Figure 4.3 shows flow chart for PGA estimation at ground surface.

### 4.3.1 Selection of Earthquakes around the Site

To estimate the seismic hazard in any particular site within a region requires a selection of earthquakes which affect significantly the value of the hazard output. However, there is no strict rule for selecting the maximum epicentral distance to the site. A small area around the site results in a smaller number of earthquakes to be considered and some events outside the zone considered may affect the hazard in the site. This, naturally, will decrease the data set for regression. On the other hand, a too large area may include earthquakes which do not affect the seismic hazard in the site and are thus useless. It has been observed (Sharfuddin, 2001) for an epicentral distance of 200 km and beyond, the b-coefficient of the Gutenberg-Richter formula is relatively stable. 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 (Appendix B, Figure 4.4).

### 4.3.2 Selection of Attenuation Law of Peak Ground Acceleration

In Bangladesh, no PGA based attenuation law exists. To get engineering bedrock level **(**depth of 30 m**)** PGA, equations presented in Table 2.6 (chapter 2) were used. The historical earthquakes around the study area and their magnitude, epicentral distance, focal depth and intensity were considered to estimate PGA (%g) value in this study.

To select the most suitable attenuation law for predicting rock motions, the methodology adopted in few previous studies were followed (Sabri 2001, Sharfuddin 2001). From these studies it is 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 has already been used for Bangladesh for seismic hazard analysis (Sharfuddin, 2001) and due to its simple form it was selected for further use. Table 4.1 shows the PGA values at bedrock level from two attenuation laws for the most significant earthquakes around the study area. The attenuation laws for rock used in this study, McGuire (1978) and Joyner and Boore (1981) are presented as Equations 4.9 and 4.10 respectively.

$$PGA = 0.0306e^{0.89M}r^{-1.17} \quad (4.9)$$

$$PGA = 0.0955\ e^{(.573M)}\ d^{(-1)} * e^{(-0.00587d)},\ \ d = (r^2+h^2)^{0.5} \quad (4.10)$$

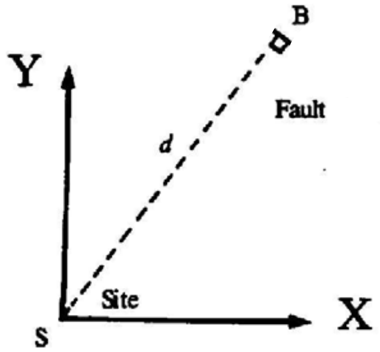
Where, M = Earthquake Magnitude, d = Epicentral Distance, r = Hypocentral Distance and h = Depth

Table 4.1: PGA values (% of g) at bedrock level from different attenuation laws for different scenario events

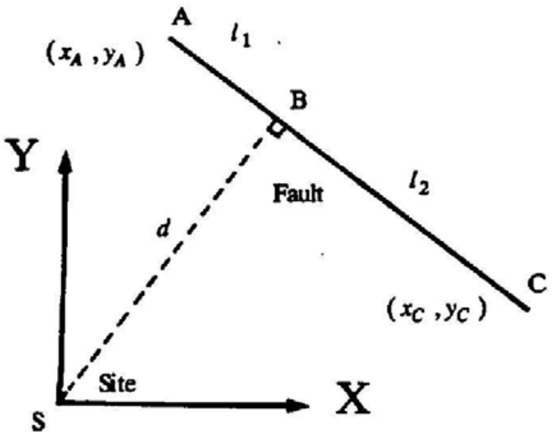
| Attenuation Law | M = 7.8 (1664) | M = 7.66 (1858) | M = 7.9 (1912) | M = 6.5 (1955) | M = 6.24 (1959) |
|---|---|---|---|---|---|
| McGuire (1978) | 0.0330 | 0.0214 | 0.0266 | 0.0562 | 0.0780 |
| Joyner and Boore (1981) | 0.0029 | 0.0011 | 0.0013 | 0.0260 | 0.0401 |

### 4.3.3 Regression Analysis

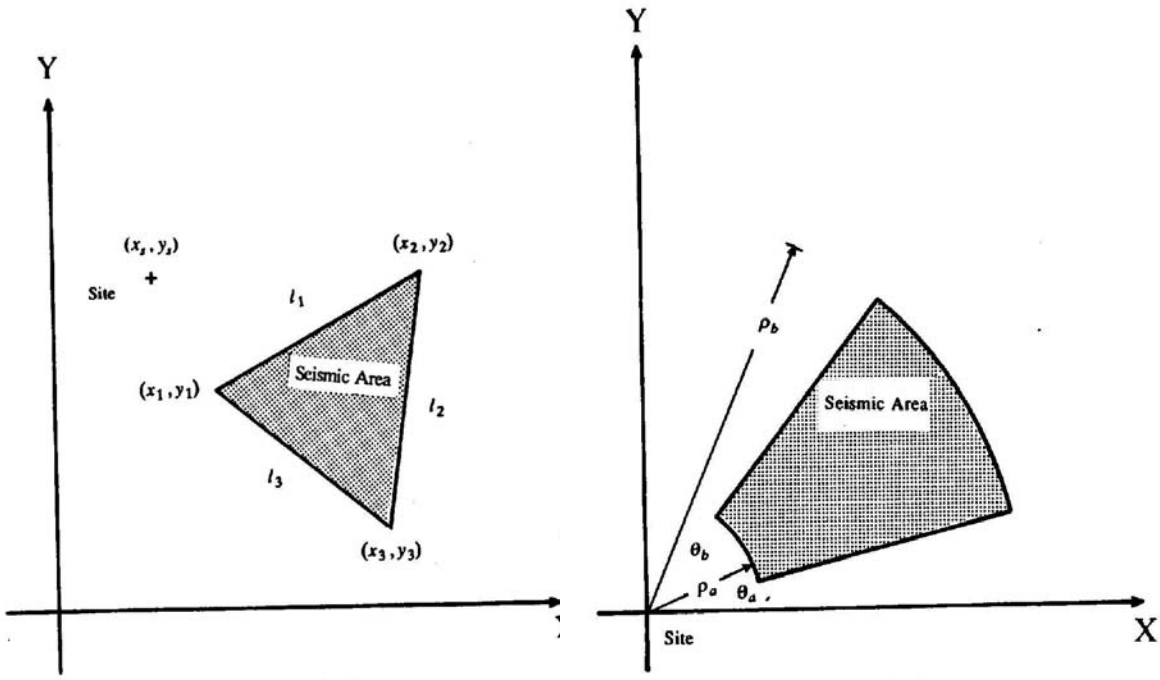
Seismic parameter b was evaluated from G-R relationship (Gutenberg and Richter, 1944), a method utilizing extreme, instrumented and complete catalogs. Linear regression was applied to each site which is taken as the centre of an area of 250 km radius where past earthquakes are likely to occur again. The hazard curves of Mean Annual Rate of Exceedance (ν) versus Peak Ground Acceleration (PGA) and Mean Annual Rate of Exceedance (ν) versus Earthquake Magnitude (M) were generated at the rock levels. Figure 4.5 and 4.6 show the regression curves fitting for Cox's Bazar Municipal area. The hazard in terms of the rock level PGA values and probable earthquake magnitude corresponding to return periods of 200 years were quantified from equation 4.3 and 4.4 as, 0.18g and 8.26 consecutively. Since the largest Magnitude earthquake around the 350-450 km radius of the study area is 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.




(a) Point




(b) Line source




(c) Different area sources

Figure 4.1: Different source models

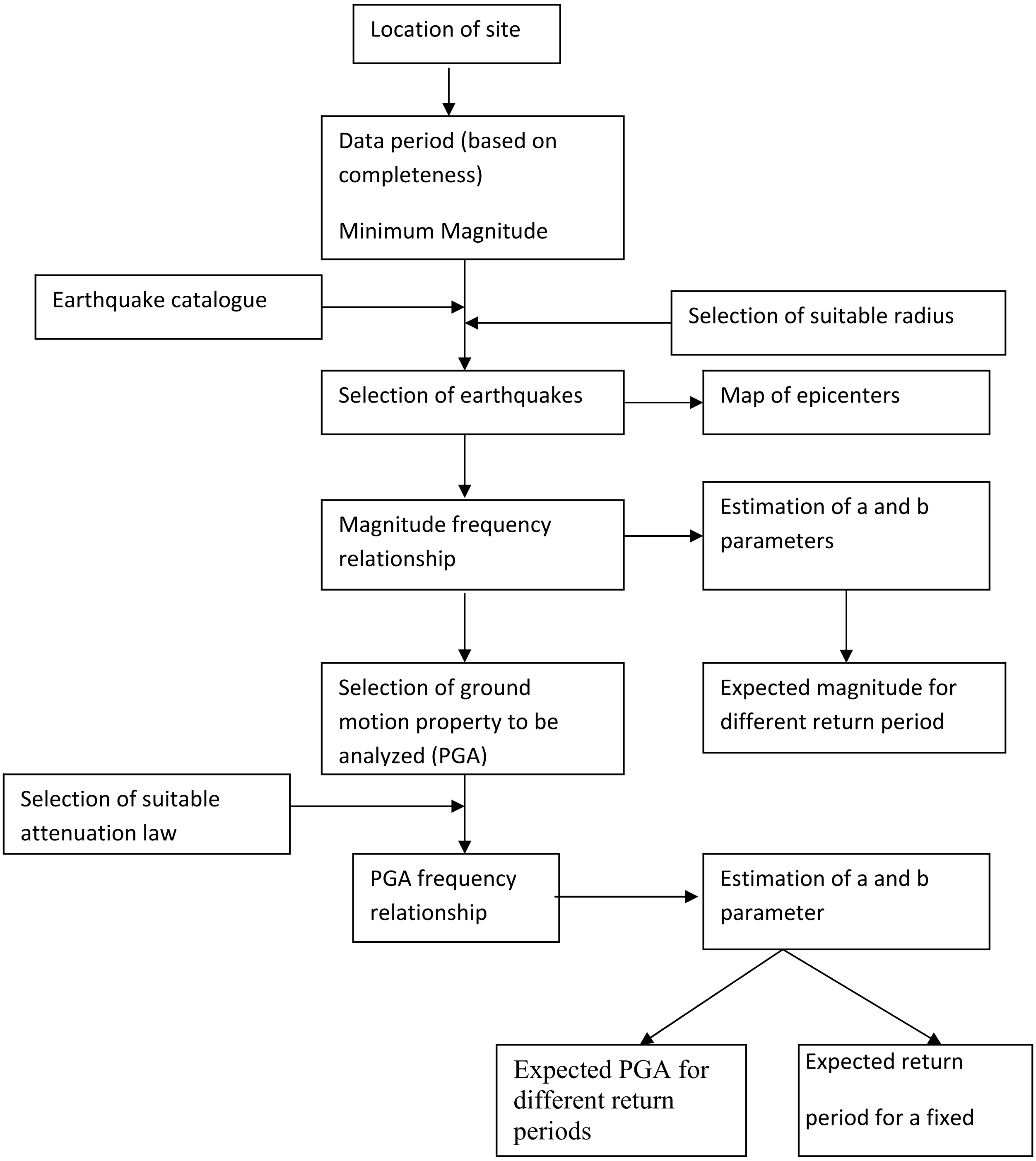



Figure 4.2: Schematic flow of PGA determination at bedrock

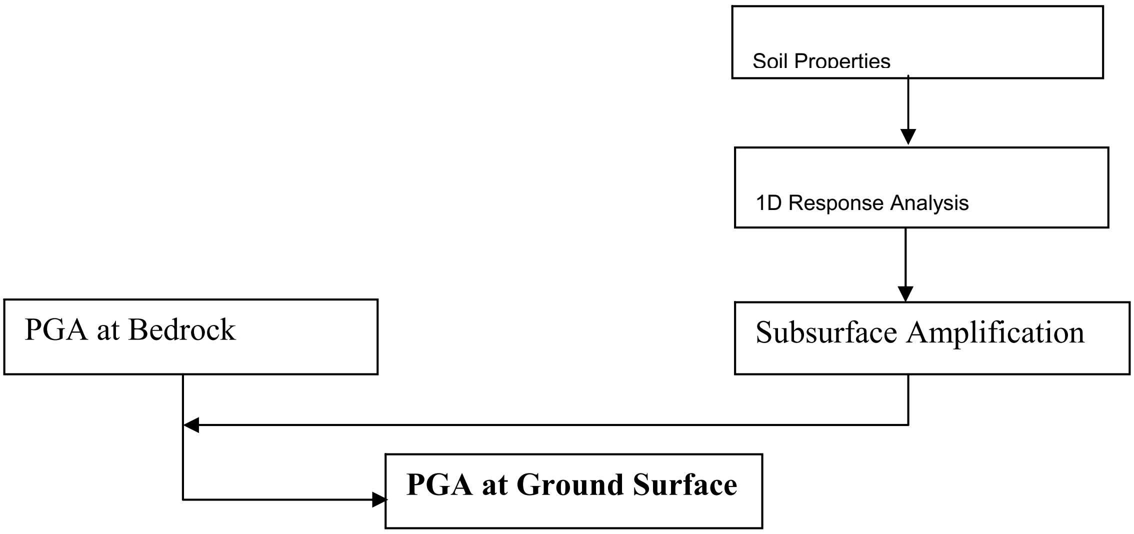



Figure 4.3: Flow chart for PGA determination at ground surface

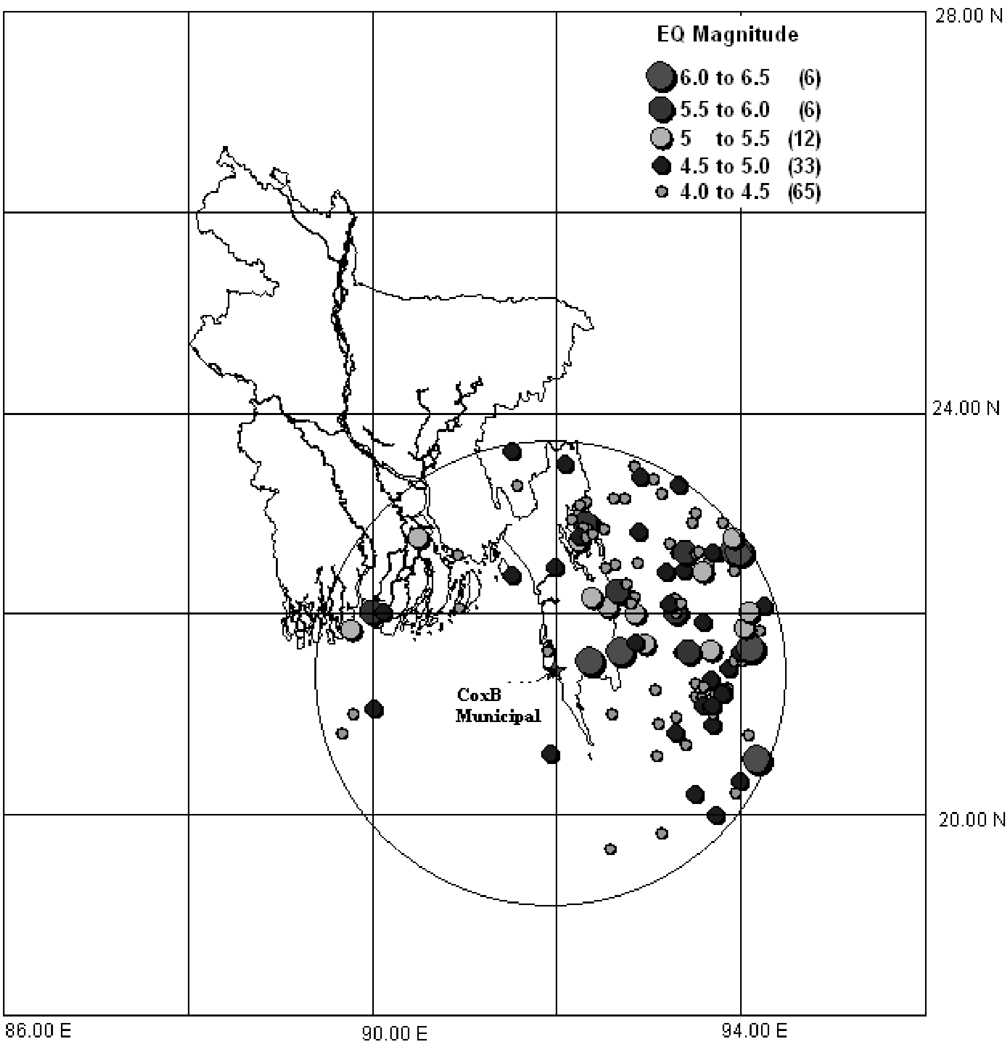



Figure 4.4: Historical Earthquakes around Cox's Bazar Municipal

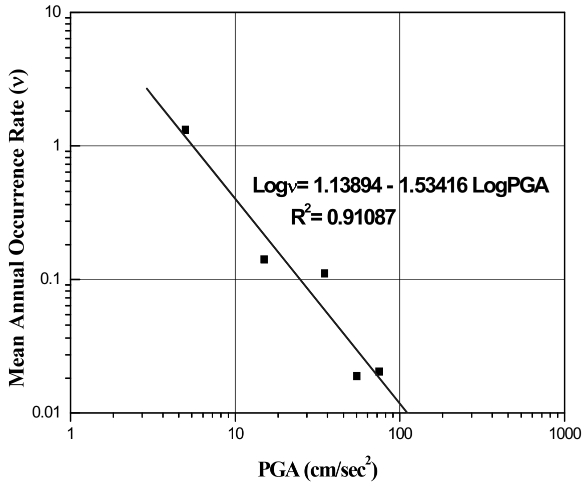



Figure 4.5: PGA versus mean occurrence rate for Cox's Bazar Municipal

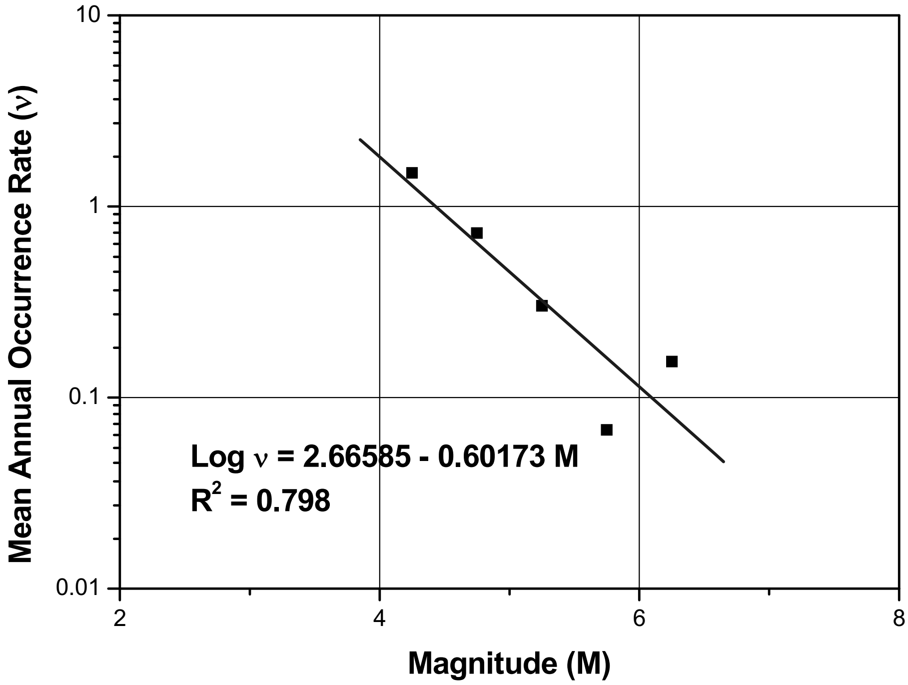



Figure 4.6: Magnitude versus mean occurrence rate for Cox's Bazar Municipal

### 4.4 Local Site Effects

Seismic zonation maps for strong-ground shaking, liquefaction and landslide can play a significant role in mitigating the effects of earthquakes. Geographic information system (GIS) provides an ideal environment for compiling and integrating regional databases of spatial geologic and geotechnical information for purposes of seismic zonation.

#### 4.4.1 Site Amplification Analysis

For site amplification analysis, shear wave velocity for 26 borehole data up to a maximum depth of 30m were calculated by using equation of Tamura and Yamazaki (2002) presented in Table 2.7. This empirical relation combines both depth and SPT-N value with soil conditions. A soil database of 26 boreholes was developed in MS-EXCEL. In this study, the engineering bedrock was 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. 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. An estimation of the fundamental frequency and the maximum value of the amplification were obtained for each site from the transfer functions. Typical graphical representation of frequency versus amplitude is shown in Figure 4.7. For estimating the site amplification and predominant frequency from the two approaches were taken into consideration. To evaluate the extreme and worst hazard condition first peak of the plot was considered assuming that the largest amplification of the soil will occur at the lowest natural frequency or its fundamental frequency. The other approach involved the estimation of average horizontal spectral amplification (AHSA). This was adopted to derive more precise quantitative relationship between surface geology and local amplification. In this case the average amplification value was estimated in the 0.1-10.0 Hz frequency range (Shima, 1978) and the frequency value corresponding to that average amplification factor were selected. Table 4.2 presents the site amplification factors and corresponding predominant frequencies estimated at different locations of Cox's Bazar Municipal area.

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 ranges of frequencies. The results were plotted on the Cox's Bazar municipal area map using spatial interpolation among the borehole locations and converting the vectorial point features into continuous raster map through grid generation. Thus microzonation maps (Figure 4.8 to Figure 4.11) based on site amplification (times) and fundamental frequencies (hz) were developed considering the two conditions.

In this study, the intensity attenuation law (Equation 4.11) for proposed by Sabri (2001) was also used to verify the surface PGA. These intensities were converted into PGAs by following Trifunac and Brady (1975) equation 4.12. The maximum PGA obtained from this relationship for alluvial soil was 0.25g for M = 6.24 earthquake of 1959. This PGA was further compared to the ground surface PGA obtained through imposing subsurface amplification to the bedrock PGA from McGuire (1978) equation.

$$I = 8.378+1.283*M-0.0007483*r-4.9*\log(r) \quad (4.11)$$

$$\log PGA = 0.014+0.3 * I \quad (4.12)$$

where, I = Intensity of Earthquake

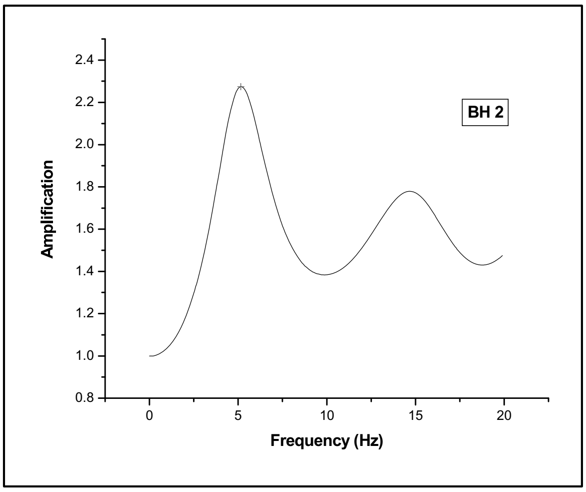
M = Magnitude of Earthquake and

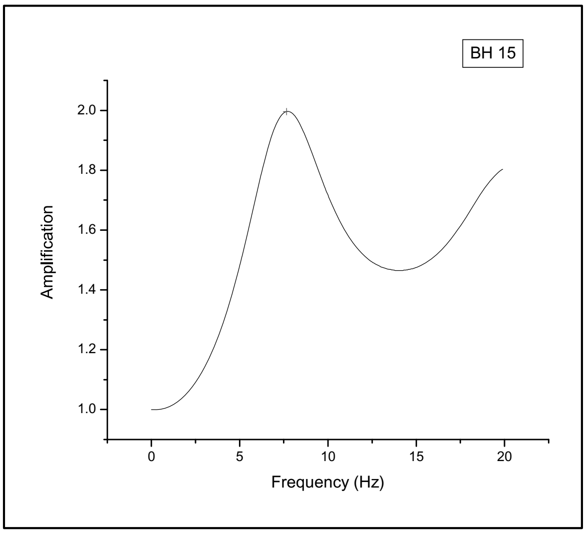
r = Hypocentral Distance

Table 4.2: Results of Amplification factor and corresponding predominant frequency at different locations of Cox's Bazar Municipal Area

| Sl No. | Location | Frequency (Hz) | | Amplification | |
|---|---|---|---|---|---|
| | | 1st Peak | AHSA | 1st Peak | AHSA |
| 1 | Diabetic Hospital Cyclone Shelter | 5.3 | 3.8 | 2.0 | 1.7 |
| 2 | Baharchhara High School | 5.2 | 3.6 | 2.3 | 1.7 |
| 3 | Shaibal Hotel Water Tank | 5.2 | 3.4 | 2.2 | 1.6 |
| 4 | Golf Field Laboni Moore | 5.0 | 3.3 | 2.0 | 1.6 |
| 5 | Shamudra Bilash, Middle Saikat Para | 5.3 | 3.6 | 2.0 | 1.6 |
| 6 | Baharchhara Gol Chattar Field | 5.9 | 4.1 | 2.1 | 1.7 |
| 7 | Cox's Bazar Nursery | 6.1 | 4.1 | 2.0 | 1.6 |
| 8 | Cox's Bazar KG & Model High School | 5.5 | 3.7 | 2.2 | 1.6 |
| 9 | Fulbagh, Rice Market Road | 4.2 | 3.6 | 2.2 | 1.6 |
| 10 | Tekpara, Near Pond | 4.6 | 3.2 | 3.6 | 2.0 |
| 11 | Rumaliar Chhra, HSA Road | 7.1 | 5.1 | 2.9 | 2.2 |
| 12 | Bibekanondo Bidya Niketon, Ghonarpara | 6.8 | 4.4 | 1.9 | 1.6 |
| 13 | 76/A, Kalatoli-3 | 5.9 | 4.2 | 2.2 | 1.7 |
| 14 | Cox's bazar Press Club | 5.6 | 4.0 | 2.6 | 1.9 |
| 15 | Central Govt. PS cum CS | 7.7 | 5.5 | 2.0 | 1.6 |
| 16 | Peskarpara Govt. PS cum CS | 8.0 | 5.2 | 2.8 | 2.1 |
| 17 | Kosturaghat Govt. PS | 7.7 | 5.2 | 2.2 | 1.7 |
| 18 | Kolatoli World Vision MCS | 8.1 | 5.4 | 2.2 | 1.7 |
| 19 | Baitus Sharaf Jameya Mosque | 7.9 | 4.7 | 1.9 | 1.5 |
| 20 | Bangladesh Red Crescent Society | 7.3 | 4.8 | 2.0 | 1.6 |

| | | | | | |
|---|---|---|---|---|---|
| 21 | Bangladesh Water Development Board | 7.2 | 4.8 | 1.9 | 1.6 |
| 22 | Tekpara Govt. PS | 5.7 | 4.1 | 3.2 | 2.1 |
| 23 | Ghonarpara, Near Kaderia Non-Govt. PS | 7.3 | 4.8 | 2.2 | 1.7 |
| 24 | Mosjid Compound, Ice Factory Road | 3.8 | 2.8 | 2.8 | 2.1 |
| 25 | Ramkrisna Shebasram, Baiddorghona | 5.3 | 3.3 | 2.4 | 1.6 |
| 26 | Primary Education Officers' Compund | 11.2 | 4.3 | 2.4 | 1.5 |




area

Figure 4.7: Typical Plots of transfer functions for two different boreholes conducted at the study

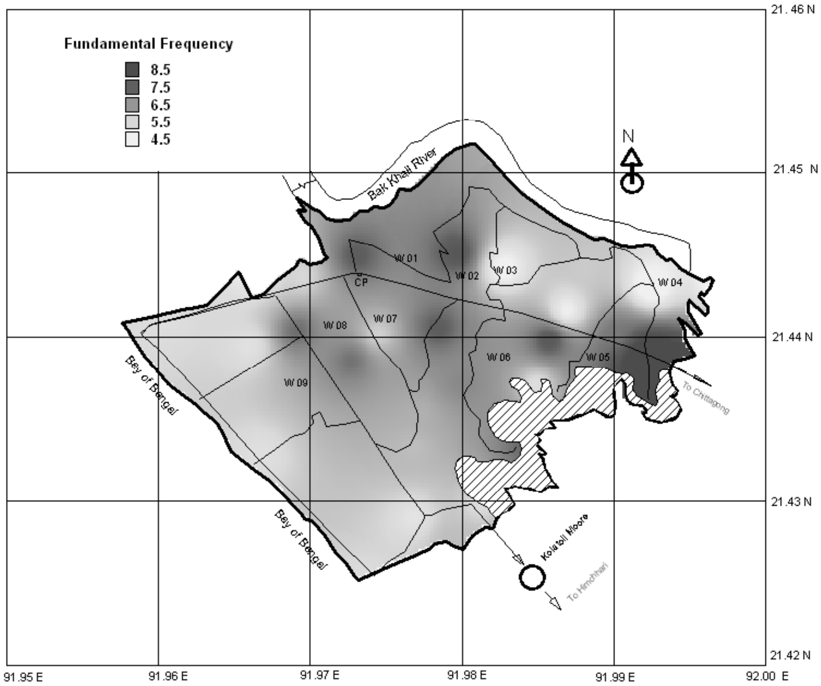



Figure 4.8: Microzonation map based on fundamental frequencies considering extreme condition

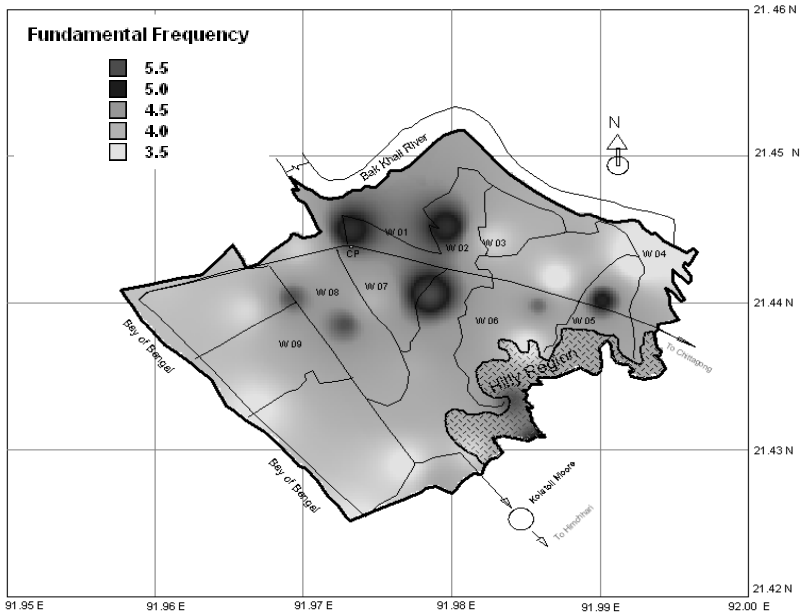



Figure 4.9: Microzonation map based on fundamental frequencies considering AHSA

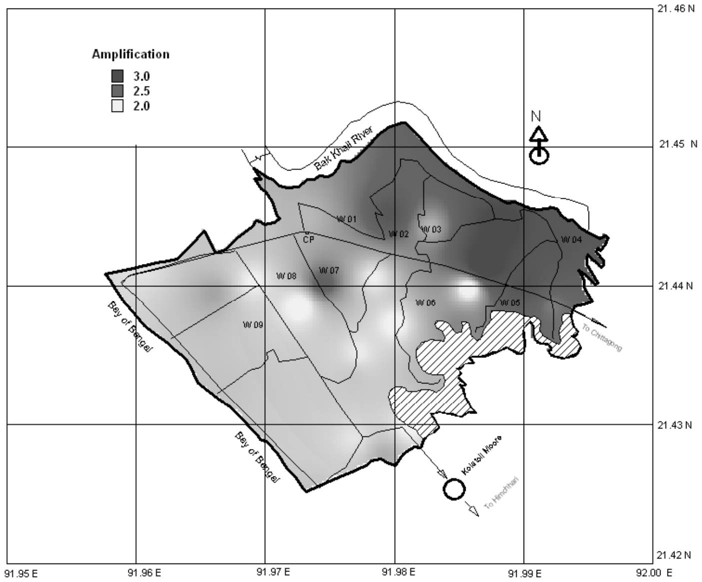



Figure 4.10: Microzonation map based on maximum amplification considering extreme condition

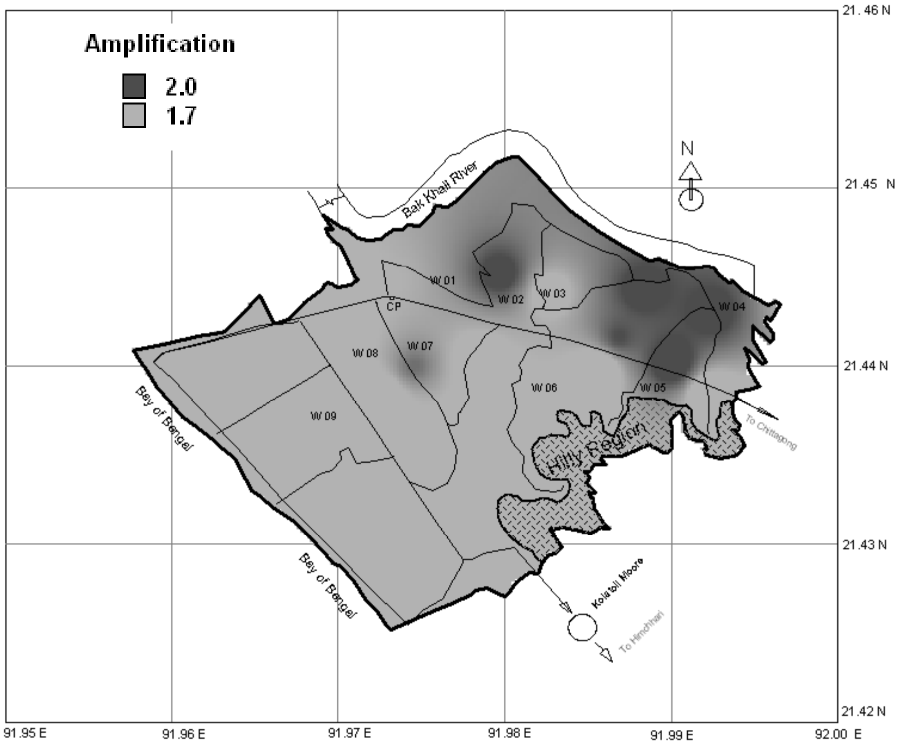



Figure 4.11: Microzonation map based on maximum amplification considering AHSA

### 4.4.2 Liquefaction Analysis

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 0.41 g at extreme condition and 0.31 g considering AHSA. These PGAs were used in liquefaction analyses for the two cases. Figure 4.12 shows the flow chart for liquefaction potential analysis for the study area. Since the largest earthquake magnitude has been considered as 7.5, the relevant Magnitude Scaling Factor (MSF), as shown in Table 2.8, was selected as 1.0. Particle diameter data for a particular depth of soil was obtained from grain size distribution curves which were used to find out the CRR values from curves (Figure 2.24). Borehole data from 26 points in Cox.s Bazar municipal area were stored in MS Excel Worksheets. All the boring data include SPT N-values measured at 1.5 m interval. To consider the worst condition ground water table have been assumed at a depth of 1.5 m. The liquefaction resistance factor, $F_L$, for the top 20 m of soil, and the resulting liquefaction potential, $I_L$ for the 26 sites were calculated. The flow chart of liquefaction analysis used in this study is shown in Figure 4.12. Result of Liquefaction potential was provided in a tabulated form in Table 4.3. The computed results (Table 4.3) 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 2.8). Thus microzonation maps were developed for liquefaction potential for the two conditions which have been shown as Figure 4.13 and Figure 4.14. Microzonation maps were also developed based on the surface PGA (Figure 4.15 and Figure 4.16) expected to be experienced by the area based on the surface PGAs calculated for different sites.

Table 4.3: Liquefaction Potential Indices for different Locations of Cox's Bazar Municipal area

| Sl No. | Location | Liquefacion (Extreme) | | Liquefacion (Average) | |
|---|---|---|---|---|---|
| 1 | Diabetic Hospital Cyclone Shelter | 43 | high | 20 | high |
| 2 | Baharchhara High School | 102 | high | 38 | high |
| 3 | Shaibal Hotel Water Tank | 141 | high | 74 | high |
| 4 | Golf Field Laboni Moore | 43 | high | 9 | moderate |
| 5 | Shamudra Bilash, Middle Saikat Para | 89 | high | 37 | high |
| 6 | Baharchhara Gol Chattar Field | 82 | high | 54 | high |
| 7 | Cox's Bazar Nursery | 25 | high | 8 | moderate |
| 8 | Cox's Bazar KG & Model High School | 81 | high | 35 | high |
| 9 | Fulbagh, Rice Market Road | 0 | No | 0 | No |
| 10 | Tekpara, Near Pond | 0 | No | 0 | No |
| 11 | Rumaliar Chhra, HSA Road | 0 | No | 0 | No |
| 12 | Bibekanondo Bidya Niketon, Ghonarpara | 0 | No | 0 | No |
| 13 | 76/A, Kalatoli-3 | 52 | high | 29 | high |
| 14 | Cox's bazar Press Club | 56 | high | 37 | high |
| 15 | Central Govt. PS cum CS | 4 | low | 1 | low |
| 16 | Peskarpara Govt. PS cum CS | 31 | high | 30 | high |
| 17 | Kosturaghat Govt. PS | 16 | high | 12 | moderate |
| 18 | Kolatoli World Vision MCS | 27 | high | 11 | moderate |
| 19 | Baitus Sharaf Jameya Mosque | 5 | low | 0 | No |
| 20 | Bangladesh Red Crescent Society | 4 | low | 1 | low |

| Sl No. | Location | Liquefacion (Extreme) | | Liquefacion (Average) | |
|---|---|---|---|---|---|
| 21 | Bangladesh Water Development Board | 3 | low | 0 | No |
| 22 | Tekpara Govt. PS | 0 | No | 0 | No |
| 23 | Ghonarpara, Near Kaderia Non-Govt. PS | 41 | high | 29 | high |
| 24 | Mosjid Compound, Ice Factory Road | 128 | high | 100 | high |
| 25 | Ramkrisna Shebasram, Baiddorghona | 115 | high | 94 | high |
| 26 | Primary Education Officers' Compund | 20 | high | 13 | moderate |

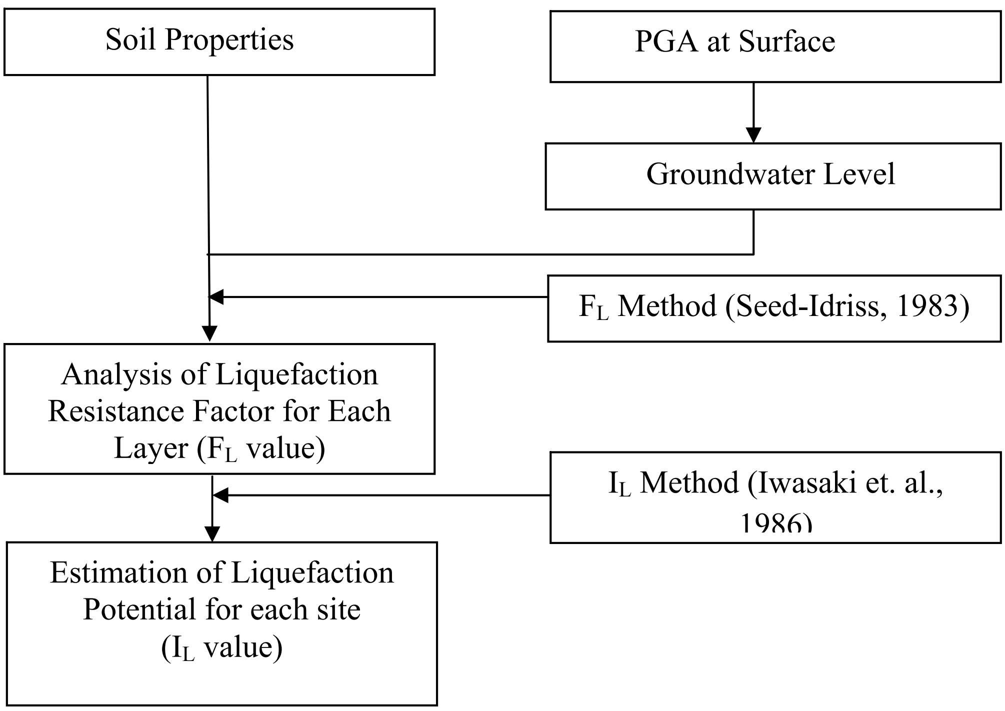



Figure 4.12: Flow chart of Liquefaction Analysis of the study area

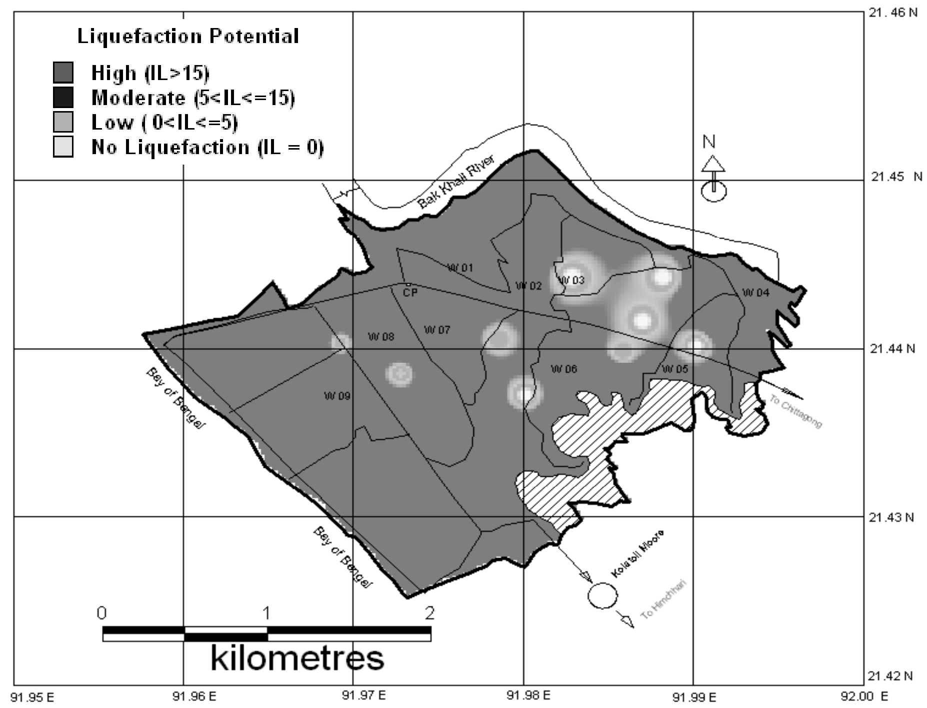



Figure 4.13: Microzonation map based on liquefaction potential considering extreme condition

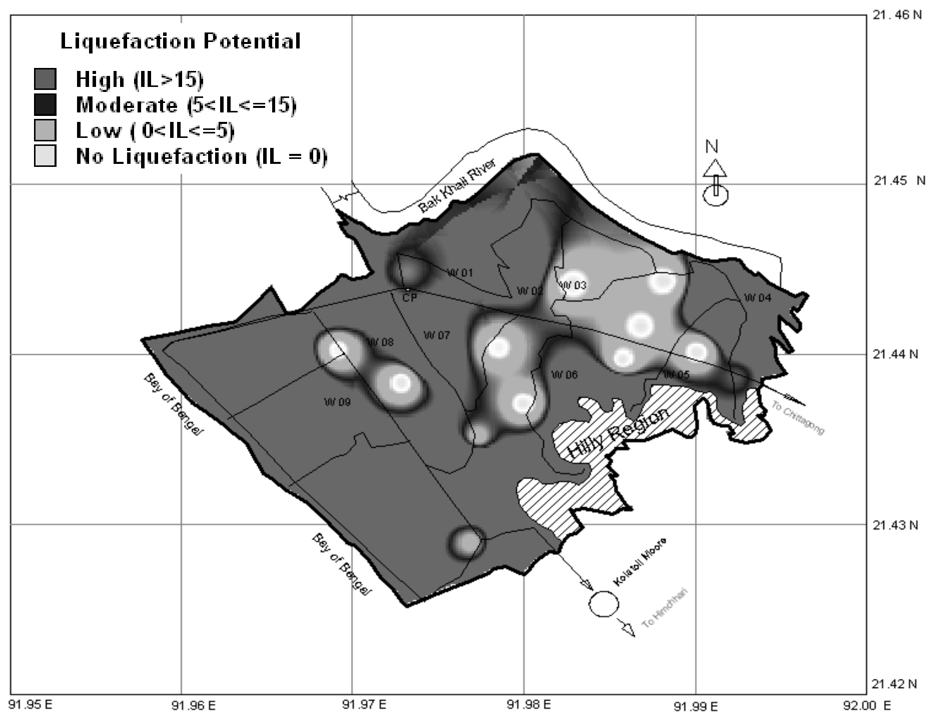



Figure 4.14: Microzonation map based on liquefaction potential considering AHSA

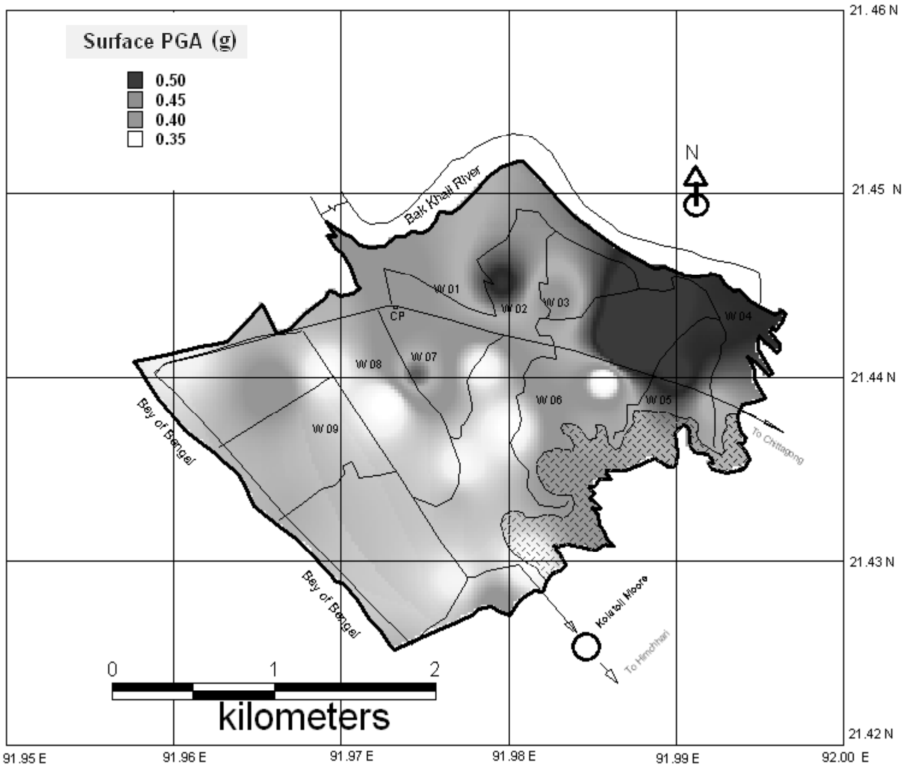



Figure 4.15: Map showing regional distribution of surface PGA considering extreme condition

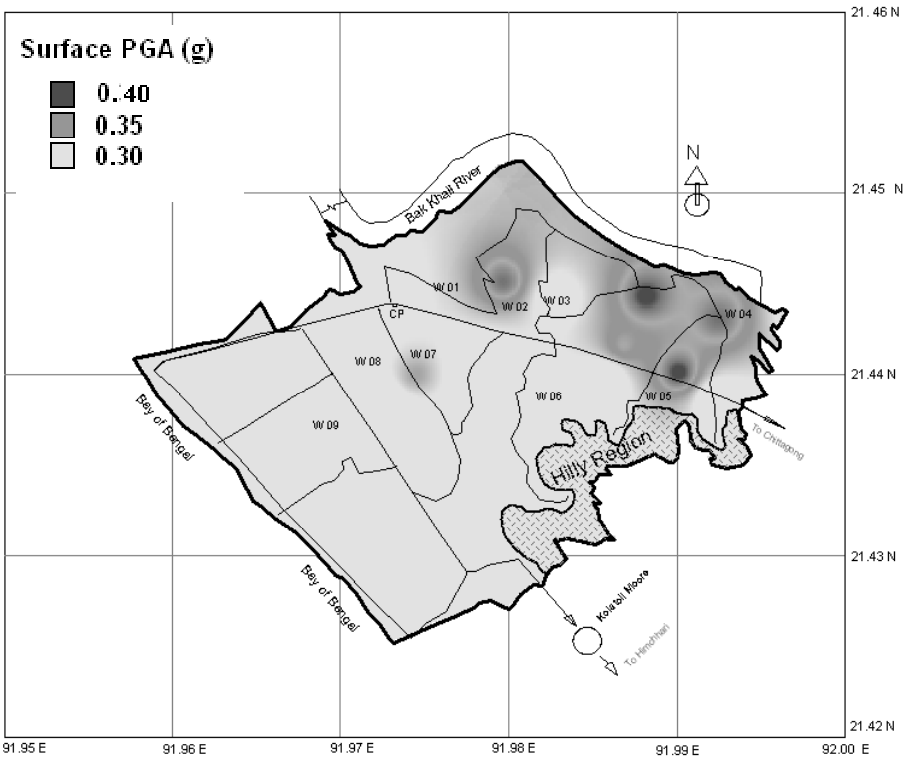



Figure 4.16: Map showing regional distribution of surface PGA considering AHSA

### 4.4.3 Landslide Potential Analysis

The overall stability failure mechanism is development of slip circles resulting in a deep sliding surface. This is a conventional soil mechanics stability problem. Pre-existing 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. XSTABL performs two dimensional limit equilibrium and analysis to evaluate the factor of safety for a layered slope using the simplified Bishop Method. The strength parameters of the slope and foundation materials required for the analyses could be obtained from consolidated undrained direct shear tests performed on soil samples. The minimum values of undrained cohesion ($c_u$) and undrained angle of internal friction ($\phi_u$) were used in the slope stability analyses. The values of $c_u$ and $\phi_u$ used in all the analyses have been provided in Appendix I. The location of the water table in all the slope sections was assumed to be well below the toe of the slopes. The height of the slope was considered as 30 m (100 ft) which was observed from field survey as the average height of the hills of Cox's Bazar. Generally the slopes were found to be 60° to 80°. Considering human activities and ongoing hill cutting activities the average slope of the hills were assumed to be 70°. From the analyses it was observed that only single data contained the representative value of 'satisfactory' Factor of Safety (Table 2.10) and the rest were 'unsafe'. Thus 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 which is shown as Figure 4.17.

Table 4.4: Summary of Landslide Potential Analysis

| Sl No. | Sample | Factor of Safety |
|---|---|---|
| 1 | Hill behind P.T.I High School | 1.44 |
| 2 | Ghonarpara Hill | 0.31 |
| 3 | Light house Hill | 0.69 |
| 4 | Kolatoli Bypass Hill | 0.68 |
| 5 | Boiddorghona Hill | 0.30 |
| 6 | Kolatoli Saikat Para | 0.58 |
| 7 | Bus Terminal Hill | 0.72 |
| 8 | Khaja Monjil, Pahartoli | 0.33 |
| 9 | Circuit House Hill | 0.60 |
| 10 | Ghonerpara Road (M r. Subrata’s House) | 0.30 |
| 11 | Boillarpara Temple Hill | 0.31 |

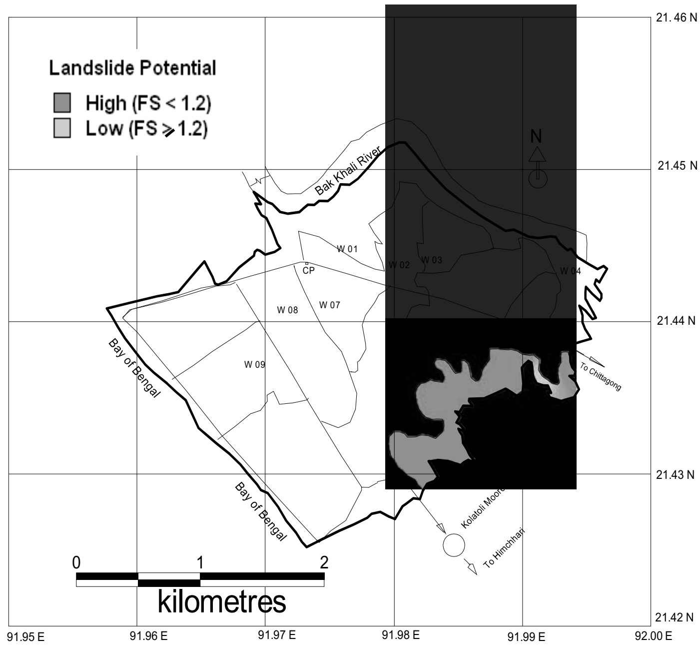



Figure 4.17: Microzonation map based on landslide potential in Cox's Bazar Municipal area

### 4.5 Seismic Hazard Integration

The most important endeavor of this study is 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.

### 4.5.1 Integration of Site Effects in the GIS Environment

Since every analysis region is different; the quantification of the secondary site effects and the weighting scheme for combining the various seismic hazards is considered to be heuristic, based on judgment and expert opinion about the influence of local site conditions in the region and the accuracy of the available geologic and geotechnical information. Figure 4.18 shows the flow chart for developing combined seismic hazard maps.

The rock level ground shaking in the region was determined as 0.18g. This PGA was considered as constant since the study area is small. The seismic intensity is basically a subjective one, based on the human sensations or damage during an earthquake. It was assumed that the final combined seismic hazard would be quantified in terms of Modified Mercalli Intensity (MMI) (Appendix K). The equation used here to convert PGA to intensity is developed by Trifunac and Brady (1975) and is given by Equation 4.12.

For the extreme condition the regional distribution of ground shaking hazards ($MMI_{GS}$) considering 2.0, 2.5 and 3.0 times amplification of the PGA were calculated and presented as Figure 4.19. The MMI scale is subjective and assigned as integer values, therefore the $MMI_{GS}$ values are rounded to the nearest 0.5

Figure 4.13 shows the regional distribution of liquefaction potential in the study area categorized as “high” and “low”. Figure 4.17 shows the qualitative description of landslide hazard in the region. For simplicity, areas were designated as having “high” and “low” landslide potential. The following heuristic rules are used to quantify the seismic hazards due to liquefaction and landslide:

$MMI_{LIQ}$ / $MMI_{LAN}$ = $MMI_{GS}$ +2 (For region designated as “high”)

$MMI_{LIQ}$ / $MMI_{LAN}$ = $MMI_{GS}$ +1 (For region designated as “moderate”) and otherwise

$MMI_{LIQ}$ / $MMI_{LAN}$ = 0

The rules for combining the various hazards are based on expert opinion (after Stephanie and Kiremidjian, 1994) about the relative accuracy of the hazard information and the behavior of the local geology. For this study, it is assumed that the ground-shaking hazard is the most accurate followed by liquefaction and landslide.

For this study, the possible combinations and their assumed weights are shown in Table 4.5. The final combined hazard ($MMI_F$) is computed as a weighted sum of the various hazards. The weights in each rule must sum to 1.0. The additive factor in rules in Table 4.5 is to account for the increase in hazard due to two or more hazards occurring. Table 4.6 summarizes the results of the calculations for combined hazard analysis which are presented by Figure 4.20.

Following the similar procedure calculations were performed for combined hazard analysis considering the approach based on average horizontal spectral amplification (AHSA). The results are shown in Table 4.7. The regional distribution of combined hazards for this condition is presented in Figure 4.21.

Figure 4.22 and 4.23 show the regional distribution of the final combined seismic hazard ($MMI_F$) for extreme condition and considering AHSA.

Table: 4.5: Quantification rules for seismic hazard (Stephanie and Kiremidjian, 1994)

| Rule | Possible hazards | Weighting Scheme for Final combined Hazard ($MMI_{F}$) |
|---|---|---|
| (a) | Ground shaking | $MMI_F = MMI_{GS}$ |
| (b) | Ground shaking + Liquefaction | $MMI_F = .55\ MMI_{GS} + .45 MMI_{LIQ} + .5$ |
| (c) | Ground shaking+ Landslide | $MMI_F = .65\ MMI_{GS} + .35 MMI_{LAN} + .5$ |

1. $MMI_F$= Final Combined Hazard
2. $MMI_{GS}$= Ground Shaking Hazard
3. $MMI_{LIQ}$=Liquefaction Hazard
4. $MMI_{LAN}$=Landslide Hazard
5. $MMI_F$ must be less than or equal 12

Table 4.6: Combination of possible hazards for Cox's Bazar Municipal Area considering extreme condition due to a scenario event equivalent to M= 7.5 Earthquake

| **Possible Ground Shaking Hazards** | | **Intensity ($MMI_F$)** | **Area (sq km)** | **Area (%)** |
|---|---|---|---|---|
| 2.0 times Amplification | | VIII | 3.20 | 47.26 |
| 2.5 times Amplification | | IX | 2.87 | 42.36 |
| 3.0 times Amplification | | IX | 0.70 | 10.38 |
| **Possible Hazards** | **Combination of Possible Hazards** | **Intensity ($MMI_F$)** | **Area (sq km)** | **Area (%)** |
| Ground Shaking + Liquefaction | 2.0 times Amplification + High Liquefaction | X | 2.95 | 43.62 |
| | 2.5 times Amplification + High Liquefaction | X | 2.40 | 35.50 |
| | 3.0 times Amplification + High Liquefaction | X | 0.54 | 7.96 |
| | 2.0 times Amplification + Low Liquefaction | VIII | 0.13 | 1.95 |
| | 2.5 times Amplification + Low Liquefaction | IX | 0.06 | 0.93 |
| | 3.0 times Amplification + Low Liquefaction | IX | 0.19 | 2.75 |
| Ground Shaking + Landslide | 2.0 times Amplification + High Landslide | X | 0.11 | 1.65 |
| | 2.5 times Amplification + High Landslide | X | 0.42 | 6.25 |
| | 2.5 times Amplification + Low Landslide | IX | 0.02 | 0.23 |

Table 4.7: Combination of possible hazards for Cox's Bazar Municipal Area considering AHSA due to a scenario event equivalent to M= 7.5 Earthquake

<table>
<tr><th colspan="2">Possible Ground Shaking Hazards</th><th>Intensity ($MMI_F$)</th><th>Area (sq km)</th><th>Area (%)</th></tr>
<tr><td colspan="2">1.7 times Amplification</td><td>VIII</td><td>6.01</td><td>88.81</td></tr>
<tr><td colspan="2">2.0 times Amplification</td><td>VIII</td><td>0.76</td><td>11.19</td></tr>
<tr><th>Possible Hazards</th><th>Combination of Possible Hazards</th><th>Intensity ($MMI_F$)</th><th>Area (sq km)</th><th>Area (%)</th></tr>
<tr><td rowspan="6">Ground Shaking + Liquefaction</td><td>1.7 times Amplification + High Liquefaction</td><td>X</td><td>3.51</td><td>51.79</td></tr>
<tr><td>2.0 times Amplification + High Liquefaction</td><td>X</td><td>0.43</td><td>6.30</td></tr>
<tr><td>1.7 times Amplification + Moderate Liquefaction</td><td>IX</td><td>1.27</td><td>18.81</td></tr>
<tr><td>2.0 times Amplification + Moderate Liquefaction</td><td>IX</td><td>0.06</td><td>0.83</td></tr>
<tr><td>1.7 times Amplification + Low Liquefaction</td><td>VIII</td><td>0.64</td><td>9.41</td></tr>
<tr><td>2.0 times Amplification + Low Liquefaction</td><td>VIII</td><td>0.25</td><td>3.63</td></tr>
<tr><td rowspan="2">Ground Shaking + Landslide</td><td>1.7 times Amplification + High Landslide</td><td>IX</td><td>0.53</td><td>7.78</td></tr>
<tr><td>1.7 times Amplification + Low Landslide</td><td>VIII</td><td>0.02</td><td>0.24</td></tr>
</table>

Table 4.8: Comparison of the results obtained as Final Combined Intensity and affected areas for different hazard combinations considering Extreme Condition and AHSA

| Combined Intensity ($MMI_F$) | Based on First Peak Amplification (Extreme Condition) | | Based on Average Horizontal Spectral Amplification (AHSA) (Refined Condition) | |
|---|---|---|---|---|
| | **Possible Ground Shaking Hazards** | **Area (%)** | **Possible Ground Shaking Hazards** | **Area (%)** |
| IX | 2.5 times Amplification<br>3.0 times Amplification | 42.36<br>10.38 | - | - |
| VIII | 2.0 times Amplification | 47.26 | 1.7 times Amplification<br>2.0 times Amplification | 88.81<br>11.19 |
| **$MMI_F$** | **Combination of Possible Hazards** | **Area (%)** | **Combination of Possible Hazards** | **Area (%)** |
| X | 2.0 times Amplification + High Liquefaction<br>2.5 times Amplification + High Liquefaction<br>3.0 times Amplification + High Liquefaction<br>2.0 times Amplification + High Landslide<br>2.5 times Amplification + High Landslide | 43.62<br>35.50<br>7.96<br>1.65<br>6.25 | 1.7 times Amplification + High Liquefaction<br>2.0 times Amplification + High Liquefaction | 51.79<br>6.30 |
| IX | 2.5 times Amplification + Low Liquefaction<br>3.0 times Amplification + Low Liquefaction<br>2.5 times Amplification + Low Landslide | 0.93<br>2.75<br>0.23 | 1.7 times Amplification + Moderate Liquefaction<br>2.0 times Amplification + Moderate Liquefaction<br>1.7 times Amplification + High Landslide | 18.81<br>0.83<br>7.78 |
| VIII | 2.0 times Amplification + Low Liquefaction | 1.95 | 1.7 times Amplification + Low Liquefaction<br>2.0 times Amplification + Low Liquefaction<br>1.7 times Amplification + Low Landslide | 9.41<br>3.63<br>0.24 |

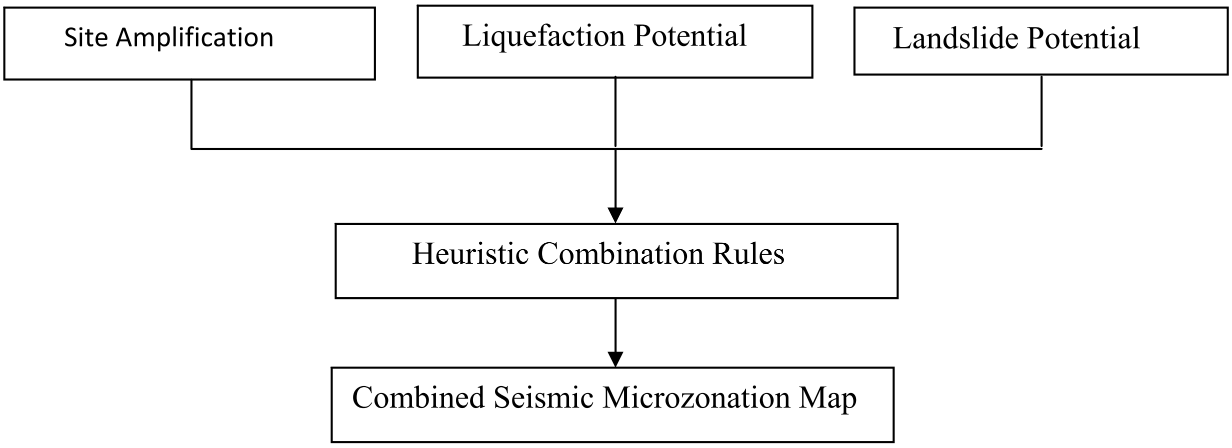



Figure 4.18: Flow chart for Combined Seismic Hazard Map

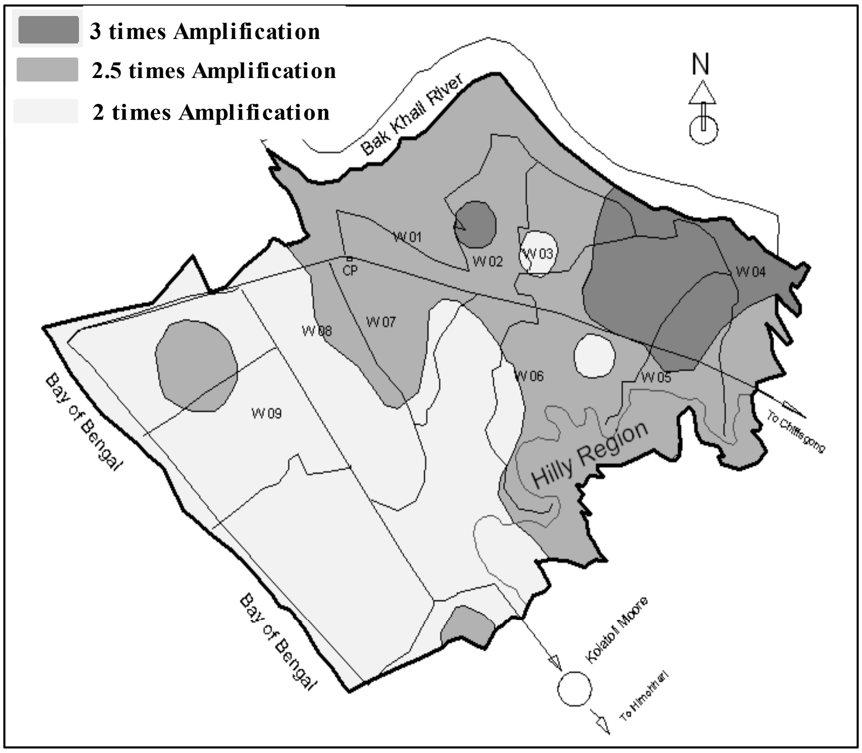



Figure 4.19: Map showing the possible Ground Shaking Hazards for extreme conditions over the area

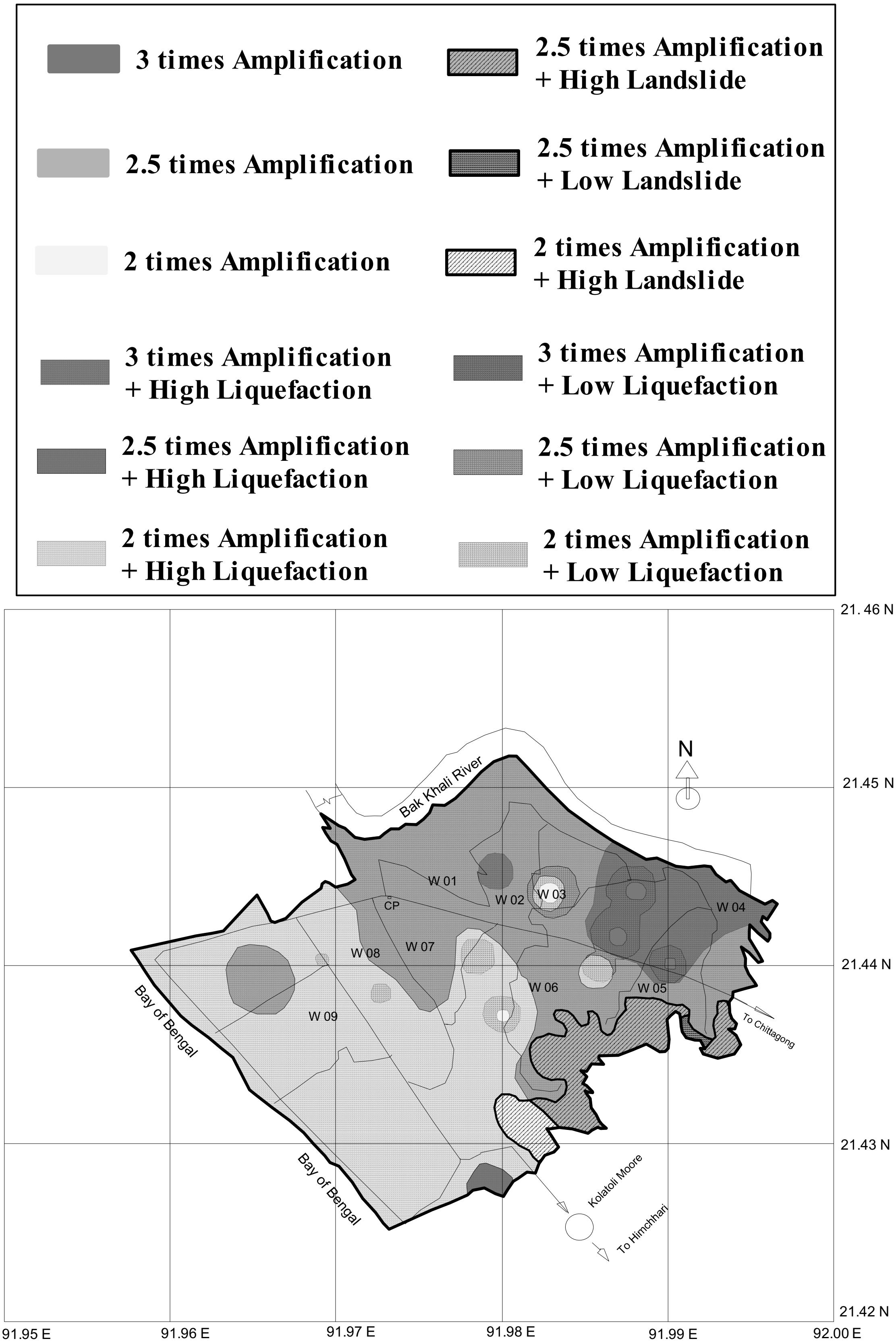



Figure 4.20: Map showing the possible hazard combinations for extreme condition

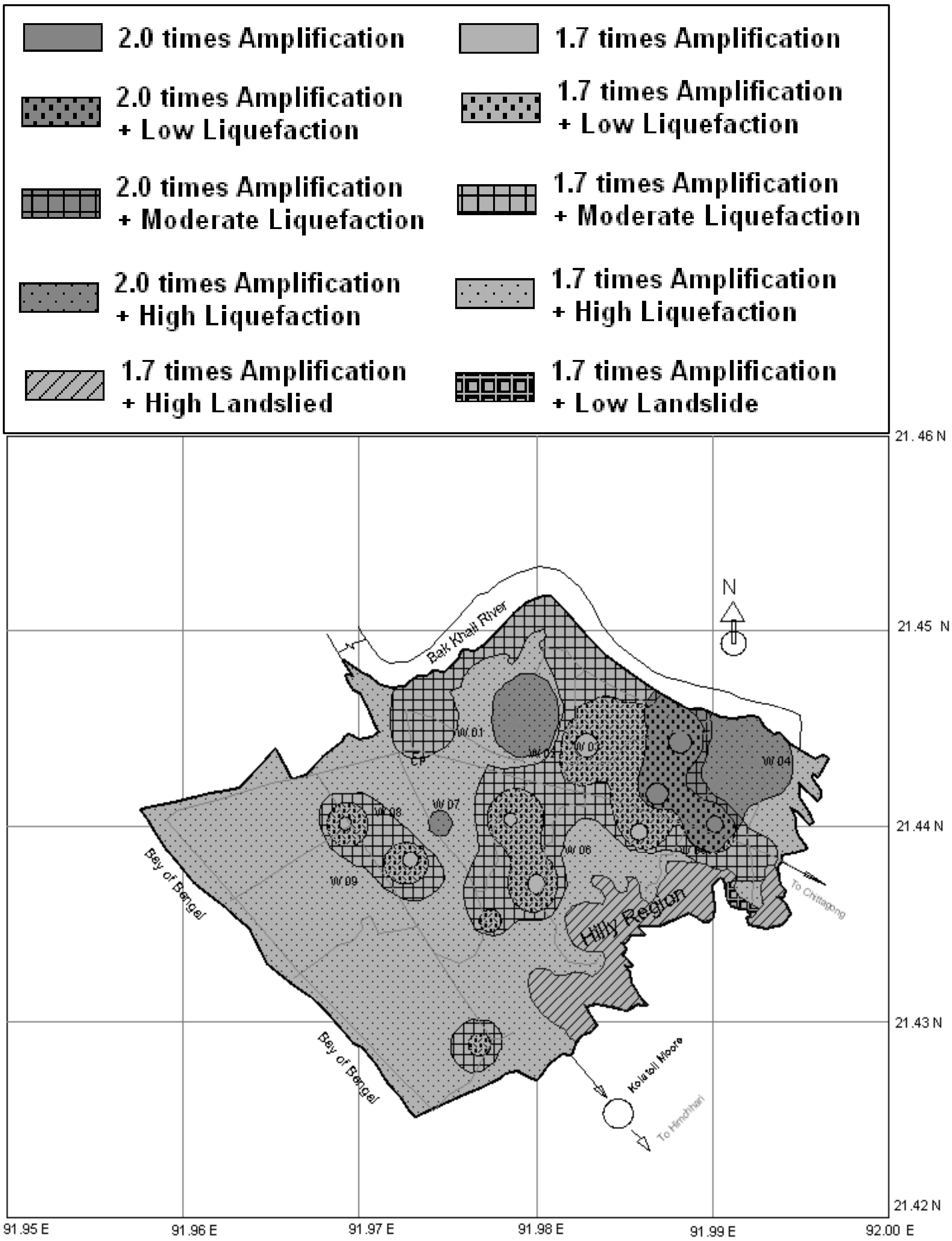



Figure 4.21: Map showing the possible hazard combinations considering AHSA

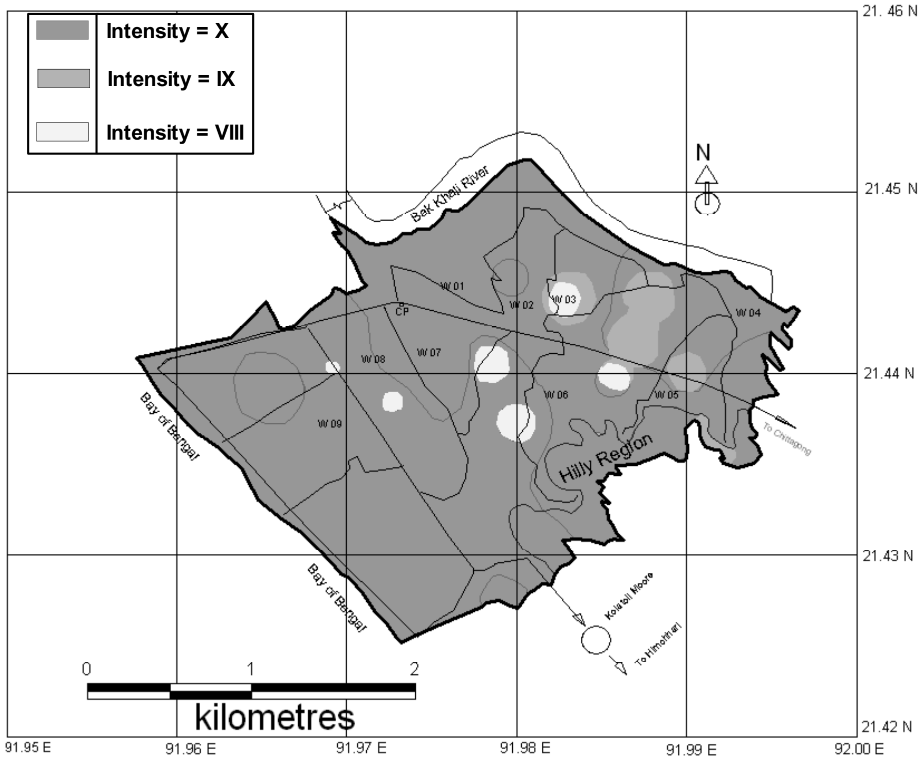



Figure 4.22: Map showing the regional distribution of combined seismic hazard ($MMI_F$) in Cox's Bazar Municipal Area for extreme condition

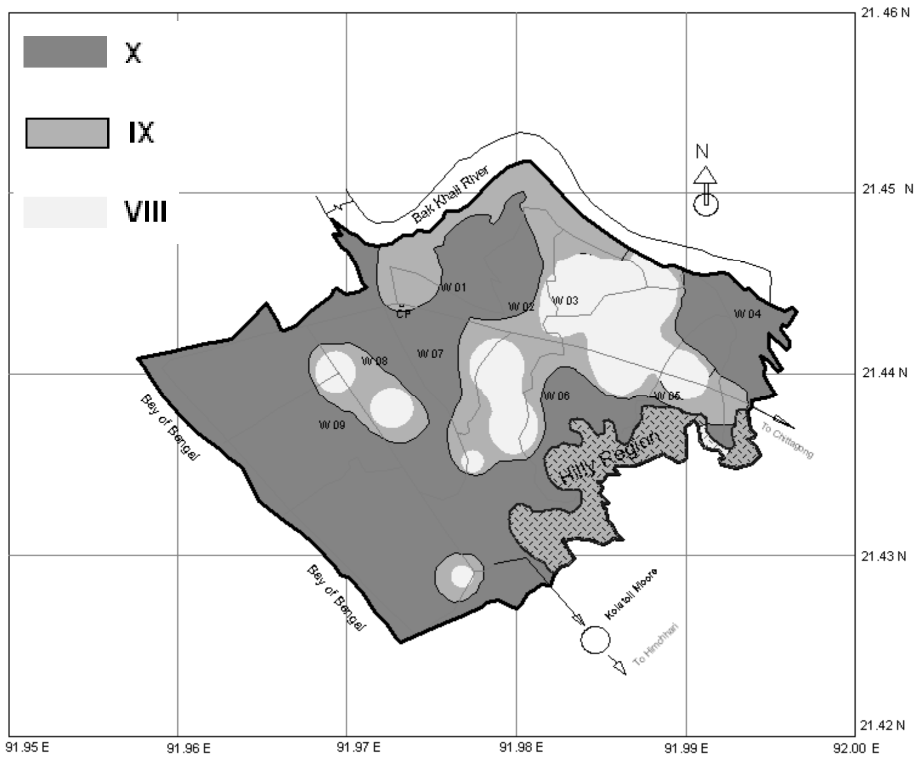



Figure 4.23: Map showing the regional distribution of combined seismic hazard ($MMI_F$) in Cox's Bazar Municipal Area considering AHSA

## 5.1 Conclusions

In this study, GIS has been used to develop seismic microzonation maps for the study area where primary hazards due to ground shaking and local site effects such as soil amplification, liquefaction and landslide have been considered. Prior to that, different field and laboratory test data collected at different depths from 26 sites and laboratory tests of soils collected from 11 hills of the study area have been performed for geotechnical characterization. Furthermore, this study introduces a methodology to combine the different hazards based on a weighted average approach. In the GIS environment, maps representing regional geologic and geographic information have been overlaid and their attributes were combined to produce intermediate maps of regional seismic hazards. This is for the first time comprehensive earthquake hazard estimation for Cox's Bazar Municipality has been carried out.

Due to an earthquake of Magnitude 7.5 with 200 years of return period around 250 km radius of Cox's bazaar Municipal Area, the rock level PGA is estimated as 0.18g. The results of the analyses for ground susceptibility can be interpreted for two different conditions.

Considering the extreme or most severe condition the rock level PGA can be amplify 2.3 times on an average in the alluvium and will gain a PGA of 0.41g in the surface. From the developed microzonation maps, it can be observed that the Southeastern end of ward no. 5 will experience the highest frequencies. Ward no. 4 consisting of East Tekpara, Rumaliarchhara and Tarabaniachhara might be affected by 3 times site amplification. Liquefaction analysis for the study area reflects that it is susceptible to very high liquefaction potential. From the borehole investigations and grain size distributions, it was observed that the soil up to 20 meter depth is mostly sandy having $D_{50}$ ranging from 0.12 mm to 0.22 mm. It was observed that the sandy silts with trace clay, layer of silt and sand, silty sand having greater particle diameters and low to medium SPT N-values showed higher liquefaction potentials. According to the study, the landslide potential of this area is very high. Approximately 8.13% area under the municipality is hilly. The hills located in Ghonerpara, Boiddorghona, Pahartoli and Boillarpara are found to be very unstable. The combined hazard analysis shows that if the area experiences both ground shaking and liquefaction during a scenario earthquake having a magnitude of 7.5, the area can be severely affected and the intensity due to the combined effect of the hazards can be as high as X in MMI scale. The town will be highly endangered (44% area is affected) if high liquefaction associates with amplification factor as low as 2 times. On the other hand if 2.5 to 3 times site amplification occurs, still there is a high risk (MMI = IX) even in case of low liquefaction occurrence. The hilly region is highly susceptible to slope instability, moreover, 77% of the hilly region is on the risk of experiencing very high intensity (MMI = X), if 2.5 times amplification of ground shaking occurs.

Considering the average horizontal spectral acceleration (AHSA), the results are obtained for a moderate hazard condition. The average frequency expected to be experienced by the area is calculated as 1.7 and thus the surface PGA is obtained as 0.31g. Approximately 89% of the area can be affected if 1.7 times amplification of the ground shaking occurs and 11% area might be affected by 2.0 times amplification. If high liquefaction associates with round shaking amplified by of these two amplification factors the area can be affected by a combined hazard intensity of X. Similarly moderate liquefaction associates with these ground shaking hazards can cause combined hazard of intensity IX. More than 50% area can be affected if high liquefaction combines with only 1.7 times amplification of ground shaking. The entire hilly region is liable to only 1.7 times amplification. Approximately 96% of the hilly region (8% of the total area) might experience a combined intensity of IX if high landslide associates with only 1.7 times amplification of ground shaking.

The developed maps can act as a guide for the authorities at the national and regional levels in land use management, revision and enforcement of appropriate building codes and formulation of plans for mitigating measures against earthquake risk affecting the region considered.

### 5.2 Scope for Future Study

The study is covered with extremely wide-ranging subject; consequently several field of future study can be recognized for instance:

i. For Bangladesh, no PGA attenuation law has been developed, due to shortage of strong motion data. PGA attenuation relationships predicting strong ground motions in terms of magnitudes, distance, site geology, and other factors, using various models and data sets should be developed for the country.

ii. Study of regional tectonics with particular emphasis to locate active faults and fault plane solutions is strongly recommended. This can lead to more accurate estimation of hazardous conditions.

iii. In this study, SPT-N values were converted into shear-wave velocities using empirical correlation. Shear-wave velocities are needed to be directly estimated for different soils using cross-hole, down-hole or blasting techniques. Then correlation should be developed for the SPT-N values of local soils with shear-wave velocities.

iv. Grain Size Analysis specially, the mean particle diameter, D50 and fine contents are important data for every 1 meter depth for proper liquefaction analysis.

v. Based on soil (natural) frequency, some zones can be suggested for building height restrictions using thumb rules.

vi. Based on liquefaction potential index zones can be suggested where ground improvement is necessary.

vii. Vulnerability of landslide depends on location, land use, land cover, rainfall as well as weather, geological structure and type of human activities. These factors should be taken into consideration during landslide potential analysis.

viii. A very simplified process for integration of various sites attributes has been used in this study. Improvements are needed in the models together with the quantification of the hazards and heuristic weighted average approach. The analysis and modeling capabilities of the GIS provide an ideal environment to conduct sensitivity studies that will help to refine different hazard combination schemes.

ix. Further study can be taken by performing analysis of site amplification and calculation of transfer functions considering real earthquake strong ground motion data as input in SHAKE.

# PART-II

# Earthquake Vulnerability Assessment at Old Dhaka (Ward No.68)

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## 1. INTRODUCTION

Bangladesh, one of the most disaster prone countries in the world deserves disaster management as the key issue for overall development of the country. The risk in urban center is compounded due to unplanned urbanization and development in high risk zones. Although most of the major earthquakes in recent days have occurred away from major cities and have only affected relatively less populated areas, significant earthquake hazard exists for the cities due to its heavy unplanned built environment and high density of ever increasing population. The 1897 Great Indian Earthquake which originated at an epicentral distance of only 230 km from Dhaka caused extensive damage on brick masonry structures in Dhaka (Oldham, 1899). Dhaka is vulnerable to earthquake due to high population density, unplanned structures, and lack of awareness and preparedness at community level, etc. Dhaka as the capital of Bangladesh accommodates a large estimated population of 12.8 million in the wider metropolitan area while the city population stands approximately at 7.0 million as of 2008 (BBS, 2009). Old Dhaka is more vulnerable to earthquake due to its relatively high density of population. The projected density of population in Kotwali Thana, a major part of Old Dhaka is 1, 61,198 per square kilometer in 2009 (BBS, 2001). Besides, the densely built fabric consisting of vulnerable aged and unreinforced masonry buildings along with narrow local streets makes the locality more susceptible to earthquake. Once a great earthquake occurs, Dhaka may suffer immense loss of life and property due to unplanned development. This will have severe long term repercussion for the entire country.

Earthquake as a disastrous event needs to be addressed in a more precise way. Earthquake social vulnerability assessment of an area put a remarkable importance in proposing an effective evacuation plan considering the prevailing local condition to reduce loss. While natural hazards will continue to occur, their capacity to become a disaster or merely a manageable event depends on many factors, including the magnitude of the hazard, the vulnerability of people and their communities and the built environment. People are the major concern in any disaster risk mitigation and people at the disaster prone areas are most vulnerable. To make an effective plan in disaster risk reduction, the major goal should be the assessment of existing social vulnerability and propose initiatives to raise awareness level of the local community in reducing loss after effects.

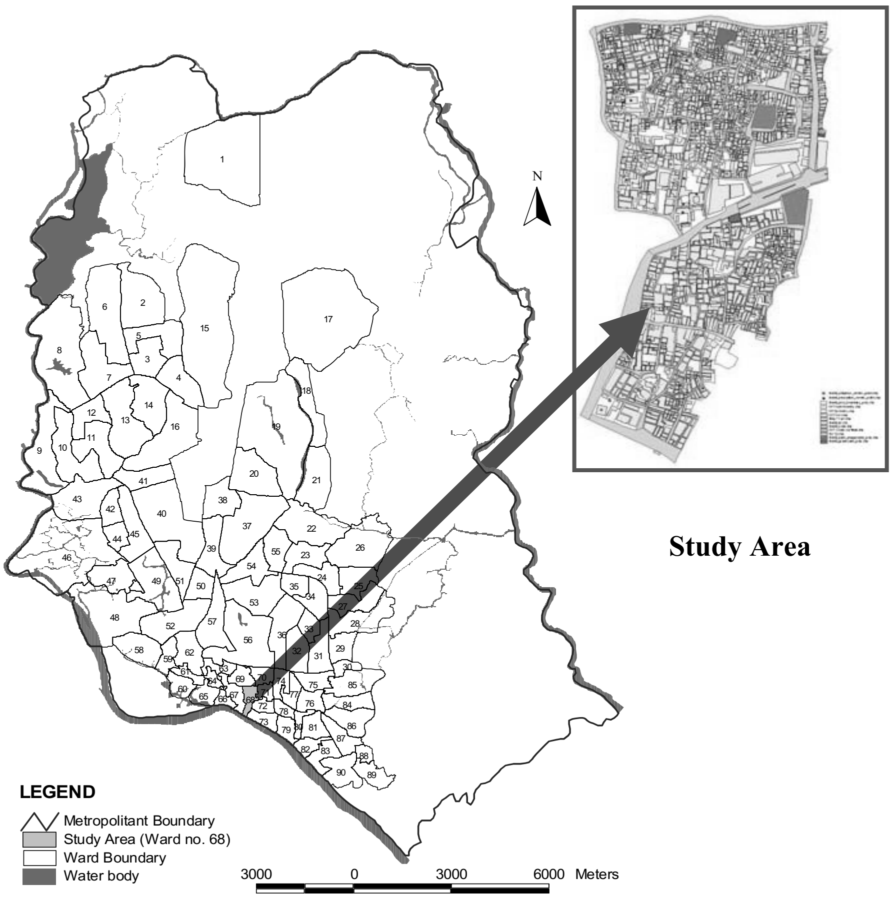
As Old Dhaka is vulnerable to earthquake, BNUS is developing the earthquake evacuation plan for Ward No.68 as part of this area. The site is characterized by high density of population living in a very compact land area with close proximity of buildings along a narrow local road. Sometimes it is become difficult to separate one building to another. The condition is inconceivable what may happen with an attack of earthquake. In order to reduce the loss due to an earthquake, BNUS has taken an effort to make an evacuation plan of the study area considering the existing situation.

## 2. METHODOLOGY

The major concern in any disaster risk mitigation measures falls on raising awareness level of the local community. A socio-economic survey of 210 households in Ward no. 68 of the older part of Dhaka City is conducted for the assessment of social vulnerability. The sample size was chosen on random basis at 95% confidence level which is 2% of total projected household 10,942 in 2009(BBS, 2001) in the study area. The social vulnerability of individuals due to an earthquake is assessed within the households. The social vulnerability indicators and relevant data have been selected from the literature. Information regarding the level of public awareness about earthquake risk of the community is found through this survey. In this study building vulnerability is also assessed by using two method, Rapid Visual Screening (RVS) method and Turkish Level-I and Level-II Method. For RVS method 1383 buildings (residential and public building) were assessed which cover more than 90 percent of the total existing buildings in the study area. Turkish Level-I and Level-II, a more detail analysis of the building is used to assess, which are proposed to be used as evacuation shelter. Around twenty seven public buildings as well as common places are selected for evacuation place. Among them only the Reinforced Concrete buildings are assessed by Turkish method, includes religious place like mosques, community center, educational institutes like schools, colleges and other public places along with the open spaces like park, playground etc. are considered as evacuation site. For structured and organized analysis, the collected data has been compiled and analyzed to understand the earthquake vulnerability of the study area. This portrays a clear view of the whole community.

## 3. STUDY AREA AT A GLANCE

The study area, Ward no. 68 is located on the northern bank of river Buriganga being a part of Old Dhaka. The area covered by the study ward is 1.5 sq. km and accommodates approximately 1.5 lacs population. Among these large number of population, 18362 are adult. It is under the jurisdiction of Bangshal Thana and part of Kotwali Thana. The ward is surrounded by five wards of DCC in three sides and the river Buriganga at the south. In north there lies ward no. 66, to the west ward no. 67 and to the east lies three ward – ward no 71, 72 and 73. In this area sixteen educational institutions are found including govt. primary school, high school, madrasha and Girls College etc. In the study area seven health care centers is placed and on the west Sir Salimullah Medical College and Hospital is situated which is one of the reputed and renowned places within Old Dhaka. Old Dhaka is well-known for mosque and in the study ward 13 mosques are found with different architectural design. There is also some DCC approved service center found like community center, gymnasium, public library and play ground. Ward no. 68 is confined by Haji Abdur Rashid Lane and French Road at the east; Sharatchandra Chakrabarti Road at the west; Bangshal Road at the north and Badamtali at the south (see MAP- 1).




Map-1: Location Map of Study Area

Photo1: Old and Aged Building

Photo 2: Congested Residential Building

Photo 3: Narrow Local Road

Photo 4: Ahmed Bawani School and College

Photo 5: Babubazar Ghat Jame Mosque

Photo 6: Shajadi Begum Jame Mosque

# 4. SOCIAL VULNERABILITY ASSESSMENT

The surveyed 210 households having total family members of 1092 has the average family size five. It is found from the survey that 21% of the surveyed household members age group varies between 0-14 years and over 59 years represents only 6% of the household members. Among the total family members 42% are female. In any disaster female, kids and aged members are considered more vulnerable than others. In Bangladesh usually the person who can sign his name is considered as literate. With respect to this criterion in the study area only 7% members are illiterate. If the overall situation is considered regarding what have to be done during and after an earthquake strikes, people of the area is almost unfamiliar with it. With respect to these criteria the area could be said to be vulnerable to earthquake hazard in social context.

## 4.1 EARTHQUAKE AWARENESS OF THE HOUSEHOLD MEMBERS

A percentile configuration of 75% members of the surveyed households shows their perception of being aware about earthquake. Table-1 shows the awareness level of the household members in the study area. It is a good indication that 94 households among the 210 contain 100% awareness level i.e. all of their family members are aware about earthquake while only 4 families are unaware about the risk.

Table-1: Earthquake Awareness Level of the Household Members

| **Percentage of the Household members** | **Household Number** | | **Percentage of the Household members** | **Household Number** | |
|---|---|---|---|---|---|
| | Aware | Unaware | | Aware | Unaware |
| 1-19% | 4 | 13 | 51-69% | 22 | 15 |
| 20-29% | 8 | 34 | 70-92% | 47 | 12 |
| 30-49% | 15 | 22 | 100% | 94 | 4 |
| 50% | 16 | 16 | | | |

## 4.2 EARTHQUAKE AWARENESS OF THE HOUSEHOLD MEMBER ACCORDING TO AGE GROUP AND EDUCATIONAL LEVEL

Figure-1 depicts that household members of the age group 15-29 years are more aware than other age group. The members who are in the age group of 0-14 years, maximum are school going and kids. Among the school going members, very few are aware about earthquake. As a result, it is observed that the number of aware and unaware members is more or less equal in this group. A number of students especially who had primary to high school level education, got a sort of awareness training related to earthquake preparedness in their school (see Figure-1 and 2). Most of the student studies in the local schools such as Armenitola Govt. High School, Narinda Govt. Boys' High School, Anondomoyee Girls' High School, etc. which prepared the students to confront earthquake danger (Jahan and Ansary, 2007). This preparedness involves class lectures on earthquake, its risk and effects on life, earthquake drill and what should anyone do before, during and after an earthquake attack.

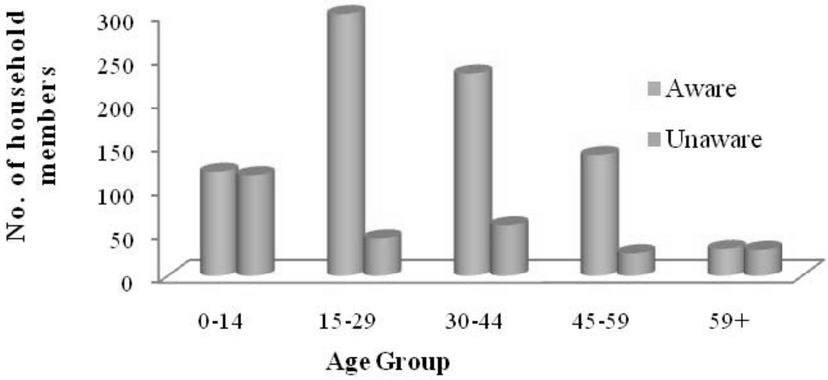



Figure-1: Earthquake Awareness of the Household Member according to Age Group

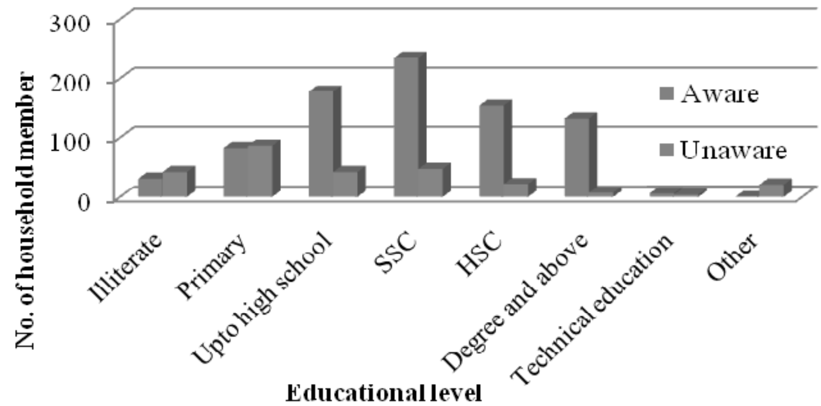



Figure-2: Earthquake Awareness of the Household Member according to Educational Level

### 4.3 COMPARISON BETWEEN AGE GROUP AND EDUCATIONAL LEVEL

From the study, it is found that almost 96% literate respondents have earthquake awareness. Table-2 shows that the literacy rate is more in the age group 15-29 and 30-44 years and they are more aware about earthquake than the people of other age groups. The age group 15-29 years is more aware about earthquake because most of them are student and 30-44 age groups are basically engaged with different professions. Professional group keeps themselves up to date with day to day information received through professional activities and so they have more experience than others.

Table-2: Comparison between Age Group and Educational Level

| Age Group | Educational Level | | | |
|---|---|---|---|---|
| | Illiterate | | Literate | |
| | Aware | Unaware | Aware | Unaware |
| 0-14 | 1 | 10 | 118 | 105 |
| 15-29 | 13 | 7 | 287 | 36 |
| 30-44 | 5 | 5 | 227 | 53 |
| 45-59 | 1 | 2 | 137 | 24 |
| 59+ | 11 | 18 | 20 | 12 |

### 4.4 Earthquake Awareness of the Household Head

The household head (male or female) of the family plays a vital role in any decision making and in Bangladesh mostly the male possess the position to be head of any family. So the status of the family head is also examined to find out the real condition of the family to cope with any disaster along with the families' resilience. Figure-3 shows the earthquake awareness level of each household head in comparison with their educational level and occupation. It is clear from the figure that most of the household head are businessmen in the study area and most of them are aware about earthquake.

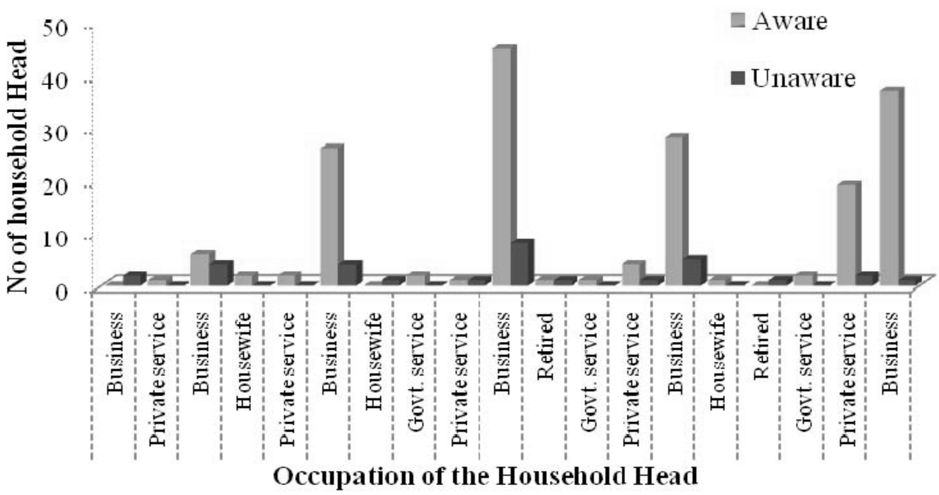



Figure 3: Earthquake Awareness level of the Household Head

### 4.5 EARTHQUAKE KNOWLEDGE OF THE RESPONDENT

The field survey reveals that most of the respondents know what is an earthquake and 69% of them think earthquake as the shaking of land, rolling of earth surface. Among them maximum respondents came to know about earthquake from newspaper and by watching television or movie. Students acquire knowledge about earthquake from the lessons taught at schools. Vulnerability of earthquake depends on the awareness of the community people. About 74% respondents in the study area are aware about earthquake.

### 4.6 EARTHQUAKE EXPERIENCE OF THE RESPONDENT

It is found in the study area that about 70% respondents have experience of earthquake. When the people experienced earthquake they take some immediate actions to protect themselves from earthquake exposure. In Bangladesh, in most cases ground shaking occurs only for few seconds though the average magnitude varies from 5.0 to 6.0 in Richter scale. From field survey, it is found that most of the respondents felt earthquake but it was over before taking any actions. The next common response is to go out of home immediately which has reported by more than 30% of the respondents. A number of respondents also mentioned about being awakened from sleep when earthquake occurred at night (see Figure -4).

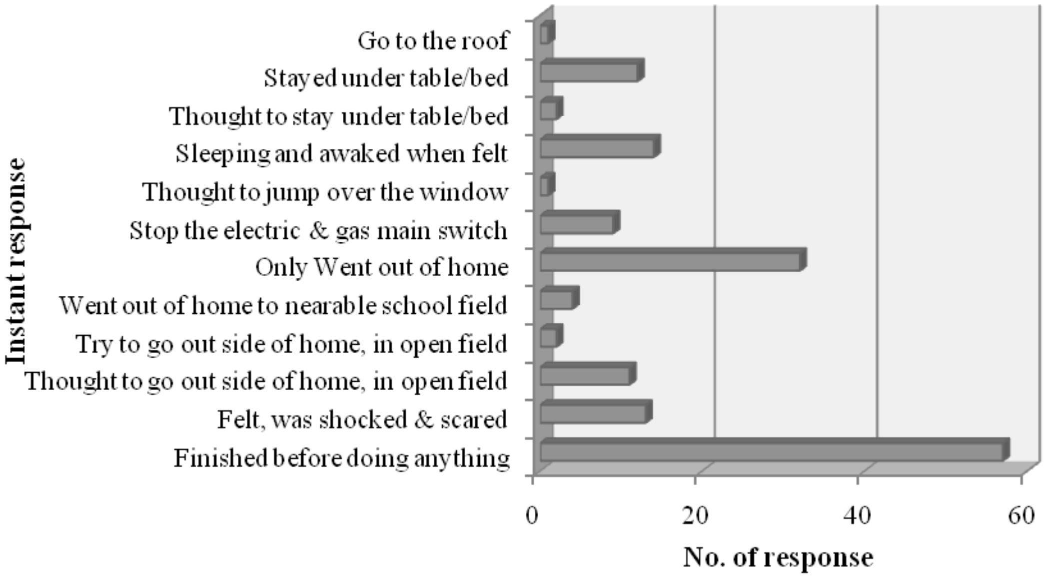



Figure-4: Instant Response of the Respondent when Felt Earthquake

### 4.7 EARTHQUAKE VULNERABILITY OF THE COMMUNITY

In the study area most of the respondents (75%) think their community is exposed to earthquake vulnerability. The surveyed respondents considered a range of factors that caused the area to be earthquake vulnerable. They gave response to identify the reasons behind earthquake vulnerability according to raking or priority basis. From Figure-5, it is found that maximum respondents prioritize the fact that buildings in Old Dhaka are aged and damaged. The next importance goes for weak construction with defective building

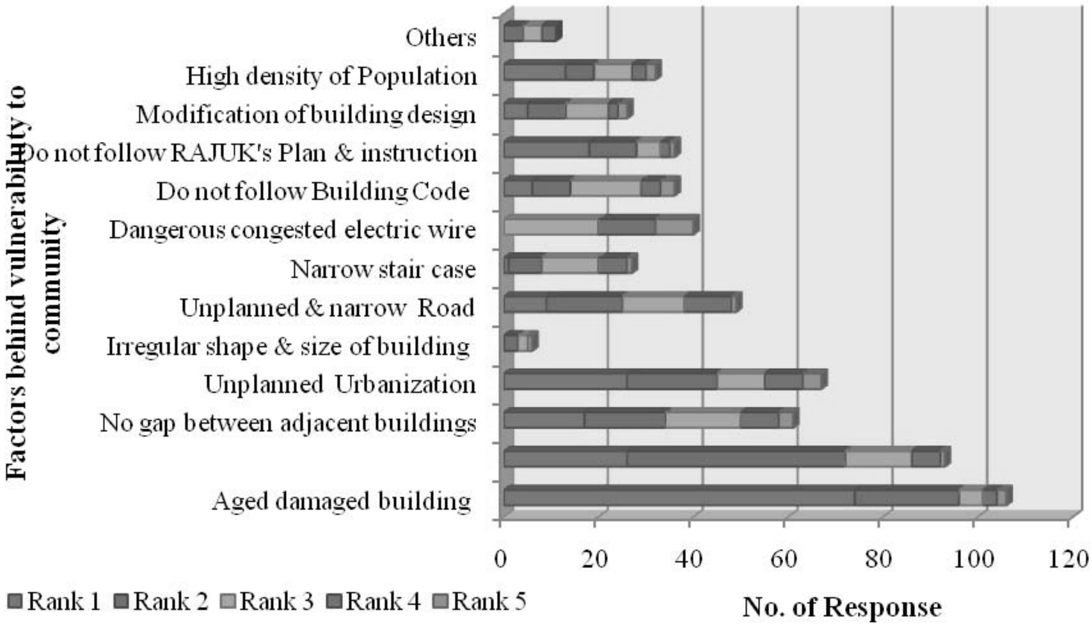



Figure-5: Reasons behind Earthquake Vulnerability to Community

design (pillar, column and foundation of building). Danger imposed from congested electric wire in the area is also considered as a factor of earthquake vulnerability to the community.

The socio-economic condition of the study area indicates that the area is in between low and middle income group. It can be said that if a disaster attacks, most of them could not recover the losses. The expected loss is unpredictable, financial help will be required from the outside people, government and foreign agencies.

### 4.8 EARTHQUAKE VULNERABILITY OF THE RESIDING BUILDING

From field survey it is found that 44% respondents claimed their residing building is vulnerable, there are various factors behind the perception. From Figure-6, shows maximum respondents think "the residing buildings are old" in the locality and it is the main reason.

Another important factor recognized by the respondents for earthquake vulnerability is weak column, beam and foundation of building. There are other important factors which are related to earthquake vulnerability such as building construction without following RAJUK set back rules, congested and unplanned buildings in the locality, narrow stair cases, unplanned narrow roads etc. It is also observed that 55% of the surveyed buildings staircase width is less than or equal to 3 feet that is not apt in terms of evacuation from the building.

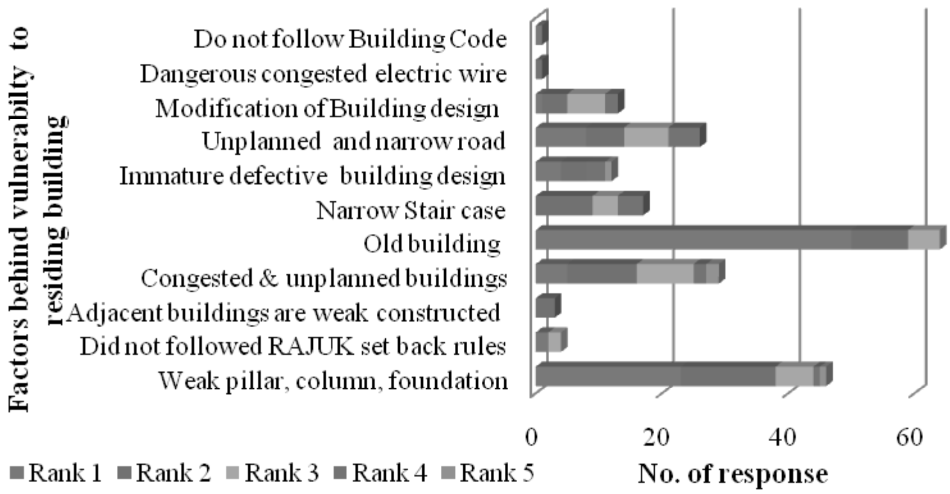



Figure-6: Earthquake Vulnerability of the Residing Building

The earthquake vulnerability of the residing buildings is also assessed by Rapid Visual Screening (RVS) Method. A total number of 1383 buildings have been analyzed for vulnerability assessment by this method. A RVS score "2" of a building is considered as "cut-off" score for the study area. The score below 2 for a structure is assumed to vulnerable and require further investigation. From building vulnerability assessment it has found that 53%

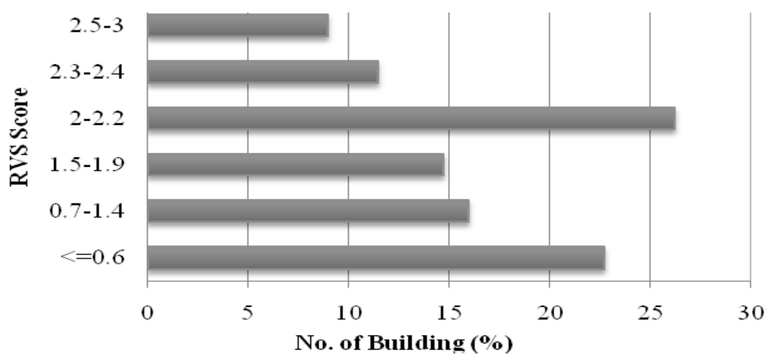



Figure-7: Buildings Classified on RVS Score buildings in this area are vulnerable and require detail evaluation and tenacious action for structural improvement (see Figure -7). Other wise all of these buildings should collapse if an intense magnitude of earthquake strikes on the area.

### 4.9 Discussion with Family Members and Community about Earthquake

People usually discuss with family members and community people about earthquake. There is disparity in the frequency of discussion among family members and community people. From Figure-8, it is observed that maximum respondents (79.05%) discuss with the family members rather than the community.

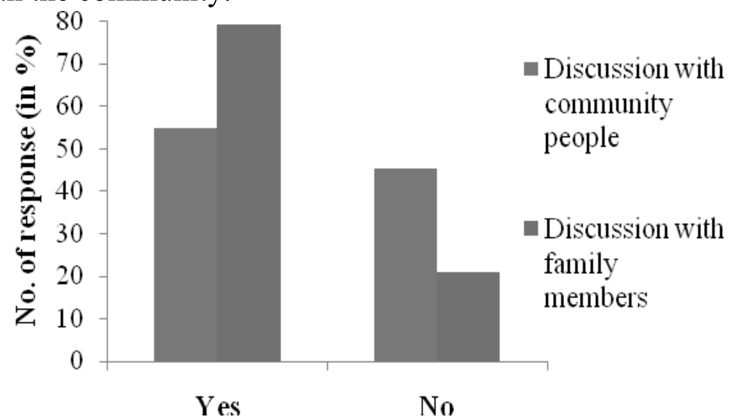



Figure-8: Comparison in Discussion with Family Members and Community about Earthquake

### 4.10 Respondent's Plan to do during an Earthquake Occurrence

Though most of the respondents in the surveyed area felt earthquake which was finished before doing anything, all of them have certain plan of responses in case of earthquake occurrence. From Figure-9, it is clear that they give more importance to run out of home immediately. They also have plan to try to go to a safe place like open field, big hall room, stay under table or bed, take position near column etc to save their lives of themselves and family members.

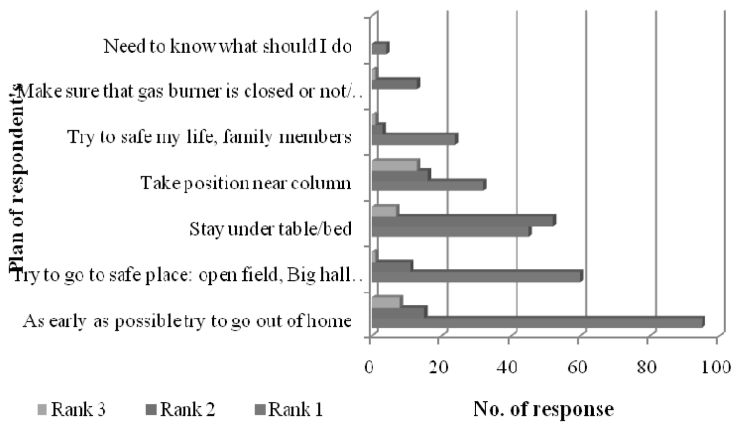



Figure-9: Plan of Respondent's During an Earthquake Attack

### 4.11 Participation in Earthquake Awareness Program

It is found from field survey that 30% respondents took part in earthquake awareness program like seminar, workshop, and training or drill, mostly organized by different non-government organization (NGO) and educational institutions. Amongst the trained respondents, 83% have taken part in earthquake awareness training, seminar or workshop organized by NGOs in educational institutes like school, university etc and 13% community people also got training from Bangladesh Red Crescent Society (BDRCS) (see Figure-10).

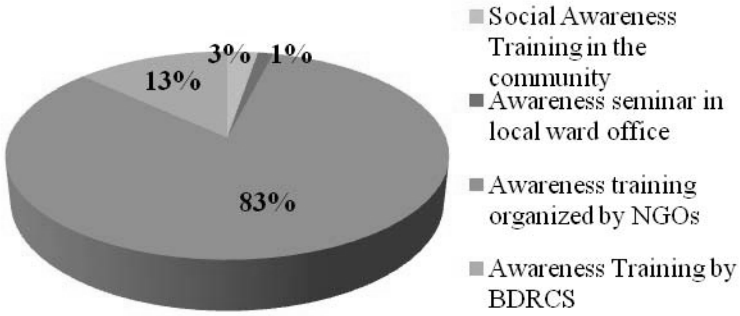



Figure-10: Earthquake Awareness Training Program Attained by Respondent

## 5. Pressure and Release Model

After the social vulnerability assessment of the study area the "Pressure and Release Model (PAR model)" is set up on the basis of existing condition of the community. This model is prepared for showing how an earthquake induced disaster occurs when it affects vulnerable people. For the occurrence of any disaster t there is a series of social factors which causes hazard and generates vulnerability to the people. Their vulnerability is rooted in social processes and underlying causes which may ultimately be quite remote from the disaster event itself. The basis for the Pressure and Release model is that a disaster is the intersection of two opposing forces: those processes generating vulnerability on one side, and the natural hazard event (or sometimes a slowly unfolding natural process) on the other. The 'release' idea is incorporated to conceptualize the reduction of disaster, to ease the pressure, and to reduce vulnerability.

In PAR model, root causes, dynamic pressures, and unsafe conditions apply pressure on those in vulnerability. For the study ward, root causes are *unequal economic distribution, prejudice towards their social minority,* these manifest a progression in vulnerability through dynamic pressures like *lack of knowledge about an earthquake and building construction rules and regulations, inadequacies in training etc*. These dynamic pressures produce unsafe conditions in the physical and social environments of those persons and groups most susceptible to vulnerability to risk. Physically unsafe conditions include *unsafe and non-engineered buildings (39% URM buildings) due to design faults, aged and damaged building, narrow staircase (55% residing building).* Socially unsafe conditions include risks to local economies*; most of the businesses (21% businessman) run in ground floor or at front side of the building and upper floor used as residential purpose and unsafe conditions in different factories like printing and packaging, workshop,mechanical workshop, recycling industry, bottle factory etc and lack of mobility of elderly persons during earthquake to escape and institutional weakness in the implementation of disaster management planning and lack of coordinated action. In the root cause phase of this model, the most important root causes are those which have an economic, demographic, or a political foundation. These foundations affect society's social, financial, and political systems and sometimes influence on the allocation and distribution of resources, among different groups of people.* Figure-11 is an attempt to identify the factors which could be adopted by the respective authorities to reduce the pressure before any upcoming earthquake event. (Blakei et al., 2003)

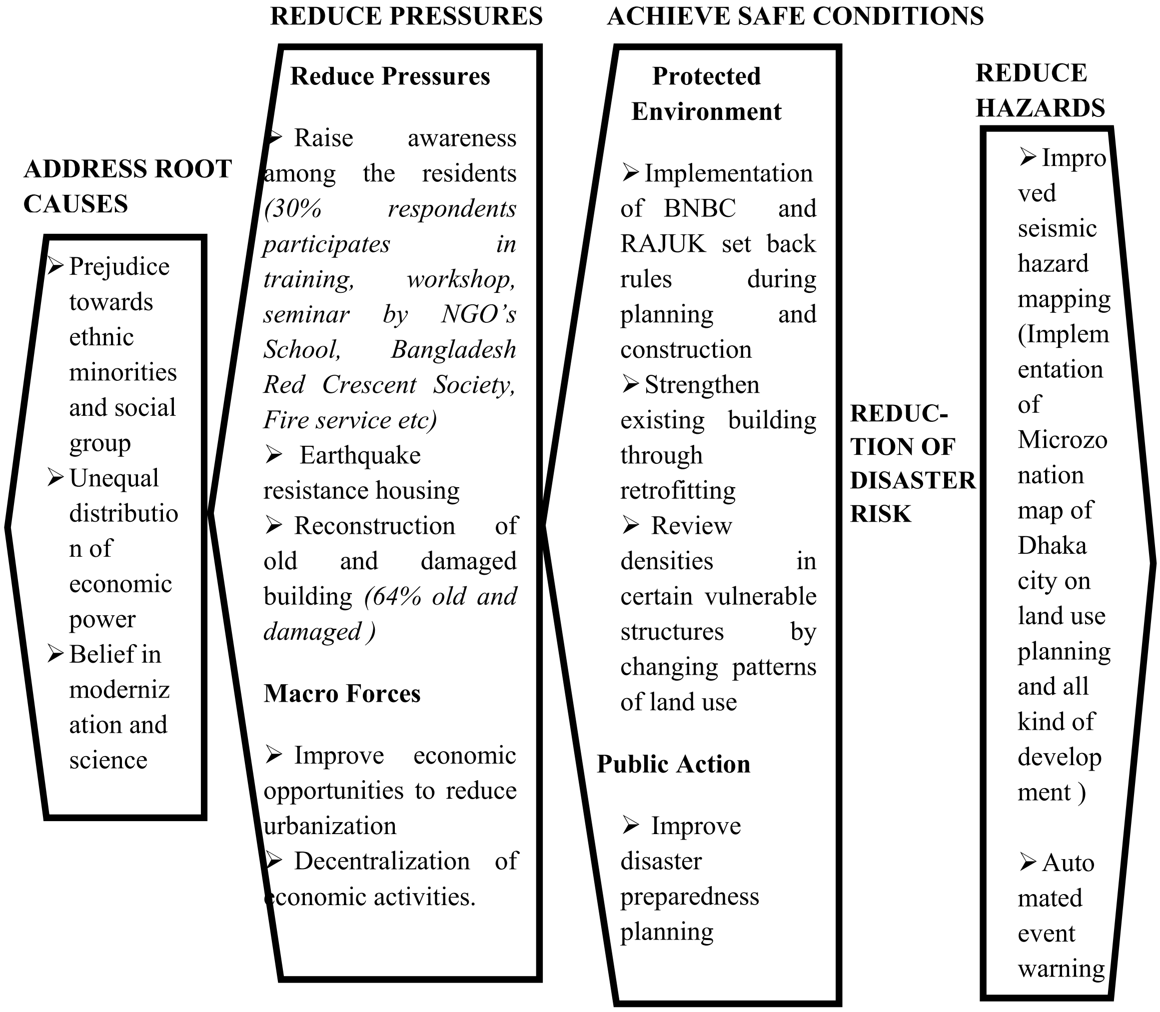



Figure-11: Release of Pressure to Reduce Earthquake

## 6. Vulnerability Assessment Of The Public Buildings Proposed As Evacuation Shelter

There are many public buildings in the study area. Public buildings are selected on the basis of land use as religious center, school, college, community center, meeting place etc. In this study area twenty seven public buildings and three playfields are selected for the evacuation of inhabitants while an earthquake strikes. Many features are considered to assess the public buildings as evacuation place for the dwellers of selected study area.

### 6.1 Assessment Of Public Buildings using RVS Score

Mainly three types of structures- C3, C2 and URM are found in the study ward. But among the public buildings 81% have C3 structure and only 19% have URM structure. Among them 56% public buildings RVS score is greater than two and 44% buildings score less than two. These buildings require further detail analysis.

#### *6.1.1 Plan and Vertical Irregularity*

Irregularity in building plan is a deviation from a rectangular plan. Such deviation from plan irregularity leads to irregularities in stiffness and strength distributions, which in turn increase the risk of damage localization under strong ground excitations. In earthquake resistant design, regularity in plan is encouraged. In the study area a number of public buildings have irregularity in plan. About sixteen buildings have rectangular shape and eleven buildings have irregular plan. It has found from field survey that 89% public buildings in the study area have regularity in their elevation shape i.e. they are vertically regular and 17% buildings have irregular shape.

Photo 7: Vertical Irregularity of Building

### 6.1.2 HEIGHT OF THE PUBLIC BUILDING

It has observed that among all public buildings in the study area 70% are one to three storied and only 9% buildings are more than six storied (see Figure-11). It has also found that only two public buildings (Islampur Jame Mosque and Zindabahar Jame Mosque) are seven storied.

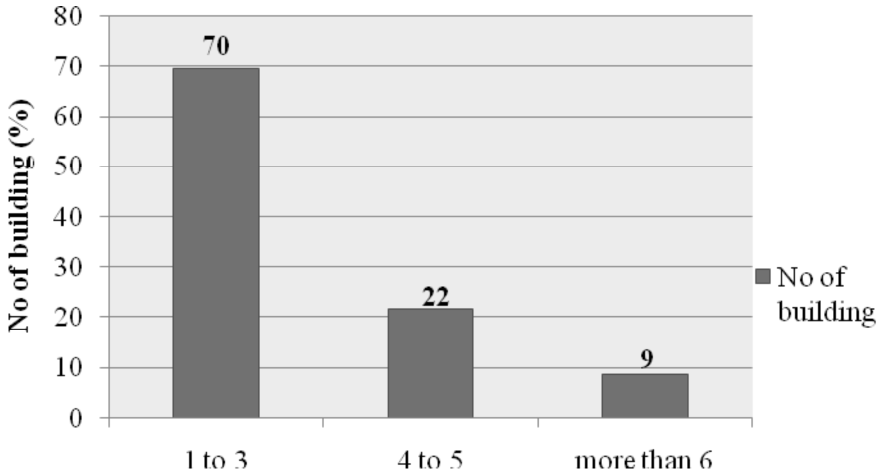



Figure-11: Height according to storey of Public Building

## 6.2 ASSESSMENT OF PUBLIC BUILDINGS USING TURKISH LEVEL-I AND LEVEL-II METHOD

A more detail analysis of buildings is done in Turkish Level-I & Level-II method in comparison with the RVS method. It has been found from other studies that the Turkish method is more compatible in the circumstances of Bangladesh. The detail evaluations of 21 structures which are proposed to be the evacuation sites are done (see Table 3). For detail study of the building Turkish Level-II has executed and many aspects of the building is assessed such as pounding effect, overhang, short column, soft storey, apparent quality of the building.

### 6.2.1 SOFT STOREY OF THE PUBLIC BUILDING

Soft storey buildings are open ground storey buildings, consistently shown poor performance during earthquakes. A significant number of them have collapsed. In the study area it has found that 95% buildings have no open ground and only 5% public buildings have open ground i.e. presence of walls at upper storey (see Figure-12). In accordance with CDMP, 30% buildings in this Ward have soft storey. The existence of walls in upper storey makes them much stiffer than the open ground storey. The existing open ground storey buildings need to be strengthened suitably so as to prevent them from collapsing during strong earthquake shaking. The owners should seek the services of qualified structural engineers who are able to suggest appropriate solutions to increase seismic safety of these buildings.

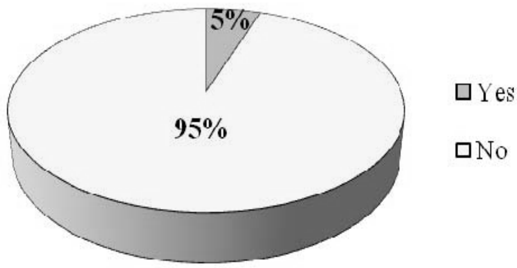



Figure-12: Soft Storey of the Public Building

Table 3: Turkish Method Performance Score and RVS Score

| Public Building | Turkish Method | | RVS Score |
|---|---|---|---|
| | Level I survey | Level II Survey | |
| Ahmed Bawni College | 75 | 85 | 1.9 |
| Ahmed Bawni School | 75 | 85 | 1.9 |
| Anandamoyee Girls' High School (Strc-1) | 125 | 125 | 1.7 |
| Anandamoyee Girls' High School (Strc-2) | 125 | 123 | 2.2 |
| Anandamoyee Girls' High School (Strc-3) | 115 | 120 | 2.2 |
| Haibat Nagar Primary School | 115 | 113 | 1.7 |
| Hammadia School | | | 2.2 |
| Islampur Jame Mosque | 65 | 57 | 0 |
| Jabbu Khanam Jame Mosque | 90 | 100 | 1.9 |
| Jummon Community Center | 125 | 125 | 1.7 |
| Kamranga Jame Mosque | 110 | 106 | 0 |
| Kashaituli Panchayet Committee and School | 80 | 77 | 2.4 |
| Kona Party Center | 80 | 85 | 0.4 |
| Mahuttuli Mosque | 125 | 130 | 2.2 |
| Maulana Mosque | 125 | 130 | 2.1 |
| Moshjid-e-Baitul Mamur | 120 | 125 | 2.2 |
| Samsabad Boro Mosque | 120 | 125 | 2.2 |
| Samsabad Primary School | 75 | 72 | 1.9 |
| Shahjada Mia Jame Mosque | 115 | 118 | 1.7 |
| Shahjadi Begum Jame | 125 | 121 | 2.2 |

| Public Building | Turkish Method | | RVS Score |
|---|---|---|---|
| | Level I survey | Level II Survey | |
| Mosque | | | |
| Zindabahar Jame Mosque | 50 | 47 | 2.4 |

#### 6.2.2 Overhang of the Public Building

From field survey it has observed that most of the public buildings (84%) have no overhang in their structures. These buildings expanded without any desecration of as per plan. Only three buildings (16%) do not follow the plan and design accurately. According to CDMP, it has found that among all buildings in Ward 68, 77% building do not follow the design and rest of the building follows the plan during construction.

#### 6.2.3 Pounding of Public Building

Pounding between closely spaced building structures can be a serious hazard in seismically active areas. It is one of the main causes of severe building damages in earthquake. The non-structural damage involves pounding or movement across separation joints between adjacent structures. Seismic pounding between two adjacent buildings occur during an earthquake. In old Dhaka it is conspicuous that most of the buildings are constructed in the means of congested way. So that it is evident that 84% building in the study area might face pounding effect and only 16% buildings are free from this (see Figure-13).

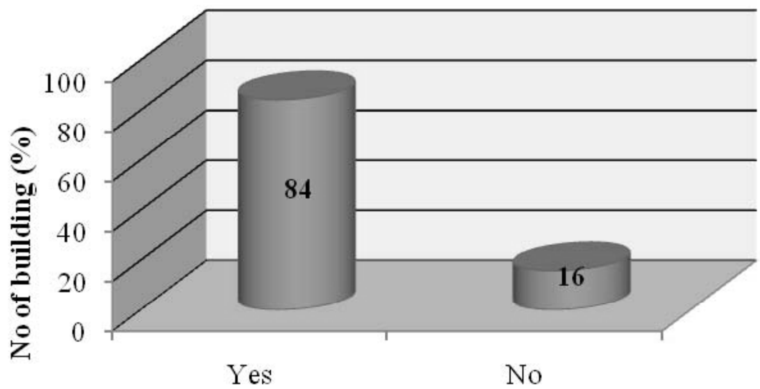



Figure-13: Pounding Effect of Public Building

### 6.2.4 Short Column of Public Building

During past earthquakes, reinforced concrete (RC) buildings that have columns of different heights within one storey, suffered more damage in the shorter columns as compared to taller columns in the same storey. The short column is stiffer as compared to the tall column, and it attracts larger earthquake force. If a short column is not adequately designed for such a large force, it can suffer significant damage during an earthquake. Figure-14 shows 16% buildings short column has identified and rest of the buildings (84%) column is designed consistently. From CDMP, short column of 63% building in the study area are identified and 37% are not identified. In existing buildings with short columns, different retrofit solutions can be applied to avoid damage in future earthquakes.

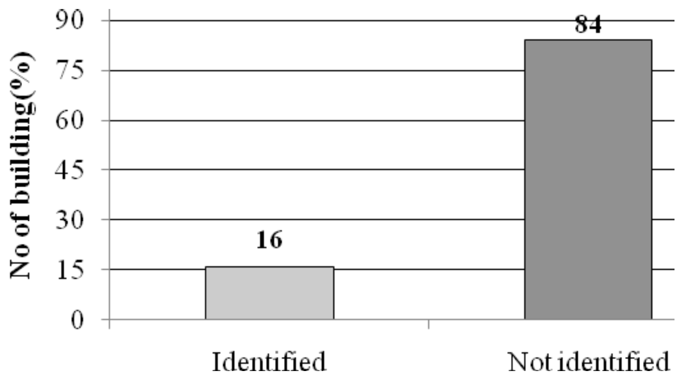



Figure-14: Short Column of Public Building

It is clear that most of the structures fall below the cut-off score in the RVS method but in the Turkish Method, most of them fall above the cut-off score that is they don't need further detail analysis.

### 6.3 Capacity of Public Building and Open Space as Evacuation Shelter

The selected public buildings floor area and total area has calculated. For the calculation of accommodation capacity of a building 80% usable area and for play ground or open space 100% usable area is considered and 10sq.ft space per person is considered. Table -4 shows the capacity of each building to evacuate the residents.

Table-4: Accommodation Capacity of Public Building and Open Space

| Public Building / Open Space | Floor Area | Total Accommodation in a Building |
|---|---|---|
| **Building Name** | | |

| Public Building / Open Space | Floor Area | Total Accommodation in a Building |
|---|---|---|
| Shahajadi Begum Mosque | 7486 | 599 |
| Kashaituli Panchayet Committee | 4560 | 365 |
| Babubajar Ghat Mosque | 4400 | 352 |
| Jummon Community Center | 15720 | 1258 |
| Zindabahar Mosque | 6440 | 515 |
| Haibat Nogor Primary School | 5634 | 451 |
| Mahuttuli Primary School | 2250 | 180 |
| Mahutuli Mosque | 5760 | 461 |
| Anandomoyee Girls -1 | 12600 | 1008 |
| Anandomoyee Girls -3 | 2520 | 202 |
| Anandomoyee Girls -2 | 1800 | 144 |
| Ahmaed Baowani College | 24840 | 1987 |
| Ahmaed Baowani School | 21120 | 1690 |
| Samsabad Primary School | 7500 | 600 |
| Jabbu Khanam Mosque | 10500 | 840 |
| Hammadia School | 10800 | 864 |
| Kona Party Center | 14000 | 1120 |
| Mosjid-E-Baitul-Mamur | 3000 | 240 |
| Malibagh Peyala Mosque | 3200 | 256 |
| Mokimbazar School | 2250 | 180 |
| Islampur Jame Mosque | 27300 | 2184 |
| Shahjada Mia Jame Mosque | 2544 | 204 |
| Kashaituli Old Jame Mosque | 3080 | 246 |
| Samsabad Boro Mosque | 9520 | 762 |
| Maoulana Mosque | 10080 | 806 |
| Kamranga Mosque | 5268 | 421 |

| Public Building / Open Space | Floor Area | Total Accommodation in a Building |
|---|---|---|
| Bongshal Rokonuddin Jame Mosque | 8276 | 662 |
| **Open Space** | | |
| Samsabad Play Field | 13290 | 1329 |
| Armanitola Play Field | 20250 | 2025 |
| Zindabahar Play Field | 60625 | 6063 |
| **Total Accommodation** | | **28012** |

## 7. CONCLUSIONS

The local people are main focus of this study as they will have to face the disaster and their instant response in that time will measure the level of losses after the strike. From the assessment it is found that most of the surveyed people are more or less knows about earthquake and don't have any idea that what have to be done in preparatory phase, during and after the occurrence of the event. A small portion of them got some training arranged by different organizations. The main problem is the built environment with faulty defective infrastructure, narrow road network and the lack of open spaces along with many other symptoms that made the locality vulnerable to earthquake. The main concern is the lack of open spaces. After the earthquake, one should come out from the building and take shelter to open areas. If the people of the vulnerable areas are provided with an evacuation plan they can be aware of that and the loss due to earthquake hazard may be reduced to a great extent.

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# PART-III

# STRONG MOTION MONITORING SYSTEMS IN BANGLADESH: 2007 TO 2009

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ABSTRACT

Five large earthquakes occurred surrounding Bangladesh between 1869 and 1930. Recently no large earthquakes occurred in this area. A large earthquake may occur any time in the future. For seismic hazard analysis earthquake monitoring is important. To measure ground motion within Bangladesh, seven accelerometers was deployed within a 60 km radius of Jamuna Bridge in 2003. Another 34, Strong motion accelerographs (SMAs) were deployed in PWD offices all over Bangladesh. This accelerometers and accelerographs give data in North-South, East-West and Up-Down direction. For the last couple of years, twelve earthquakes are recorded by these accelerometers and SMAs. It is hoped that the system will yield valuable data to the local researchers to have better ideas on the performance of the SMA sites as well as seismic activities of the whole region. The relationship between magnitude, epicentral distance and peak ground acceleration of those earthquakes constitute the basic parameter needed for assessing seismic hazard at a given site. This paper presents earthquake ground motion within Bangladesh recorded by the installed accelerometers and SMAs between 2007 and 2009.

## 1. Introduction

An earthquake is a sudden and violent motion of the earth usually caused by volcanic eruption, plate tectonics, or man-made explosions which lasts for a short time, and within a very limited region. Most earthquakes last for less than a minute. The larger earthquakes are followed by a series of after-shocks which also may be dangerous. Volcanic eruption or plate tectonics is responsible for causing earthquakes. Also small earthquakes can be caused by blasting, quarrying and mining. Man made earthquakes are like underground nuclear explosions. But plate tectonics cause large number of big earthquakes. The low incidence of severe earthquakes during the century has led to a situation where most of the population and policy makers don't perceive seismic risk to be important. For this purpose there are thirty-four analog SMAs obtained from USGS were deployed in free-field (on ground) at different PWD offices all over Bangladesh, especially in moderately seismic zoning areas such as Chittagong, Sylhet, Dhaka, Mymensingh, Rangpur, and Sathkhira district. The Strong Motion Accelerograph must be situated in the ground surface, soil condition to be hard or sandy soil. The rapid urbanisation, development of critical engineering works, industrialization of cities with modern types of buildings and the concetration of populations living or settling in hazardous areas are matters of growing concern, as they contribute to heavier loss of life and increase considerably the cost of disaster damage. Macroseismic earthquake data of the historical earhquakes are important for seismic hazard analysis. The relationship between magnitude, epicentral distance and peak ground accleration of these earthquakes constitute the basic parameter needed for assessing seismic hazard at a given site.

## 2. Objectives

During the last two centuries, Bangladesh and its neighbouring region have experienced several large earthquakes. The peak ground acceleration of these earthquakes has been estimated using different existing attenuation law. But for earthquake hazard analysis, unified acceleration attenuation relationship for Bangladesh is required. The major objectives of the study are as follows:

(a) To develop an acceleration based attenuation relationship for Bangladesh and it's surrounding region.

(b) To obtain building respones during an earthquake

(c) To obtain strong motion data which can be used to update BNBC 1993

(d) To exchange earthquake data with neighbouring countries

## 3. Earthquake Monitoring System in Bangladesh

Strong Motion Acclerograph (SMAs) is an analog earthquake data recording equipment. Thirty-four analog SMAs obtained from USGS were deployed in free-field (on ground) at different PWD offices all over Bangladesh, especially in moderately seismic zoning areas such as Chittagong, Sylhet, Dhaka, Mymensingh, Rangpur, and Sathkhira district. The operating and Monitoring Phase of the project has started on April 01, 2005 and after instalation on SMAs every two or three month latter than to be check the SMAs instrument such as, changing in rechargeable battery, recheck outer fencing in the instrument, battery voltage, connection, trigger value set-up and earthquake data collection for all free-field stations. This accelerometer gives data in North-South, East-West and Up-Down direction. The initial goal of the project is to develop an earthquake time history database for different soil condition and different earthquakes of Bangladesh. After compilation of a number of earthquakes, this database will be used to develop attenuation law for Bangladesh.

## 4. Earthquake Records

The installation of 34 SMAs at PWD offices all over Bangladesh and within BUET campus was completed in the end of March 2005. From April 2005 to November 2009, these SMAs recorded the following earthquakes:

- May 30, 2006 : Bay of Bengal Earthquake
- August 05, 2006 : Jessore Earthquake
- November 03, 2006 : Myanmar-India Earthquake
- November 10, 2006 : Bangladesh-India Earthquake
- July 28, 2007: India-Myanmar Earthquake
- November 07, 2007: Bangladesh-Myanmar Earthquake (1)
- March 20, 2008: Modhupur Earthquake
- July 05, 2008: Rajshahi Earthquake
- **July 27, 2008: Haluahhat Earthquake**

- August 23, 2008: Bangladesh-Myanmar Earthquake (2)
- January 06, 2009: Tangail Earthquake
- **September 21, 2009: Bhutan Earthquake**

**4.1 July 27, 2008: Haluahhat Earthquake**

On July 27, 2008 an earthquake was recorded by the free-field stations Netrokona, Kishoreganj, sherpur, jamalpur, Hobiganj, Rangpur and Nilphamari at 12:55:58 hrs BST (18:52:58 hrs GMT, July 27, 2008). Magnitude of this earthquake was 4.8 and depth was 44 Km. Maximum acceleration of this earthquake in Jamalpur was 54.3198 cm/sec.$^2$ and it was in North-South direction.

**4.2 September 21, 2009: Bhutan Earthquake**

Last on September 21, 2009 Bhutan Earthquake was recorded by the free-field stations Panchagarh, Dinajpur, Lalmonirhat, Rangpur and Airport Hazi-camp at 14:40:45 hrs BST (08:40:45 hrs GMT, September 21, 2009). Its Magnitute was 5.5 and depth was 16Km. Maximum acceleration of this earthquake in Dinajpur was -48.0967 cm/sec.$^2$ and it was in East-West direction.

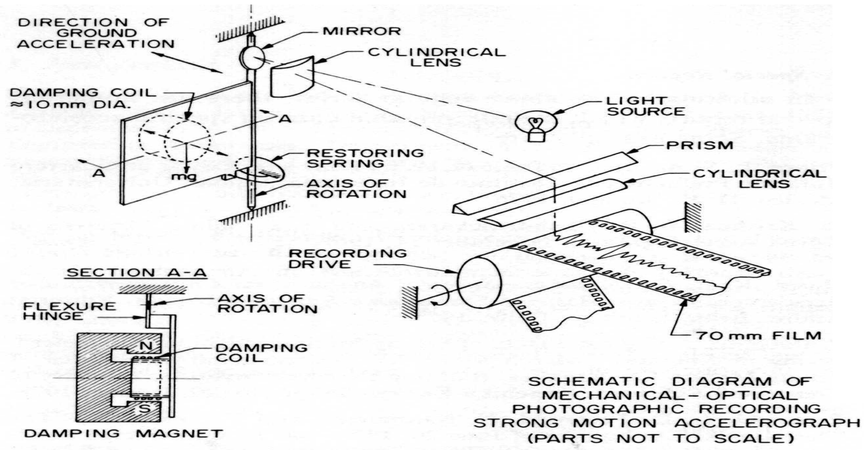


**Figure D1**

**Figure: 1 Strong Motion Accelerograph Machine**

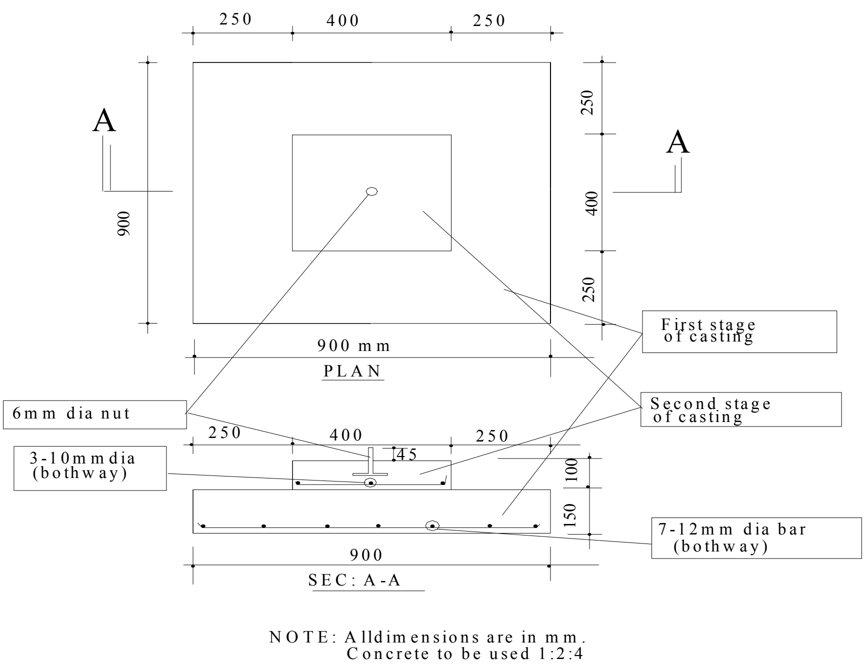


**Figure: 2 Concrete Base Foundations for SMA-Instrument**

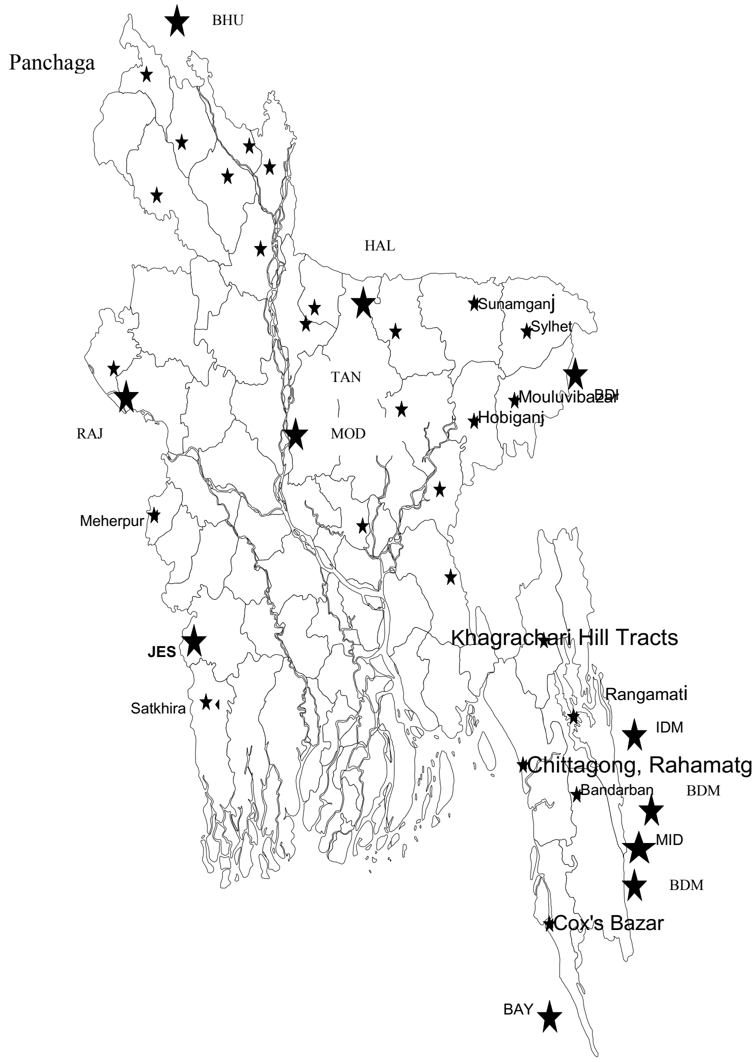


Figure.3 ★ Sign indicates the location of SMA-site and
★ Sign indicates the name and location of Earthquake.

Figure 3. Location of earthquakes and SMAs

Figure 4. ETNA-Earthquake Digital Equipment

Table 1.Summary of Recorded earthquake events with different accelerometer are shows in below

| Name of the earthquake | CODE | Occurrence date | Latitude (deg.) | Longitude (deg.) | Magnitude | Depth (km) | Maximum recorded acceleration (cm/sec$^2$) | Recorded site |
|---|---|---|---|---|---|---|---|---|
| Bay of Bengal | BAY MAY30 2006 | 30.05.2006 | 20.60ºN | 91.94ºE | 4.7 | 29 | 16.0 | Agrabad, Rahamatganj and Coxbazar |
| Jessore | JES AUG 05 2006 | 05.08.2006 | 23.10ºN | 89.20ºE | 4.0 | 15 | 24.0 | Meherpur and Sathkhira |
| Mynmar-India | MID NOV 03 2006 | 03.11.2006 | 22ºN | 93.30ºE | 5.2 | 33 | 34.0 | Rahamatganj, Coxbazar, Bandanbhan, Khagrachari and Rangamati |
| Bangladesh-India | BDI NOV 10 2006 | 10.11.2006 | 24.60ºN | 92.60ºE | 5.0 | 33 | 34.0 | Sylhet, Sunamganj, Moulovibazar and Hobiganj |
| India-Mynmar | IDM JUL 28 2007 | 28.07.2007 | 22.80ºN | 93.30ºE | 4.8 | 15 | 32.0 | Rahamatganj, Bandarbhan, Khagrachari and Rangamati |
| Bangladesh-Myanmar | BDM NOV 07 2007 | 07.11.2007 | 22.80ºN | 92.60ºE | 5.3 | 15 | 96.0 | Rahamatganj, Bandarbhan, Khagrachari,Cox'sbazar and Rangamati |
| Modhupur | MOD MAR 20 2008 | 20.03.2008 | 23.60ºN | 89.75ºE | 4.2 | 25 | 32.0 | Airport Hazicamp ,jamalpur and Serajganj Jamuna Bridge east and west end. |
| Rajshahi | RAJ JUL 05 2008 | 05.07.2008 | 24.4ºN | 88.5ºE | 4.1 | 29 | 42.9893 | Chapai-nawabganj |
| Haluaghat | HAL JUL 27 2008 | 27.07.2008 | 23.60ºN | 91.20ºE | 4.8 | 44 | 54.3198 | Sherpur, Jamalpur, Netrokona, Kishoreganj, Hobiganj, Rangpur and |
| Bangladesh-Myanmar | BDM AUG 23 2008 | 22.08.2008 | 22.80ºN | 92.60ºE | 4.9 | 25 | 58.5964 | Rangamati, Bandarban and Chittagong(Rahmatganj) |
| Tangail | TAN JAN 06 2009 | 06.01.2009 | 24.39ºN | 89.75ºE | 4.0 | 10 | 19.72705 | Jamuna-bridge East site, West site, Bogra and Natore |
| Bhutan | BHU SEP 21 2009 | 22.09.2009 | 24.50ºN | 88.75ºE | 5.5 | 60 | 48.0967 | Panchagarh,Dinajpur,Lalmonirhat,Rangpur and Airport Hazi-camp. |

Table 2.Summary of Ground Motion in Free field Stations due to (Haluaghat) - Mymensingh Earthquake on July 27, 2008

| **Station ID#** | **Channel** | **Date** | **Time (GMT)** | **Latitude & Longitude** | **Derived Max. Peak Ground Acceleration** $(cm/sec^2)$ |
|---|---|---|---|---|---|
| Sherpur | EW | 27.07.2008 | 18:52:58 | 23.25ºN 89.64ºE | -10.9215 |
| | UD | | | | 6.4647 |
| | NS | | | | -38.4383 |
| Jamalpur | EW | 27.07.2008 | 18:52:58 | 23.19ºN 89.94ºE | -32.4108 |
| | UD | | | | -6.3360 |
| | NS | | | | 29.1048 |
| Netrokona | EW | 27.07.2008 | 18:52:58 | 23.15ºN 8924ºE | -10.2193 |
| | UD | | | | 22.8482 |
| | NS | | | | 9.7069 |
| Kishoreganj | EW | 27.07.2008 | 18:52:58 | 23.01ºN 89.14ºE | -9.1392 |
| | UD | | | | 9.053 |
| | NS | | | | -18.0918 |

Note. EW represents East-West direction
UD represents Vertical direction
NS represents North-South direction

Table 3.Summary of Ground Motion in Free field Stations due to Bhutan Earthquake on September 21, 2009

Note.

| Station ID# | Channel | Date | Time (GMT) | Latitude & Longitude | Derived Max. Peak Ground Acceleration (cm/sec$^2$) |
|---|---|---|---|---|---|
| Panchagarh | EW | 21.09.2009 | 14:40:45 | 23.50ºN 88.50ºE | -28.0423 |
| | UD | | | | -32.3755 |
| | NS | | | | -24.2571 |
| Dinajpur | EW | 21.09.2009 | 14:40:45 | 23.60ºN 88.60ºE | -48.09671 |
| | UD | | | | 7.5736 |
| | NS | | | | -18.4730 |
| Lalmonirhat | EW | 21.09.2009 | 14:40:45 | 23.50ºN 88.75ºE | -20.8127 |
| | UD | | | | 17.3437 |
| | NS | | | | -34.6037 |
| Rangpur | EW | 21.09.2009 | 14:40:45 | 23.50ºN 88.70ºE | 11.2247 |
| | UD | | | | 6.2363 |
| | NS | | | | -24.4358 |
| Airport-Hazi-Camp | EW | 21.09.2009 | 21.09.2009 | 24.50ºN 89.70ºE | -23.56 |
| | UD | | | | 14.25 |
| | NS | | | | -22.36 |

EW represents East-West direction
UD represents Vertical direction
NS represents North-South direction

## Conclusions

The first earthquake recorded by SMAs was the Bay of Bengal Earthquake on May 30, 2006 and Last on September 21, 2009 Bhutan Earthquake was recorded by the free-field stations Panchagarh, Dinajpur, Lalmonirhat, Rangpur and Airport Hazi-camp at 14:40:45 hrs BST (08:40:45 hrs GMT, September 21, 2009). Its Magnitute was 5.5 and depth was 16Km. Maximum acceleration of this earthquake in Dinajpur was -48.0967 cm/sec.$^2$ and it was in East-West direction. By recording this earthquake event, the installation of the earthquake monitoring system for Bangladesh entered in to an interesting stage. The earthquake, which was a minor one, is estimated to be located close to the SMA site. This paper prsents analysis result of this particular earthquake data recorded nine free field stations namely, Sherpur, Jamalpur, Netrokona, Kishoreganj, Panchagarh, Dinajpur, Rangpur, Lalmonirhat and Airport Hazi-camp. After installation the system so far recorded twelve earthquakes. It is hoped that the system will yield valuable data to the local researchers to have better ideas on the performance of the SMA sites as well as seismic activities of the whole region. For the next few years compilation of such earthquake data is needed to develop the attenuation law for Bangladesh. This attenuation law will help us to develop the seismic zonation map for Bangladesh.

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Time history of different free-field station during Haluaghat  Earthquake on July 27, 2008 and Bhutan Earthquake on September 21, 2009

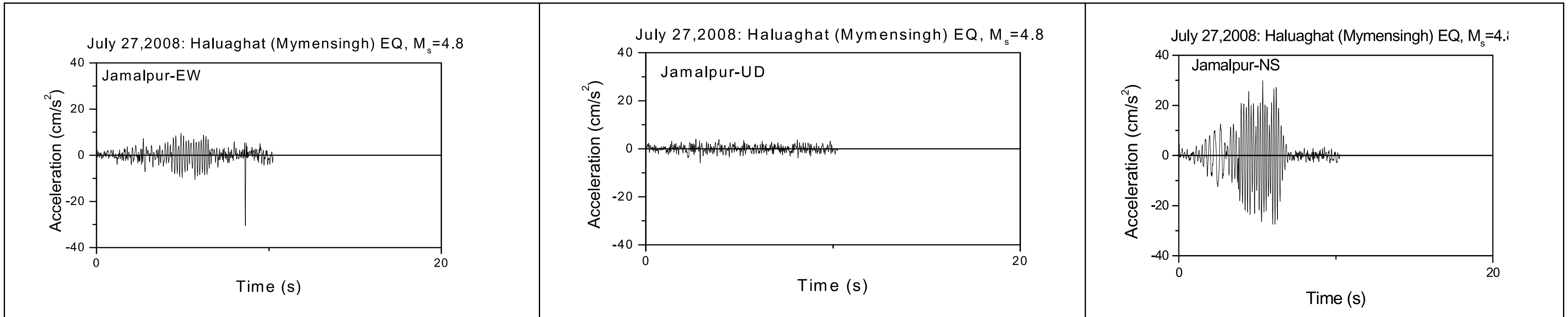


Figure 5. Time history of Jamalpur free-field station during the Haluaghat  Earthquake of July 27, 2008

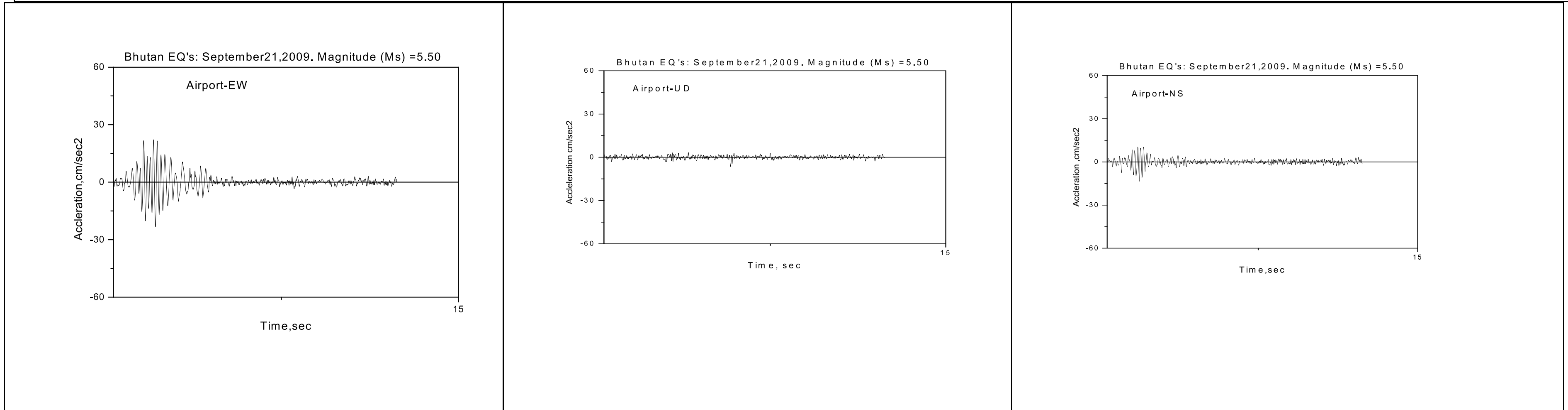


Figure 6. Time history of Airport Hazi-camp  free-field station during the Bhutan Earthquake on September 21, 2009

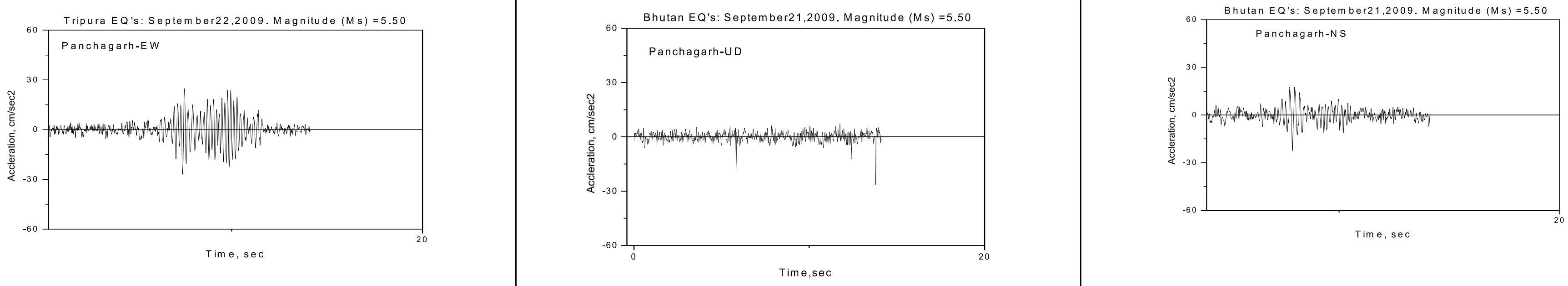


Figure 7. Time history of Panchagarh free-field station during the Bhutan Earthquake on September 21, 2009

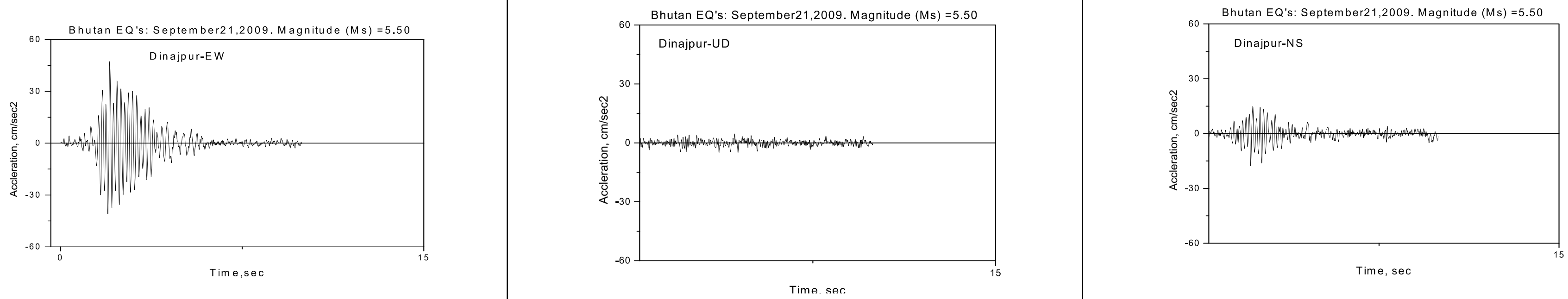


Figure 8. Time history of Dinajpur free-field station during the Bhutan Earthquake on September 21, 2009

BANGLADESH NETWORK
OFFICE FOR URBAN SAFETY

# PART-IV

# GEOPHYSICAL SURVEYS AT SRIMANGAL AREA, SYLHET


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## INTRODUCTION

BNUS together with Geology Department of Dhaka University performed two types of Geophysical tests at SriMangal, Sylhet in early January, 2010. The procedure and results are described below.

## DETERMINATION OF ELECTRIC RESISTIVITY OF SOIL

Objective of the Test:

To determine the subsurface soil characteristics and ground aquifer.

Equipments:

- Hammer
- 6 Pieces steel electrodes
- Tape
- Joint rod.
- Cables
- GPS
- Magnetic Compass
- Battery
- Electric resistivity Meter


Figure 01: Resistivity meter


Figure 02: Battery


Figure 03: GPS

Figure 04: Magnetic Compass

Field Procedure:

1. The electric Resistivity Test of Soil is not sensitive to ground vibration like Shallow Depth Shear wave velocity. As a result, special consideration for vibration is not mandatory for this test. But the adjacent electric or magnetic field will affect the Test Result. So this consideration should be justified before Testing.
2. Before arranging the device for this Test, locations are selected considering the SPT bore hole locations and Geographical position is assessed with GPS.
3. All the equipments (Resistivity meter, Battery, Electrode etc.) are connected with the cables (See Figure 05).

Figure 05: Arrangement of equipment

Figure 06: Data recording

4. To adjust the Power of resistivity meter initial data is taken for premonition the soil resistance. If the resistivity of the soil is not suitable for current flow below the soil, water should be poured into the soil to create the medium of current flow.
5. After arranging the equipment the potential drop between the electrodes is recorded. This data is taken on both sides same distance of the device. The potential electrodes are positioned at 0.5m and 1m distance on the both side of equipment.

6. This test can be performed up to 50m depth of the soil. So, the location of the ground aquifer within this limit may be identified. (See Figure 05)
7. The power of the source is proportional to the distance of the potential drop. So, the power of the source is increased with the increased of distance. As a result, more power is required for increasing the distance from the equipment.
8. The position of the electrode is planned on the basis of the log scale. This test can be covered for long arena.
9. By the potential drop of current the soil resistance and the characteristics of soil is calculated.(See Figure 06)

Functions of the Devices:

- ❖ Global Positioning System (GPS): Global Positioning System is used to locate the position of test. Generally, latitude and longitude are recorded with the GPS device (See Figure 03).
- ❖ Magnetic Compass: Magnetic Compass is used to identify the geological North direction and to adjust the field condition with the map. (See Figure 04)
- ❖ Hammer: Hammer is used to penetrate the steel electrode to the Ground.
- ❖ Resistivity Meter: Electric resistivity is a device to determine the electric resistance of soil below the ground surface.(See Figure 01)
- ❖ Battery: Battery is used for current supply. (See Figure 01)
- ❖ Cables: Good quality cables are used for the current flow and to record efficient data. (See Figure 02)

## GEOELECTRIC RESISTIVITY SURVEY

Geoelectric resistivity survey was carried out in the area to follow the variation of subsurface resistivity variation. 4 electrode Schlumberger Configuration with the maximum current electrode separation of 50m is used in the survey. 11 soundings are carried out at different sites covering the area. Measured resistivity values are expressed in the form of profiles, maps and models.

Figure 1 shows the location of VES points and the direction of the profiles along which the vertical variation of resistivity is shown. 3 profiles CC', AA' and BB' are selected to follow the vertical variation of resistivity along these directions. Profile CC' extend from NW to SE while AA' and BB' from SW to NE direction.

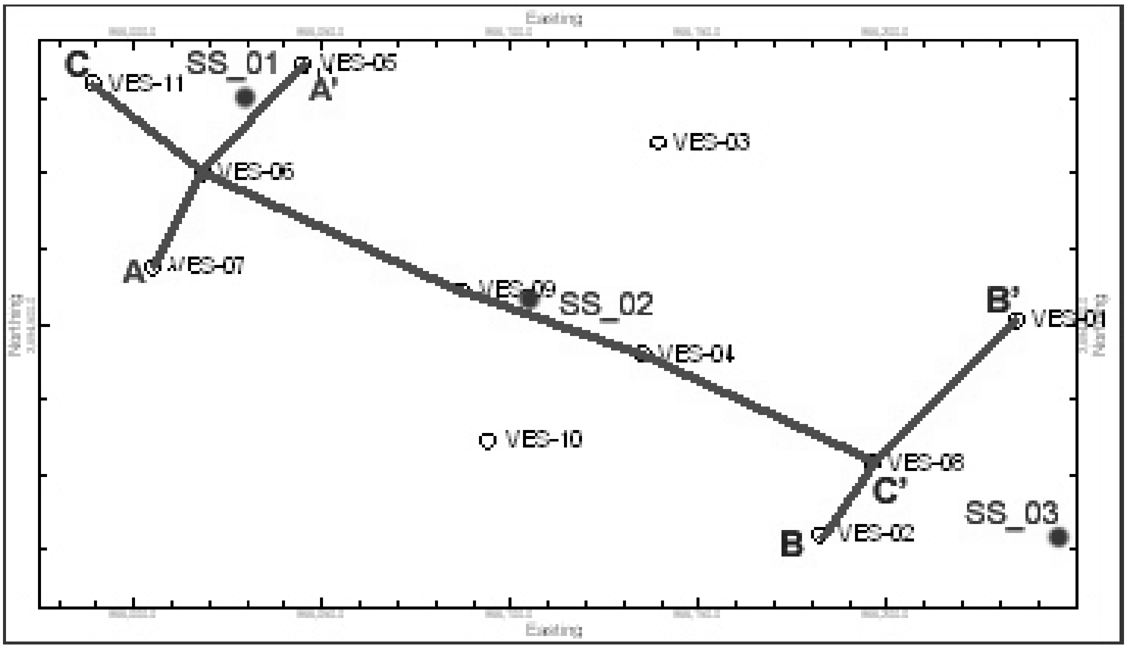


Fig. 1: Distribution of shallow seismic (SS) and vertical electrical sounding (VES) location and the direction of electrical profiles in the area

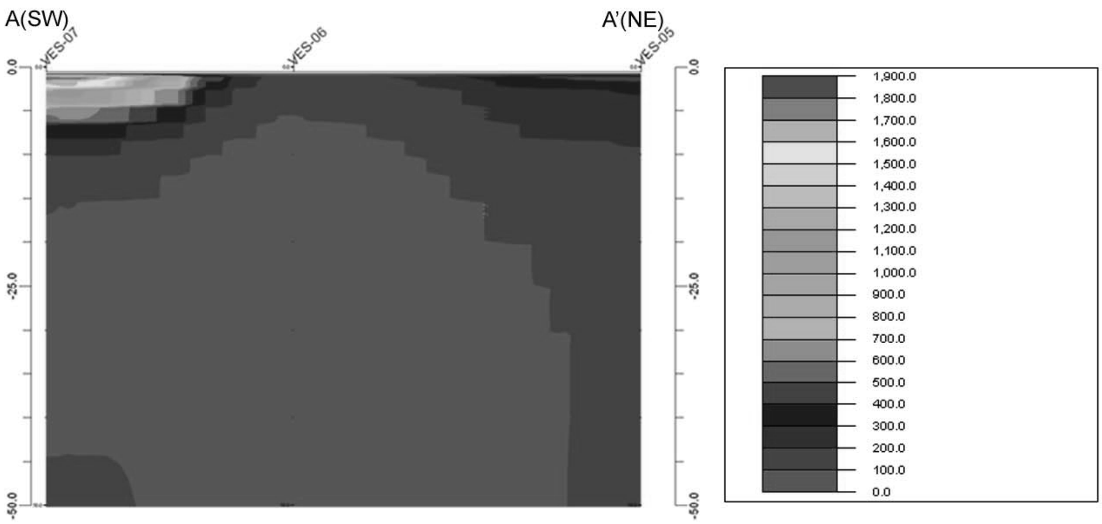


Fig. 2: Resistivity section along line AA'

Resistivity section along AA' (Fig. 2) in SW-NE direction shows the maximum resistivity along this profile in south-west corner reaching more than 1500 Ωm at the surface level. But at the central point the resistivity of the surface soil is below 500 Ωm. With the increase of

AB/2 resistivity decreases along the profile and below AB/2=15m resistivity is uniform and is below 100 Ωm in the central and western part. At the north eastern part resistivity is a bit higher and is about 150 Ωm.

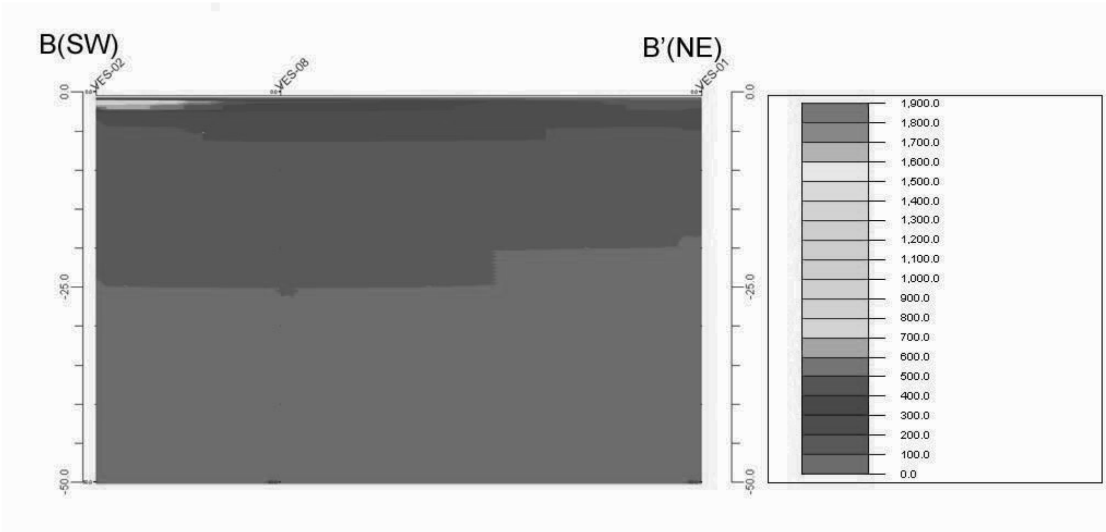


Fig. 3: Resistivity section along line BB'

Profile BB' along SW-NE direction is in the north eastern corner of the area (Fig. 1). Resistivity section along BB' shows the higher resistivity about 700 Ωm is at the south-west corner and reduces to about 400 Ωm in the central and in the north eastern part (Fig. 3). From AB/2=5m to 25m the resistivity is below 200 Ωm and the deeper resistivity zone shows resistivity below 100 Ωm.

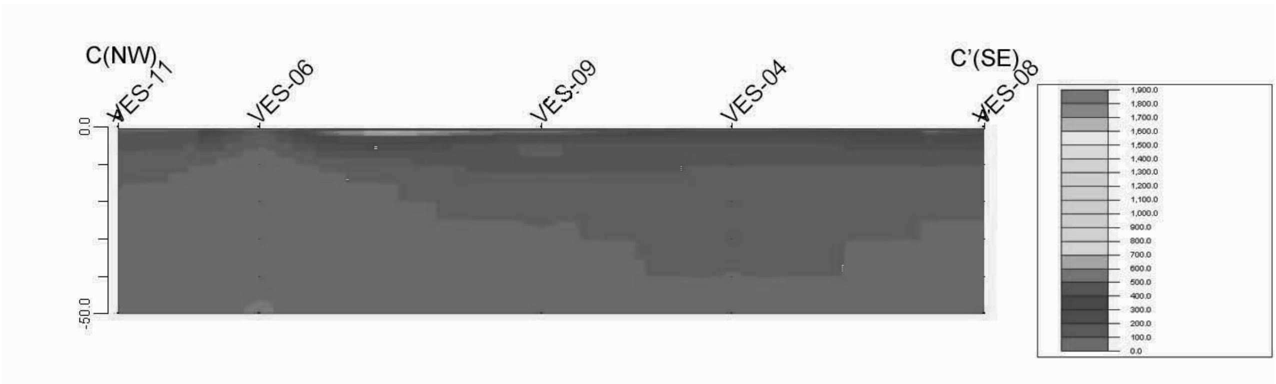


Fig. 4: Resistivity section along line CC'

Resistivity section along CC' is in NW-SE direction extends from north-west corner to the north-east corner (Fig. 1). The surface soil along this profile shows resistivity of about 400 Ωm except the zone between VES 06 and VES 09 where the resistivity is 700 Ωm. Resistivity reduces gradually downward to less than 100 Ωm. Low resistivity zone becomes thicker towards north-west and the maximum thickness occurs at VES 6 (Fig. 4).

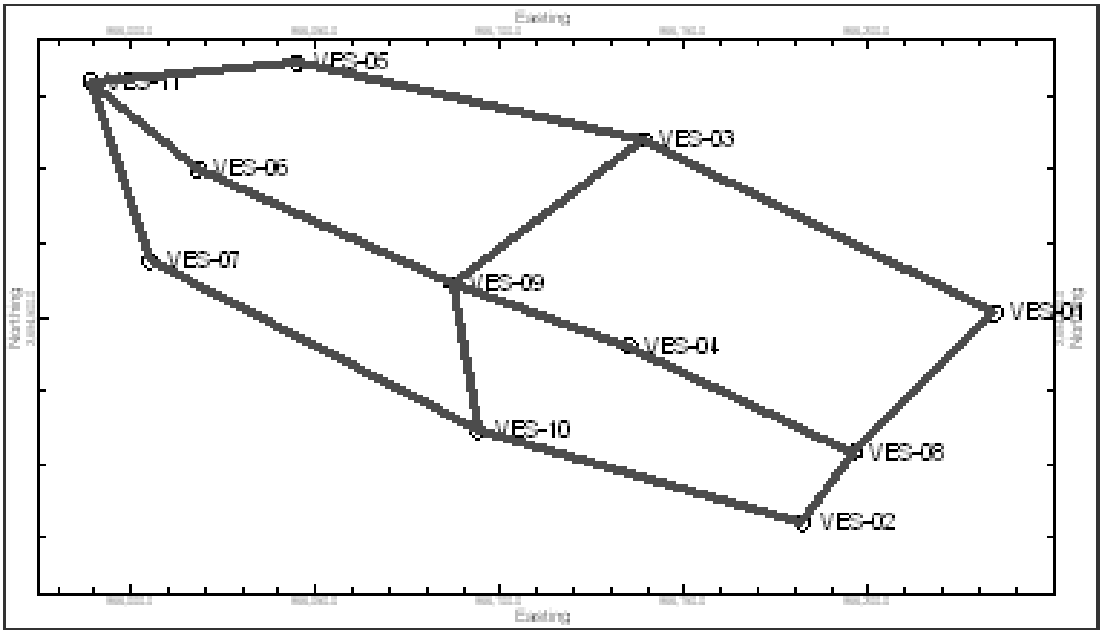


**Fig. 5: Direction of Lines of Fence diagram**

Figure 5 shows the direction of the lines used for the construction of the fence diagram. Three lines each in NW-SE and NE –SW directions are selected to observe the resistivity variation in vertically and laterally along these lines.

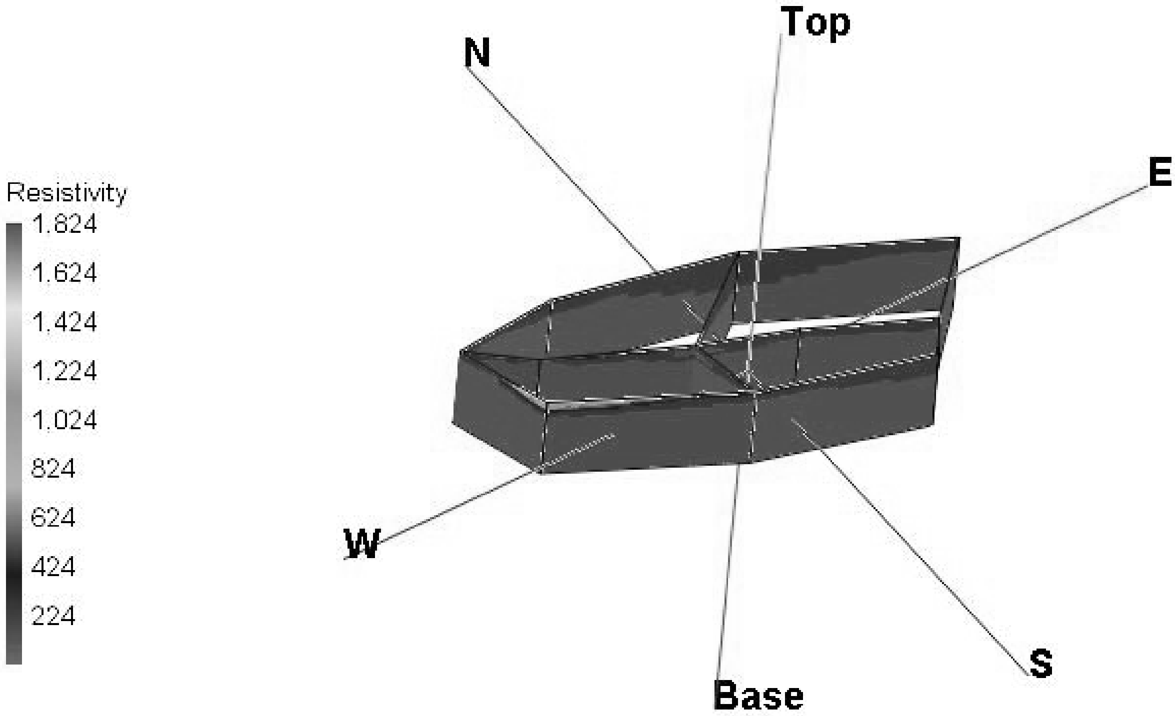


**Fig. 6: Fence Diagram of Subsurface Resistivity Variation**

Fence diagram (Fig. 6) also shows rapid variations in resistivity of the surface soil ranging from about 1500 Ωm in the central part to about 400 Ωm in the eastern and northeastern part. The following zone shows resistivity below 400 Ωm with higher thickness in the north central part. The third resistivity zone shows resistivity below 200 Ωm that continues to the investigated depth.

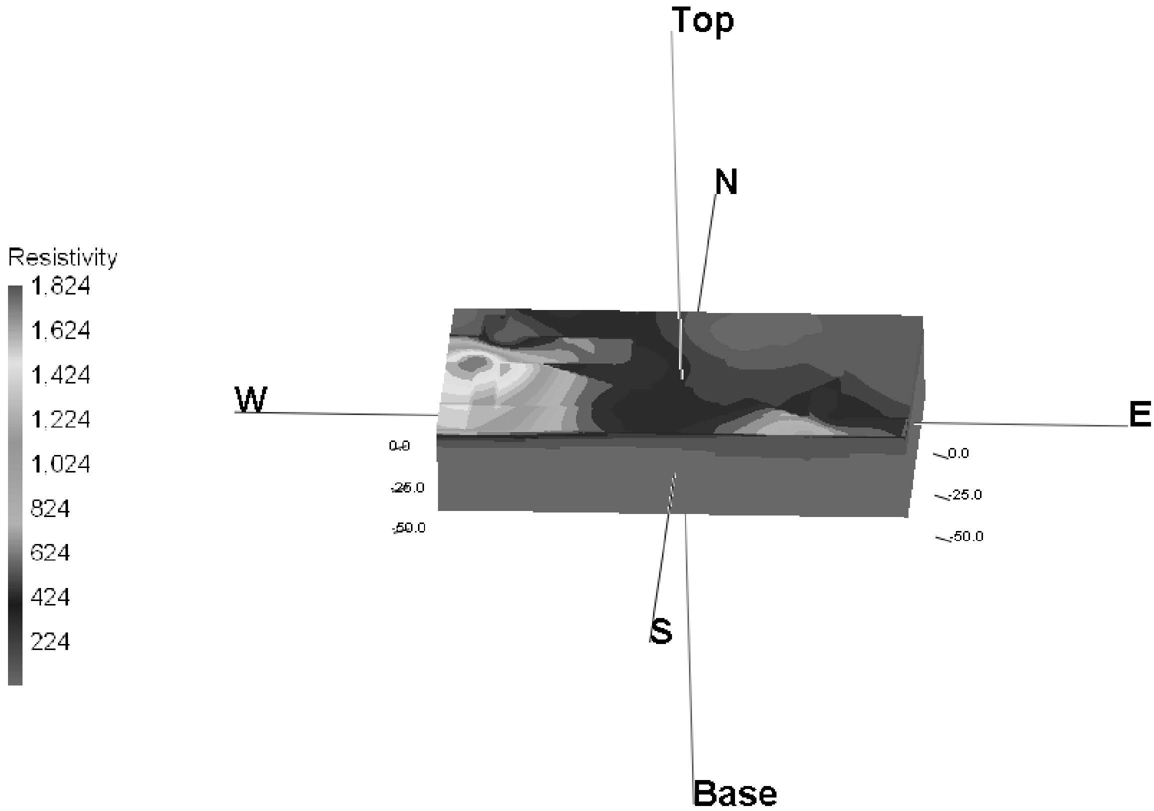


**Fig. 7: Subsurface Resistivity Model (vertical axis AB/2 in meter)**

It is evident from resistivity model constructed based resistivity measurements (Fig. 7) that surface soil resistivity is highly variable and shows resistivity around 1800 Ωm at central western part. At the central part surface soil resistivity is around 400 Ωm and in the north eastern part soil resistivity is below 200 Ωm. The highly variable resistivity of the surface soil is related to the relief, composition and moisture content of the soil. The sandy dry soil shows higher resistivity. The resistivity below top soil is uniform and is about 200 Ωm and below this zone resistivity further reduces to about 100 Ωm or below. The sudden reduction in resistivity below the top soil is related to the ground water table.

The top soil is silty to sandy clay in nature and resistivity of the top soil is controlled by its composition, dryness and relief. Below top soil the sequence is composed of sand and the resistivity is governed mostly by the texture, compactness, porosity, water content and mineralization of water.

**Subsurface Resistivity Maps**

Subsurface resistivity measured as a function of depth are used to draw contours for AB/2 = 1, 5, 10, 15, 20, 25, 30, 40 and 50m.

Contours drawn at 1m AB/2 shows spatial variation and higher resistivity ( ~ 1900 Ωm) is found to occur at the south western part of the area (Fig. 8). Resistivity gradually reduces in the central and north-eastern side of the area reaching to ~200 Ωm. Spatial variation in the top soil reflects variation in the composition, moisture content, compactness and relief.

Resistivity contours at 5m AB/2 (Fig. 9) shows the similar resistivity distribution as in figure 8 reflecting the similar condition of subsoil.

Resistivity contours at 10m AB/2 (Fig. 10) indicate much lower resistivity values with fluctuations from 70 to 230 Ωm. Distribution pattern of resistivity is also different from figure 8 and 9 for AB/2 1 and 5m. Resistivity contours drawn for larger AB/2 from 15m to 50m (Fig. 11to 16) demonstrate more or less similar distribution of resistivity indicating the uniform nature of subsurface rock media. Resistivity values (40 to 225 Ωm ) indicate the media as a sandy one.

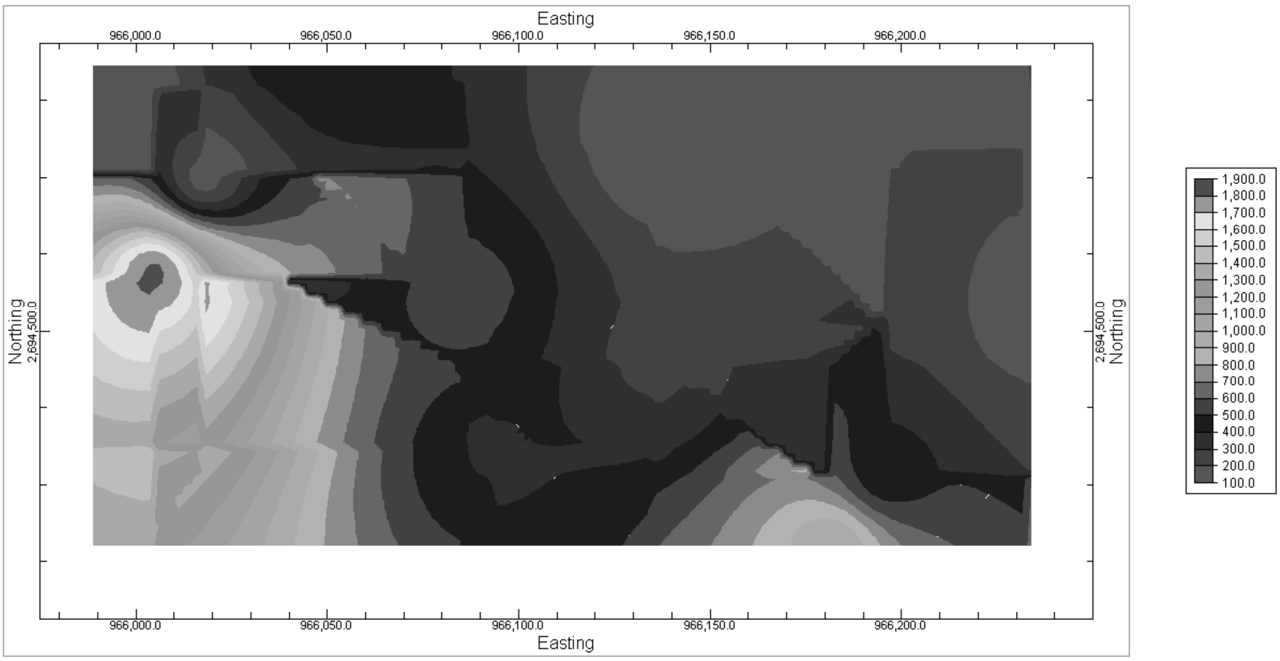


Fig. 8: Subsurface Resistivity Map at 1m Depth.

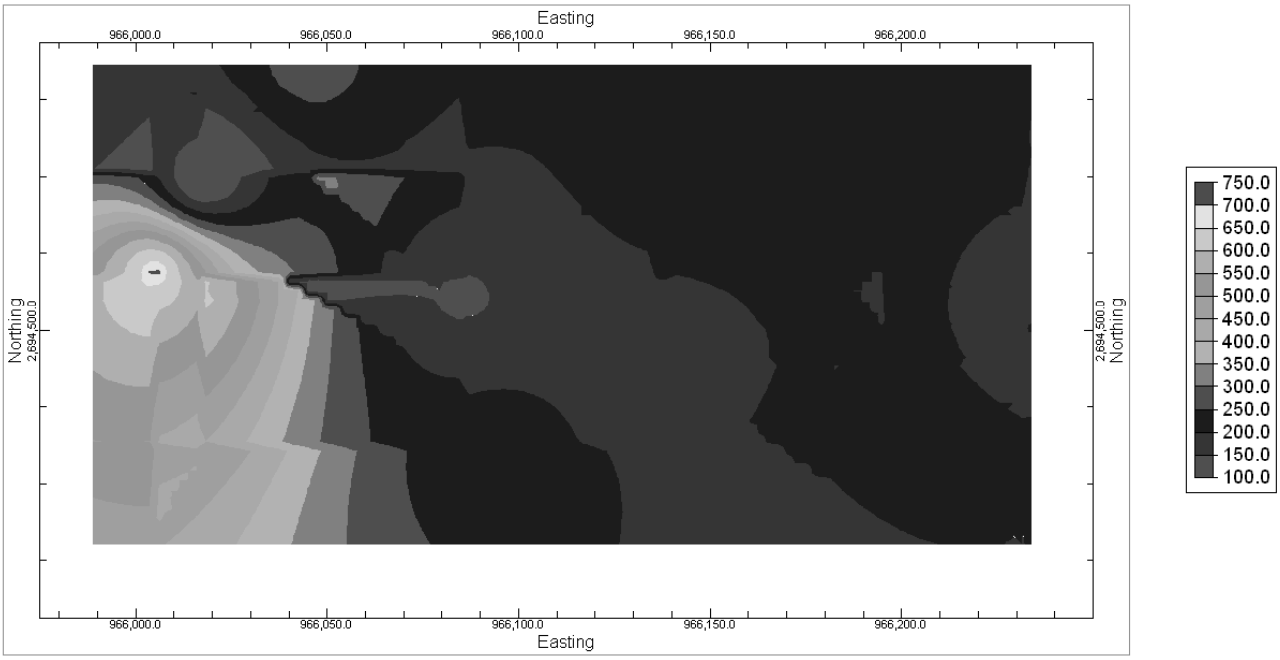


Fig. 9: Subsurface Resistivity Map at 5m Depth.

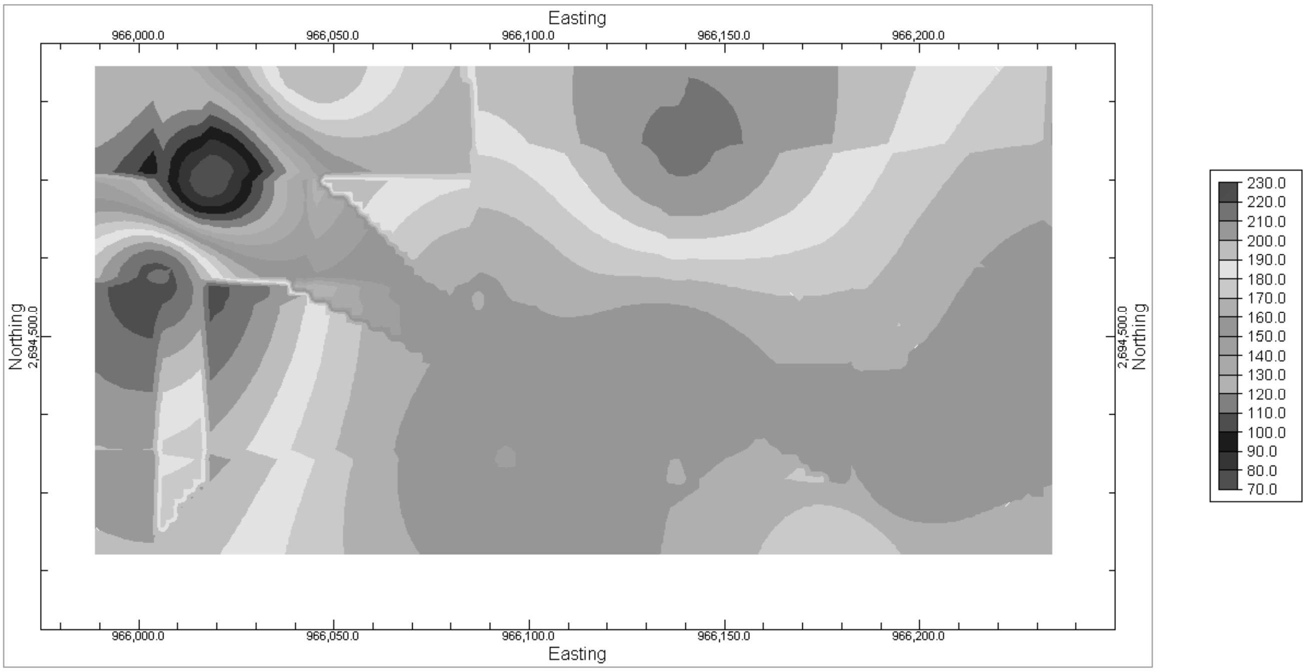


Fig. 10: Subsurface Resistivity Map at 10m AB/2.

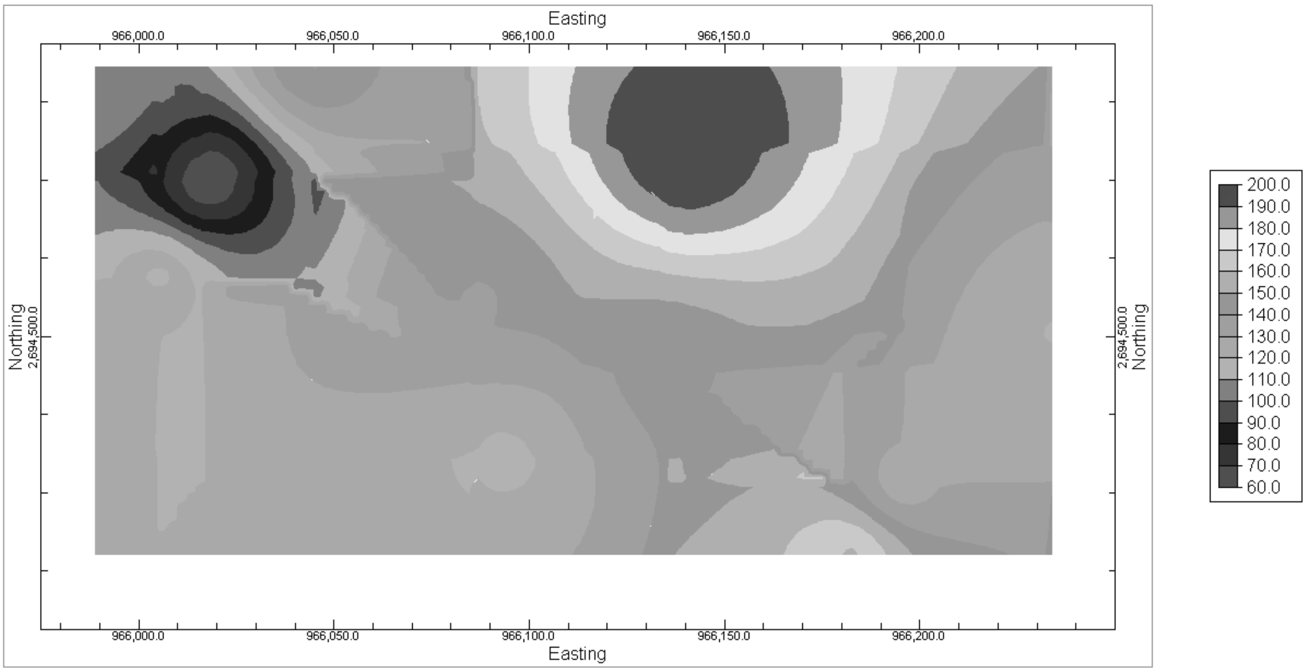


Fig. 11: Subsurface Resistivity Map at 15m Depth.

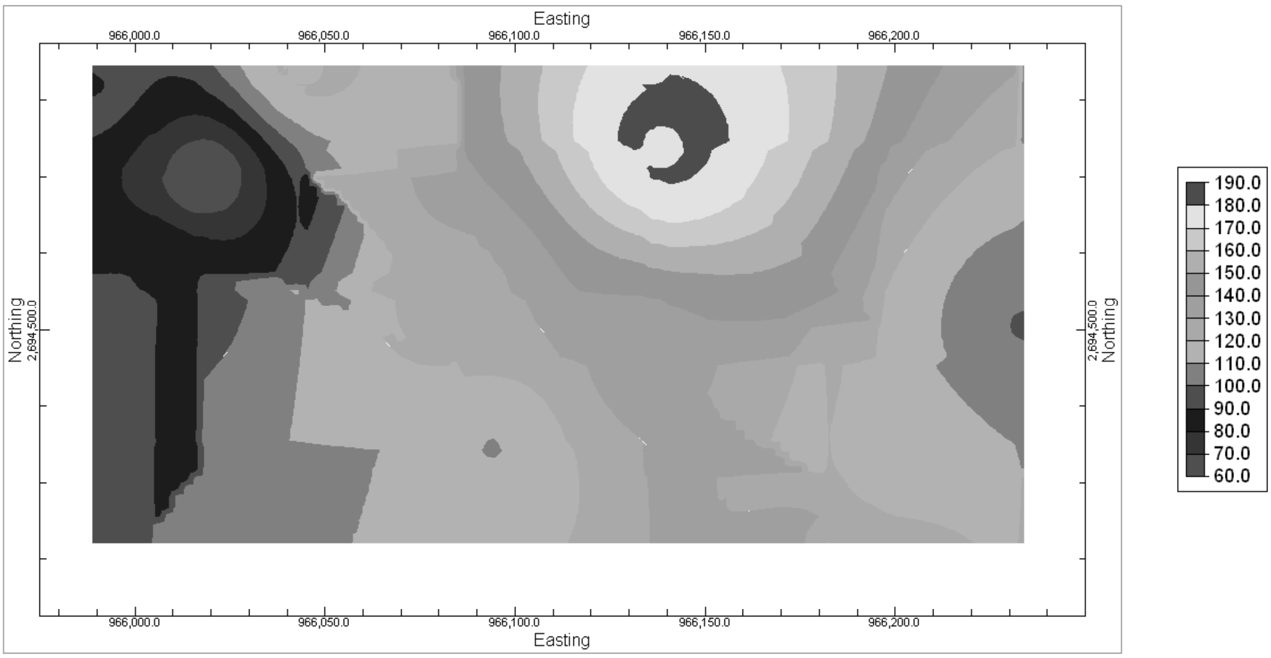


Fig. 12: Subsurface Resistivity Map at 20m Depth.

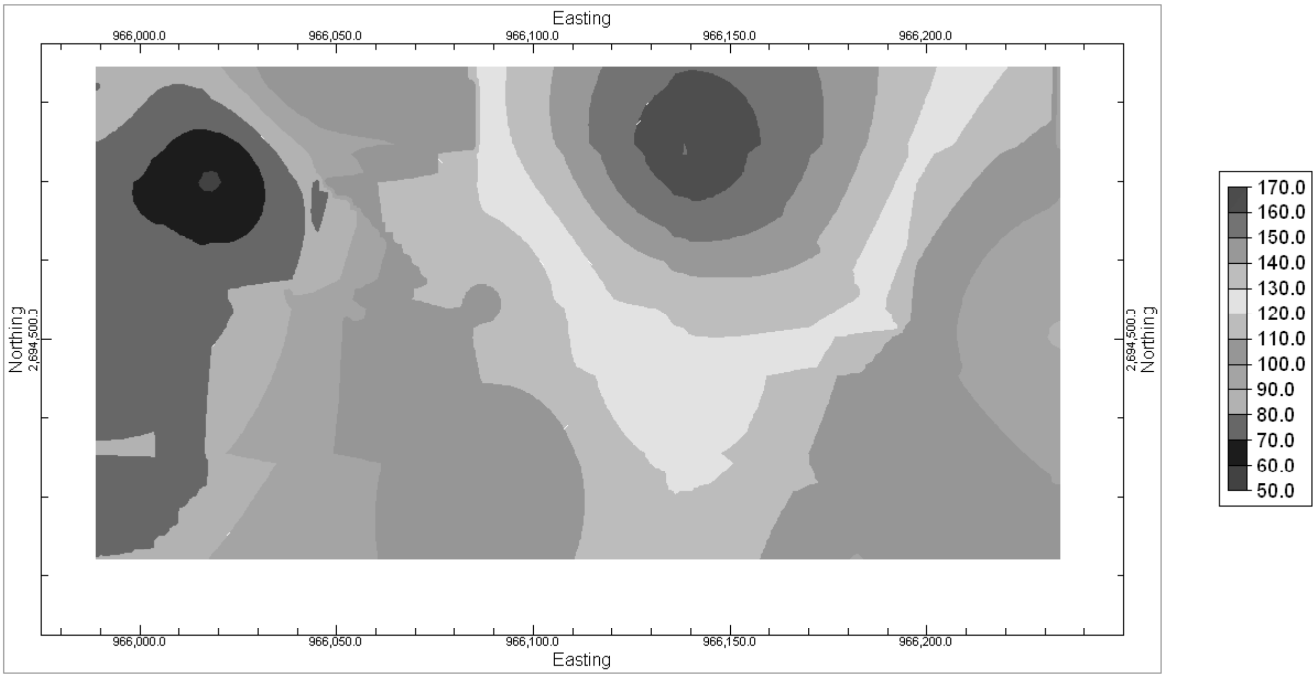


Fig. 13: Subsurface Resistivity Map at 25m Depth.

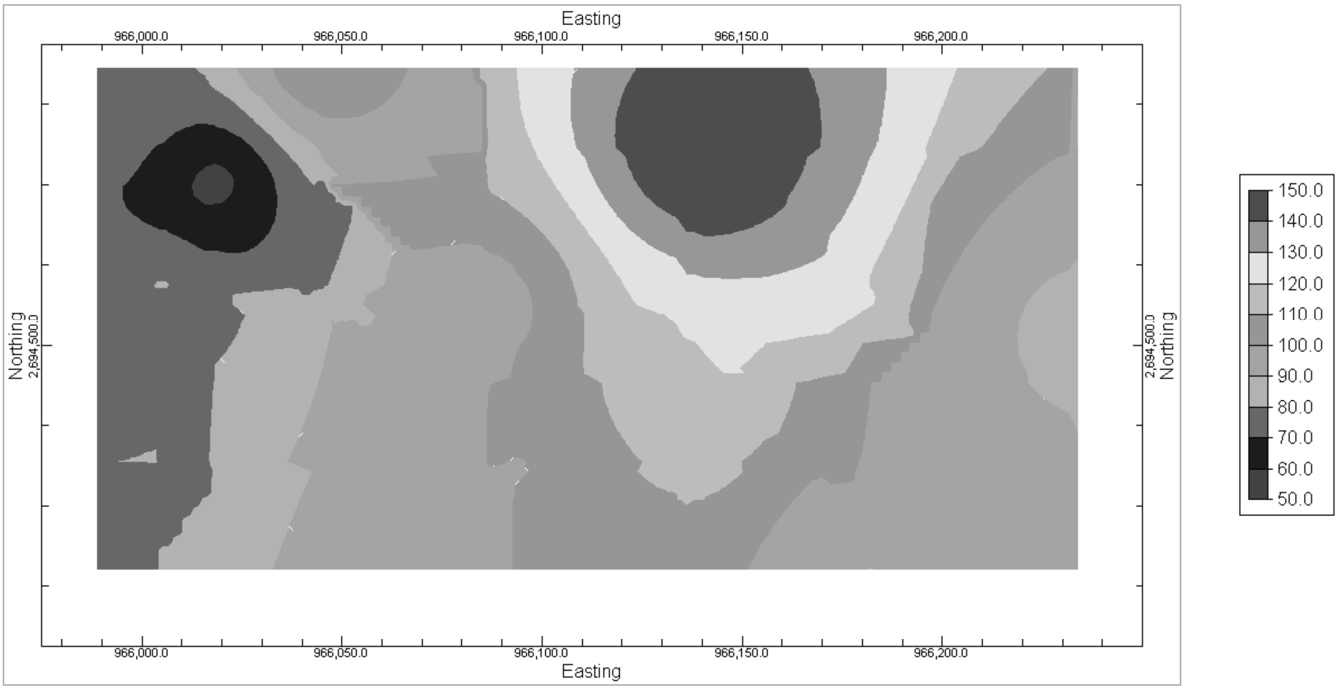


Fig.14: Subsurface Resistivity Map at 30m Depth.

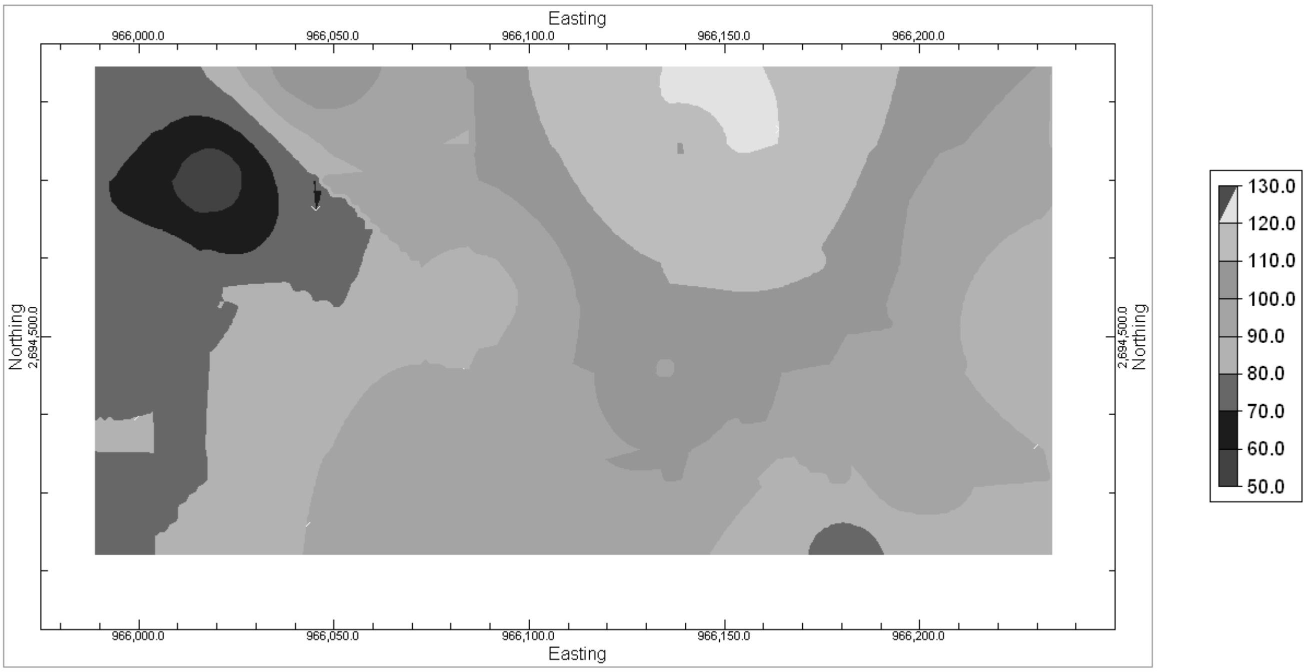


Fig. 15: Subsurface Resistivity Map at 40m Depth.

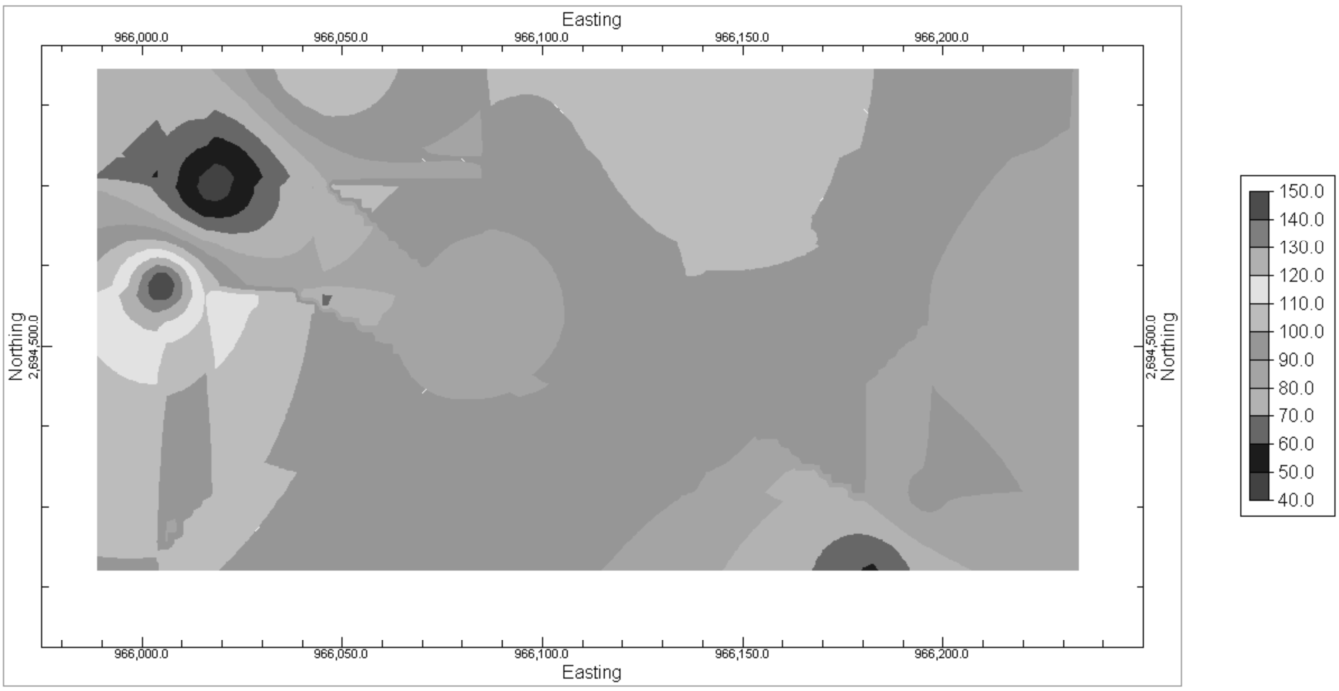


Fig. 16: Subsurface Resistivity Map at 50m Depth.

## DETERMINATION OF SHALLOW DEPTH SHEAR WAVE VELOCITY

Objective of the Test:

To determine the soil characteristics and checking the soil profile identified by the SPT-N value.

Equipments:

- Hammer
- Steel Plate
- Tape
- Eleven Geophones
- Cables
- GPS
- Magnetic Compass
- Battery
- Seismograph
- Laptop
- Additional connector

Figure 01: Seismograph and Battery

Figure 02: Laptop

Figure 03: GPS

Figure 04: Magnetic Compass

Figure 05: Steel Plate and Hammer

Figure 06: Geophone, tape and cable

Figure 07: Hammering to produce soil vibration

Field Procedure:

1. The Test site selection is considered based on the geological dip and strike. For this Test equipments are assembled parallel to the strike line. Dip is not being considered in this Test. But both Dip and strike may be considered for calculation of earthquake shear wave velocity.
2. All the equipments (Laptop, Seismograph, Geophones, battery, etc.) are connected with cables (See Figure 07) and Geophones are connected in two meters interval consecutively. (See Figure 06)

Figure 08: Array of Geophones

Figure 09: Connection of Seismograph to Laptop

3. Before recording amplitude data the surrounding of the site should be considered. The test is very sensitive to vibration. The surface shear wave is recorded from the Test. The vibration produced by the vehicle movement, Industrial noise, normal water wave produced by the Wind, etc. can affect test result. Even vibration produced by walking affects the result. So, these factors should be considered before recording the data. The vibration for recording the data of soil can be performed with hammering or without hammering. If the rudimentary amplitude is not suitable for analysis, hammering with plate is done at the proximity of the geophones to record the data. After that the data of the vibration of soil is recorded surrounding at every geophone.(See Figure 08)
4. The wave produced by hammering is refracted and reflected to the soil surface. The seismograph records these data sensitively at the 2m interval one after another. This way the amplitude at the 2m interval is recorded on the computer software. These data will be analyzed to calculate the shear wave velocity.

Functions of the Devices:

- Global Positioning System (GPS): Global Positioning System is used to locate the position of test. Generally, latitude and longitude are recorded with the GPS device (See Figure 03).
- Magnetic Compass: Magnetic Compass is used to identify the geological North direction and to adjust the field condition with the map. (See Figure 04)
- Hammer: Hammer is used to create vibration below the geophone. (See Figure 05)
- Steel plate: Steel plate is used to make vibration with the hammer. (See Figure 05)
- Seismograph: Seismograph is a device to record the amplitude data collected from the geophones. Seismograph is connected with the cable to geophones.(See Figure 01)
- Battery: Battery is used the supply current. (See Figure 01)
- Laptop: laptop is used to record and saved data from the seismograph with help of the software.(See Figure 02)

**SHALLOW SEISMIC SURVEY FOR S WAVE VELOCITY (VS) MEASUREMENT**

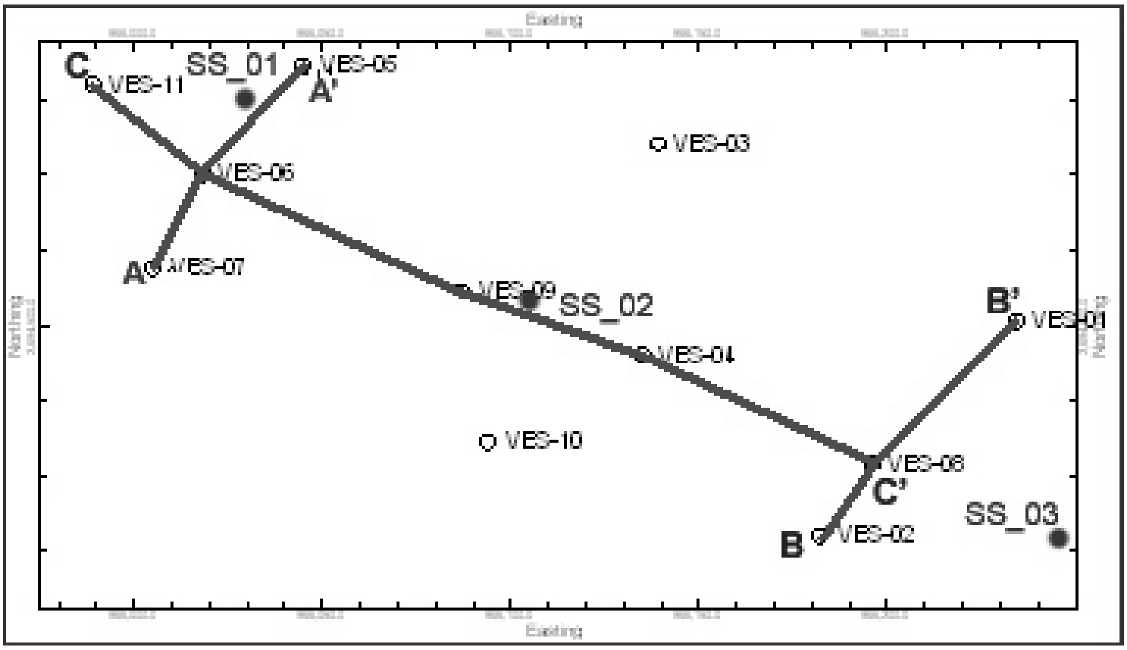


Fig. 1: Distribution of shallow seismic (SS) and vertical electrical sounding (VES) location and the direction of electrical profiles in the ar

Shallow seismic survey was carried out to evaluate shear wave velocity Vs to a depth of around 30m. Hammer source was used to generate the energy and 12 channel seismograph was used to record the data. Geophone spacing was 3m. Data were recorded when the ambient noise was minimum. The collected data are processed using Pickwin software. Shallow seismic survey was executed at three locations (Fig. 1).

Shear wave velocity study at three locations SS 1, 2 and 3 reveals three velocity layers (Fig. 2, 3 and 4).

Velocity distribution at site SS 1(Fig. 2) is 80m/s, 305m/s and 220m/s for 1$^{st}$ 2$^{nd}$ and 3$^{rd}$ layers having depth levels at 5m, 15m and 32m respectively.

Velocity distribution at site SS 2 (Fig. 3) is 80m/s, 320m/s and 180m/s for 1$^{st}$ 2$^{nd}$ and 3$^{rd}$ layers having depth levels at 5m, 15m and 32m respectively.

Velocity distribution at site SS 3 (Fig. 4) is 75m/s, 400m/s and 140m/s for 1$^{st}$ 2$^{nd}$ and 3$^{rd}$ layers having depth levels at 5m, 15m and 32m respectively.

Shear wave velocity study can be used for the site categorization. Site categories used in national earthquake hazard reduction program (NEHRP) are provided in Table 1.

Table-1: Site categories in NEHRP provisions (Martin, 1994)

| NEHRP Category | Description | Vs 30 (m/s) |
|---|---|---|
| A | Hard Rock | > 1500 |
| B | Firm to hard rock | 760 to 1500 |
| C | Dense soil, soft rock | 360 to 760 |
| D | Stiff soil | 180 to 360 |
| E | Soft clays | <180 |

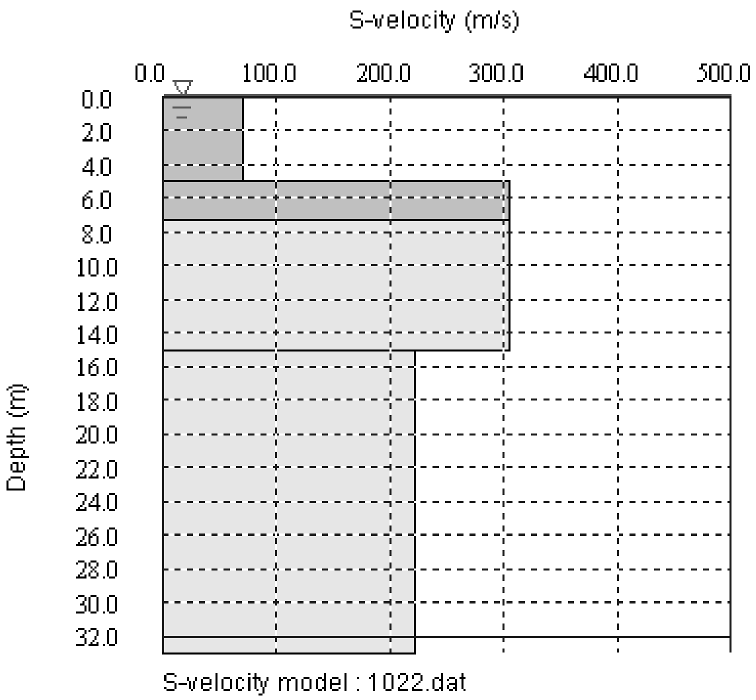


Fig. 2: Shear wave velocity Vs at Station 1

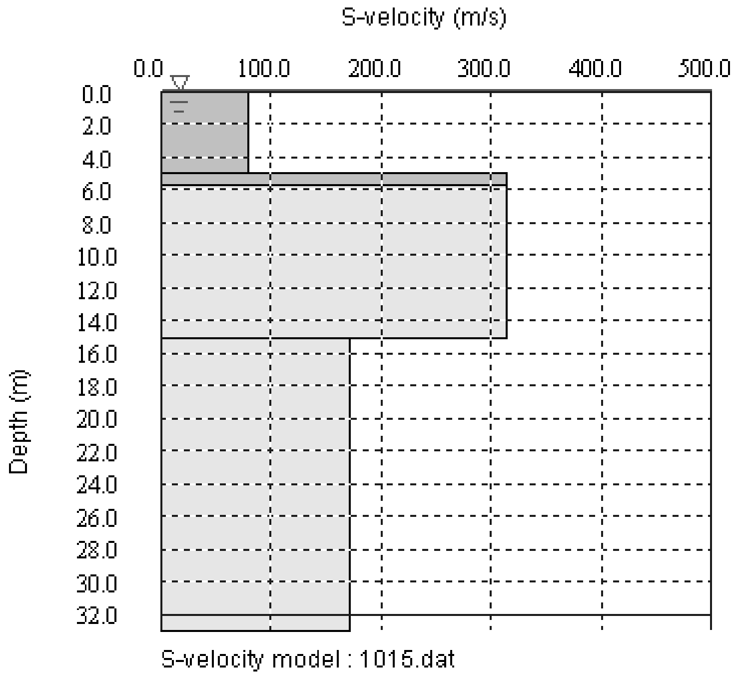


Fig. 3: Shear wave velocity Vs at Station 2

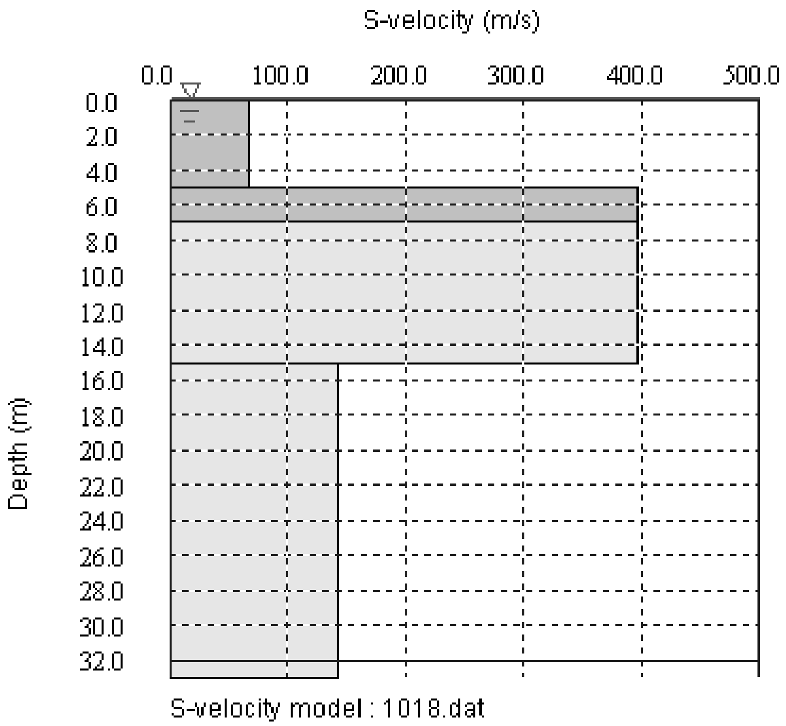


Fig. 4: Shear wave velocity Vs at Station 3

# PART-V

# ANALYSIS OF CLIMATE CHANGE PHENOMENA IN BANGLADESH

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**ABSTRACT**
Climate Change has been identified to be the most unanimous topic in the 20$^{th}$ century. Due to climate change, distribution, frequency and intensity of weather related hazards have augmented. In 2008, there were 654 natural disasters worldwide, causing around 93,700 deaths and cost of damage \$123 billion. Bangladesh has been vindicated to be one of the most vulnerable countries according to the Global Climate Risk Index. An average of 8,241 people died each year in 244 instances of extreme weather conditions in Bangladesh with cost of damage \$2,189 million a year and loss of GDP 1.81 percent. Bangladesh is the practical example of severely affected by tropical cyclone, flood, drought landslides, and salinity intrusion as well as other disasters due to climate change. High population density, high level of poverty, its landscape, geographical position and climate variability has been combined to transform highly vulnerable to natural disaster. According to fourth assessment report (AR4) of Inter governmental Panel on Climate Change, predicted sea level rise from 1990 to 2100 is 18-59 cm. Due to sea level rise saline water intrusion will be up to 150 km in inland area and 7-16% of the land will submerge. Proper construction of embankments and polders is important for the survival of our existence against imminent natural disasters. The substantial causes of the embankment failure have not been investigated yet. Forensic research is imperative for investigating such polders. If this research work is implemented, some facilities like impairment of the saline water intrusion, logistics support for proper disaster management, increasing cognizance among the people, reduction of casualties, etc. likely to be resolved. Otherwise it is not possible to cope with the disaster management under the framework of the climate change risk reduction and mitigation.

## 1.1 INTRODUCTION

Bangladesh has been recognized as the most vulnerable countries in the world according to Global Climate Risk Index (CRI index, 2010). Bangladesh is the practical example of severely affected by tropical cyclone, flood, Drought landslides, and salinity intrusion as well as other disasters due to climate change. Due to climate change, distribution, frequency and intensity of weather related hazards have augmented. The country is regularly affected by tropical cyclone because of El Niňo or La Niňa corollary. According to fourth assessment report (AR4) of IPCC, the increase of sea level has been predicted to be 41 cm from 1990 to 2100. Scientific study has found that global mean daily temperature has increased with a rate of 0.74±0.18°c per 100 years. The sea level is rising at the rate of 3mm per year due to the gradual increase of this temperature. The coastal areas of Bangladesh have been endangered due to the rising of the storm surges. 150 km inland areas may be affected because of saline water intrusion. Moreover, 7-16% of the land may be submerged with huge volume of water.

From the past record of cyclone, it has been clear to us that Bangladesh has been confronted with difficult situation. The people of Bangladesh never forget the cyclone of 1970 and1991. In 1970, more than 500,000 people died due to the effect of cyclone. After two decades another cyclone occurred in 1991, at least 138,000 people were killed and 10 million made homeless following a cyclone in the Chittagong district. The frequency of cyclones can be analyzed by the recently occurring cyclone Aila and Sidr. About 3,368 people died due to the cyclone Sidr in 2007. More than 190 causalities along with huge loss of embankment occurred due to the cyclone Aila.

There are several thousand kilometers of coastal polders in Bangladesh, which were constructed in 1960. Most of the South-Western Coastal polders, which were not designed properly, have been ravaged by the storm surges. The affliction of people has been profligated due to the failure of coastal polders. About 32.4 km entirely and 178.4 km partially embankments have been damaged by the cyclone Aila (After BWDB, 2009). 153.86 km embankments have been mutilated in the Satkhira Districts (After LGED, 2009). As a result, proper construction of embankment is essential for our existence against imminent natural disaster. Otherwise it is not possible to cope with the proper disaster management under the framework of the climate change risk reduction and mitigation.

## 1.2 CLIMATE CHANGE SCENARIOS IN WORLDWIDE

Climate change and related global concerns are the most important agenda in the 21st centuries because of climate variability in all over the world. The atmospheric scientists and environmentalist have confirmed the worldwide climate change by increasing the frequencies of natural disaster. The global Climate Risk Index (2010) analyses to what extent countries have been affected by the impacts of weather-related loss events (storms, floods, heatwaves etc.) (see Table 1). It is based on past data and is thus not a linear projection of future climate impacts, also because a single extreme event can not be traced back solely to anthropogenic climate change The Climate Risk index thus indicates a level of exposure and vulnerability to extremes events which countries see as a warning signal to prepare for more severe events in the future. The Intergovernmental Panel on Climate Change (IPCC) predicts that global temperatures will rise between 1.8°C and 4.0°C by the last decade of the 21st century. The impacts of global warming on the climate, however, will vary in different regions of the world.

The IPCC also forecasts that global warming will result in sea level rises of between 0.18 and 0.79 meters, which could increase coastal flooding and saline intrusion into aquifer and rivers across a wide belt in the south of Bangladesh, although most of the area is protected by polders.

In 2008, there were 654 natural disasters worldwide, causing around 93,700 deaths and cost of damage $123 billion. German watch's index estimates that throughout the world, 600,000 people have died in 11,000 cases of natural disasters over the past 10 years. The estimated global financial cost of natural disasters is US $1.7 trillion.

According to the Germanwatch Global Climate Risk Index, Bangladesh, Myanmar and Honduras were the countries most affected by the extreme weather events from 1990 to 2008 (See Figure1). They are followed by Viet Nam and Nicaragua, Haiti and India. Table 1 and Figure 1 show the ten most affected countries (down 10), with their average ranking (CRI score) and the specific results in the four indicators analyzed.

Table 1: The most affected 10 countries due to climate change from 1990 to 2008 (After Global Climate Risk Index, CRI, 2010)

| CRI 1990-2008 | Country | CRI score | Death toll (Annual ø) | Deaths per 100,000 inhabitants (Annual ø) | Total losses in million US$ ppp (Annual ø) | Losses per GDP in% (Annual ø) |
|---|---|---|---|---|---|---|
| 1 | Bangladesh | 8.00 | 8,241 | 6.27 | 2,189 | 1.81 |
| 2 | Myanmar | 8.25 | 4,522 | 9.60 | 707 | 2.55 |
| 3 | Honduras | 12.00 | 340 | 5.56 | 660 | 3.37 |
| 4 | Viet Nam | 18.83 | 466 | 0.64 | 1,525 | 1.31 |
| 5 | Nicaragua | 21.00 | 164 | 3.37 | 211 | 2.03 |
| 6 | Haiti | 22.83 | 335 | 4.58 | 95 | 1.08 |
| 7 | India | 25.83 | 3,255 | 0.33 | 6,132 | 0.38 |
| 8 | Dominican Republic | 27.58 | 222 | 2.93 | 191 | 0.45 |
| 9 | Philippines | 27.67 | 799 | 1.11 | 544 | 0.30 |
| 10 | China | 28.58 | 2,023 | 0.17 | 25,961 | 0.78 |

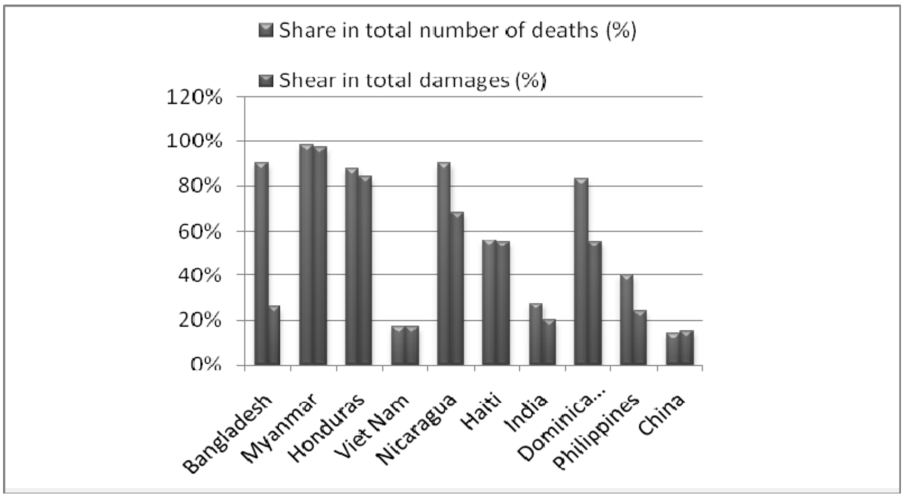



Figure 1: Share of the most extreme year in the overall deaths and losses from 1990-2008 in the ten most affected countries (After Global Climate Risk Index, CRI, 2010)

All of ten most affected countries (1990-2008) were developing countries in the low-income or lower-middle income country group. These results underscore the particular vulnerability of poor countries to climate risks, despite the fact that the absolute monetary damages are much higher in richer countries.

Table 2: The occurrence of various events in the most extreme years between 1990 and 2008 (After Global Climate Risk Index, CRI, 2010)

| Serial No. | Countries most affected from extreme weather events | Extreme year in total number of deaths | Extreme year in total losses | Total number of events |
|---|---|---|---|---|
| 1 | Bangladesh | 1991 | 1998 | 244 |
| 2 | Myanmar | 2008 | 2008 | 22 |
| 3 | Honduras | 1998 | 1998 | 49 |
| 4 | Viet Nam | 2006 | 2006 | 192 |
| 5 | Nicaragua | 1998 | 1998 | 34 |
| 6 | Haiti | 2004 | 2004 | 40 |
| 7 | India | 1998 | 1993 | 325 |
| 8 | Dominican Republic | 1998 | 1998 | 39 |
| 9 | Philippines | 1991 | 2006 | 243 |
| 10 | China | 1993 | 2008 | 558 |

According to the Climate Risk Index, in 2008 Myanmar, the Republic of Yemen, VietNam and the Philippines have been most affected by extreme weather events (See Table 2).While Vietnam and the Philippines are relatively regularly affected through storms and flooding, as can be seen in the Climate Risk Index editions 2006, 2007 and 2008, the high figures for Myanmar and Yemen are exceptional. The huge number of fatalities in Myanmar were caused by cyclone Nargis and revealed the low adaptive capacity of the country which, however, is also a result of the political failure to embark upon serious disaster preparedness.

**1.3 CLIMATE CHANGE SCENARIOS IN BANGLADESH**

Bangladesh is likely to be among the countries that are the worst affected by climate change. Tropical cyclones, storm surges, flood, drought and river erosion are likely to become more frequent and severe in the coming years. According to the Climate Risk Index, Bangladesh has been identified as the top most affected country due to extreme climate change events (Table 1). In the CRI score Bangladesh got 8, Myanmar 8.25, Honduras 12, Vietnam 18.53, Nicaragua 21, Haiti 22.83, India 25.83, Dominican Republic 27.58, the Philippines 27.67 and China 28.58. UNDP has identified Bangladesh to be the most vulnerable country in the world to tropical cyclones and the sixth most vulnerable country to floods (UNDP, 2004). Bangladesh is susceptible to floods, tropical cyclones, storm surges, and droughts. The regions of the country affected by these different hazards are shown in Figure 2.

Most of Bangladesh lies in the delta of three of the largest rivers in the world – the Brahmaputra, the Ganges and the Meghna. These rivers have a combined peak discharge in the flood season of 180,000 $m^3$ /sec. (the second highest in the world, after the Amazon) and carry about two billion tones of sediment each year. The topography of the country is mostly low and flat. Two-thirds of the country is less than 5 meters above sea level and is susceptible to river and rainwater flooding and, in lower lying coastal areas, to tidal flooding during storms (MoFDM, 2009).

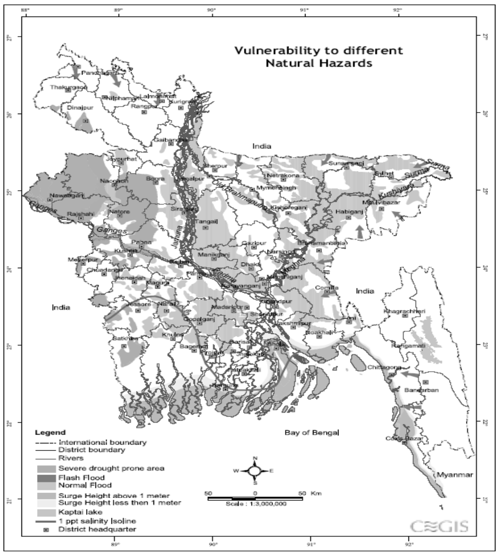



Figure 2: Vulnerability to different natural hazards in Bangladesh (Source: CEGIS, Dhaka)

In the last 25 years, Bangladesh has experienced six severe floods. In 2007, two successive and damaging floods inundated the country in the same season. During high floods, river bank erosion is common. It can result in the loss of thousands of hectares of agricultural land and scores of villages, and displace many thousands of people from their homes. Flash floods can also be a problem in the more hilly north-eastern and south-eastern regions of the country.

Bangladesh has been justified as the most affected countries due to various extreme climate change events of cyclone, storm surge flood, drought, river erosion, landslides, etc. But in this paper the climate change phenomena due to tropical cyclone has been stressed. A severe tropical cyclone hits Bangladesh, on average, every 3 years. These storms generally form in the months just before and after the monsoon and intensify as they move north over the warm waters of the Bay of Bengal. The wind speed of the most catastrophic cyclone in Bangladesh ranges 150 kph to 225 kph and can result in storm surges up to eight metres high, resulting in extensive damage to houses and high loss of life to humans and livestock in coastal communities.

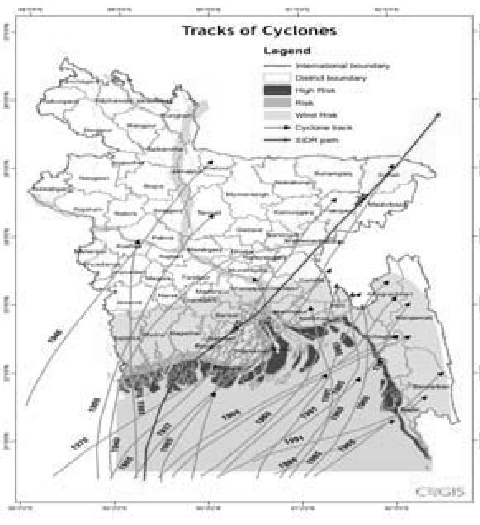



Figure 3: Tropical cyclone at different time and Path in Bangladesh (Source: CEGIS, Dhaka).

The storm surges are higher in Bangladesh than in neighboring countries because the Bay of Bengal narrows towards the north, where Bangladesh is located. The tropical cyclones in 1970 and 1991 are estimated to have killed 500,000 and 140,000 people, respectively. In recent years, general cyclonic activity in the Bay of Bengal has become more frequent (See Figure 43, causing rougher seas that can make it difficult for fishermen and small craft to put to sea. The climate change scenarios are identified by tropical cyclone like the recently occurring the super cyclone 'Sidr' in 2007 and the cyclone' Aila' in 2009.

## 1.4 HISTORY OF TROPICAL CYCLONES IN BANGLADESH

Tropical cyclone is the most devastating part of climate change phenomena in Bangladesh. Bangladesh, due to its unique geographic location, suffers from devastating tropical cyclone frequently. The funnel-shaped northern portion of the Bay of Bengal causes tidal bores when cyclones make landfall, and thousands of people living in the coastal areas are affected. Some of the most devastating natural disasters in recorded history with high casualties were tropical cyclones that hit the region now forming Bangladesh.

Table 3: Cyclone events in Bangladesh (After Wikipedia, 2010)

| Cyclone Year | Wind Speed, km/hr | Storm surge height, m | Casualties |
|---|---|---|---|
| 1960 | 210 | 4.5-6.1 | 13,000 |
| 1961 | 161 | 2.44-3.05 | 11,468 |
| 1962 | 161 | 2.5-3.0 | 1,000 |
| 1963 | 203 | 4.3-5.2 | 11,520 |
| 1965 | 201 | 4.7-6.1 | 20,152 |
| 1966 | 146 | 4.7-9.1 | 850 |
| 1970 | 222 | 10.6 | 5,00,000 |
| 1974 | 161 | 2.8-5.2 | 800 |
| 1983 | 136 | 1.52 | 343 |
| 1985 | 154 | 3-4.6 | 11,069 |
| 1988 | 162 | 4.5 | 5,708 |
| 1991 | 225 | 5-8 | 1,50,000 |
| 1994 | 210 | - | 400 |
| 1995 | 210 | - | 650 |
| 1997 | 150 | 1.83-3.05 | 126 |
| 2007 | 240 | - | >2000 |
| 2009 | 90 | 3.0 | 190 |

Among them, the 1970 Bhola Cyclone alone claimed more than 500,000 lives. The chronological cyclonic events are shown in table 03. In this table record shows the cyclone year, maximum wind speed, extreme storm surge height and number of causalities. The scenarios of cyclone Sidr and Aila has been added to analyze the recent trend of cyclone in Bangladesh.

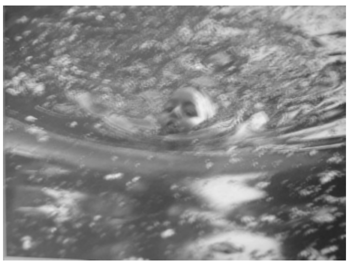
### 1.4.1 CYCLONE SIDR IN 2007

The Super cyclone 'Sidr' hit at 9 p.m. on 14 November 2007 about 670 km south of Mongla port. In Barisal coast the catastrophic of the cyclone Sidr was observed on 15 November at 21:00 hour's local time during ebb tide. Wind speeds reached up to 240 km per hour (JTWC) affecting 15 districts with 15 others partly affected. The tract of the Super cyclone is shown in Figure 3. More than 8.9 million people in 1,950 unions of 200 Upazilas under 30 districts were affected by Cyclone SIDR. Official reports indicated a total of 3,406 Bangladesh nationals perished during this event with 1,001 missing and 55,282 sustained physical and psychological injuries as a result of the disaster. Total damage is estimated to be 1.7 billionUS Dollars.

Total 3,319 people died in 12 affected districts, which is 97% of the total death reported as of 21 January 2008. Highest death toll was reported in Barguna district (1,335) followed by Bagerhat (810), Patuakhali (457) and Pirojpur (400). The MoFDM Official report indicates that 1.75 million families were affected in 12 districts, which is also 84% of the total affected families in 30 districts. Over 564,967 houses are fully damaged and 957,110 houses are partially damaged. Bagerhat suffered the most in terms of fully damaged housing (118,899 houses, 22%), followed by Barguna (95,412), Jhalakathi (69685), Pirojpur (63,896) and Patuakhali (53,291).

*(a) Erosion of soil* *(b) Uprooted trees* *(c) Fracturing of soil*

*(d) Road damage* *(e) Death of animals* *(f) Flooding*

Figure 4: Some pictures collected from Sidr affected areas in Bangladesh.

A comprehensive analysis undertaken by a team of Bangladesh Government and international experts, using state of the art assessment methodologies, estimated the total damage and losses caused by the cyclone to be BDT 115.6 billion (equivalent to US$ 1.7 billion). The effects of Cyclone SIDR are equivalent to 2.8% of Bangladesh's GDP. The damage and losses were notably concentrated in the private sector, rather than in the public sector. This has significant implications in the strategy that must be adopted for recovery and reconstruction.

Damage and losses were concentrated on the housing sector ($0.83 billion), productive sectors ($0.48 billion), and on public sector infrastructure ($ 0.25 billion). Most affected sectors were, in decreasing order, housing, agriculture, transport, water control structures, education and industry. Some photographs of the cyclone Sidr affected areas in Bangladesh are shown in Figure 4.

### 1.4.2 CYCLONE AILA IN 2009

On 25th may in 2009, the cyclone Aila passed through 14 districts in the coastal area of Bangladesh (See Figure 5). The Aila affected 14 districts were Satkhira, Khulna, Bagerhat, Barisal, Bhola, Pirojpur, Patuakhali, Borguna, Jhalokathi, Chittagong, Cox's Bazar, Laxipur, Feni, and Noakhali.

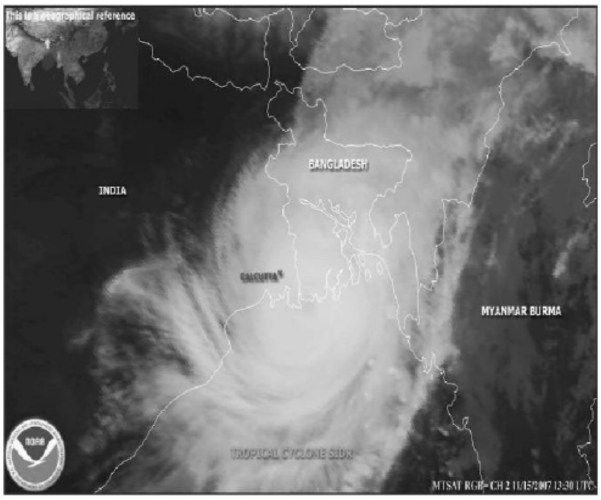



Figure 5: Tropical cyclone Aila (Map courtesy: NOAA)

Loss of life, damages to houses, livestock, crops, educational institutions, roads and embankments have been reported from 529 unions of 64 upazillas of 14districts. Official sources admitted about 190 deaths and more than 50000 homeless people. Total or partial destruction of about 6, 12,594 thatched houses, 3, 19,930 hector harvestable paddies, large number shrimp Gher, 1, 47,628 livestock and poultry. At least 7108 people were injured by the storm and about 48, 26,630 people were affected.

Mud houses and shrimp production have been damaged by storm surge. In Nizum dwip, 20,000 people are homeless, 58,950 animals are killed and 50,000 deer have been missed. Storm surge of 3m (10ft) impacted western region of Bangladesh, submerging numerous villages. More than 400000 people were reportedly isolated by severe flooding in coastal regions of Bangladesh. Numerous villages were either completely submerged in flood water. In Patuakhali, a dam broke and submerged five villages. Numerous homes were destroyed by the subsequent flooding and tens of thousands of people were left stranded in the village.

Coastal polders, which are constructed at the time of 1960, have been damaged by the storm surge of cyclone Aila. Cyclone Aila damaged 154.72 km embankments in Shyamnagar and

Assasuni upazillas in Satkhira District of which maintenance and repairing cost is \$2.68 million. Moreover, estimated cost for repairing and maintenance of Culvert, Bazar, Union Parishad Bhaban, Cyclone Shelter, Growth center and Residential Bhaban is \$0.5million.

In Satkhira districts cyclone Aila damaged 10 km embankments completely while 120 km partially where cost for maintenance and reconstruction of these embankments is \$3.8 million. In Khulna district, 211.24km damaged embankment of which 32.4 km fully and 178.84 km partial damaged \$7.75milliom is required for maintenance and reconstruction (See Table 6). Moreover, for repairing and reconstruction of Sluice gate/regulator, protective work, closure and other hydraulic structures require \$6.96 million (After BWDB, 2009).

## 1.5 THE COASTAL POLDERS IN BANGLADESH

From the cyclone data of Bangladesh it is common scenarios that over 700 km coastal areas of Bangladesh have been affected by cyclones and storm surges. Bangladesh water Development Board (BWDB) and its predecessor, East Pakistan Water and Power Development Authority (EPWAPDA) constructed a series of polders (See Figure 6) approximately 145 numbers with more than 5,000 km in length in the coastal area from the mid-sixties to the mid seventies to protect the coastal low lying areas from saline inundation in order to increase agricultural production.

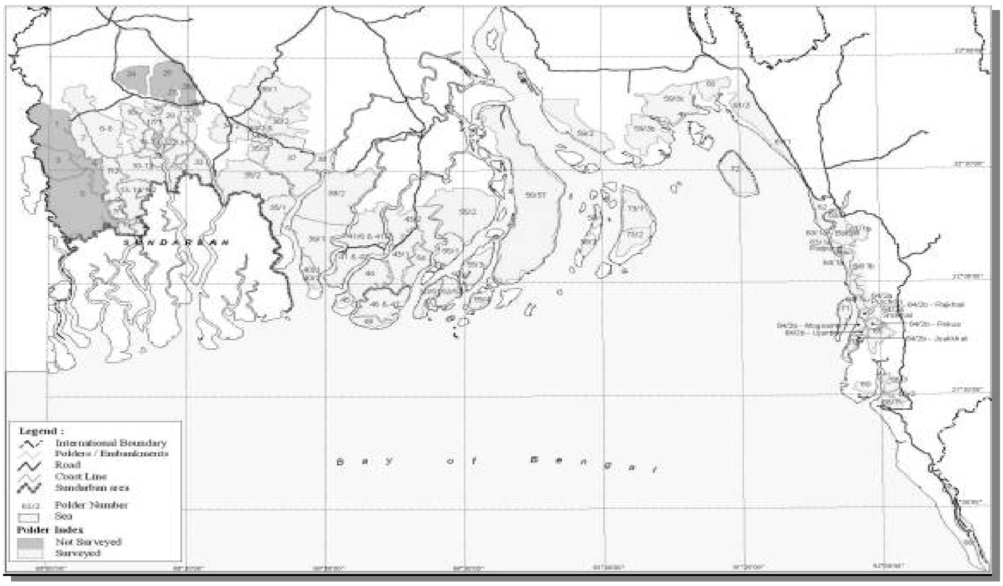



Figure 6: Coastal polders of Bangladesh (After BWDB)

Over time, those embankments proved to be very effective in protection of life and property in the coastal region, rehabilitation or construction of embankments has turned into a crucial part of coastal development. Historical record shows that more than 14 severe cyclones are generated in the Bay of Bengal in every ten years, several of which strike the coast of Bangladesh. Extremely strong storm surges with more than 10m of water elevation hit the coast of Bangladesh in the Year 1970. Within the last four Decades around 80,000 lives of the country have been the victims of the cyclones by overtopping or breaching of coastal embankments. Due to increase the sea level rise the embankments has been damaged due to the storm surges. The embankments which were affected by the cyclone sidr, have been damaged by the Cyclone Aila. Bangladesh Water Development Board (BWDB) along with other organizations is working together to repair, reconstruct such polders (See Figure 7) considering the sea level rise and storm surges.

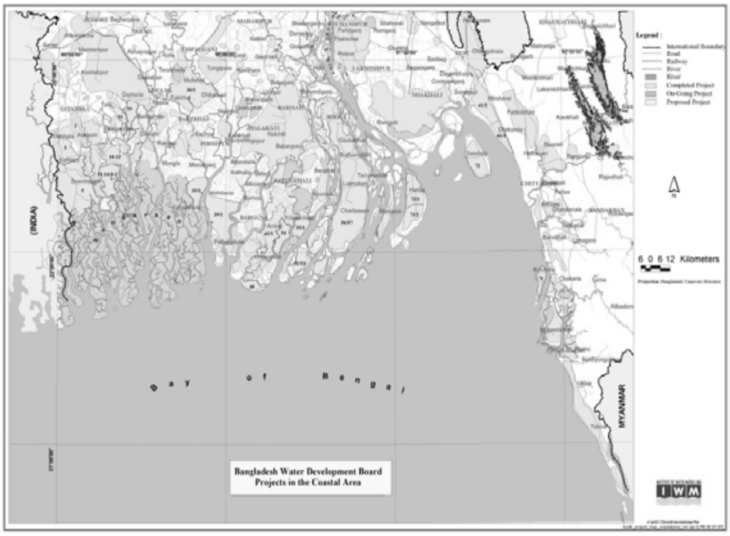



Figure 7: Ongoing project of coastal polders in Bangladesh under BWDB (After IWFM, 2009)

### 1.6 HISTORY OF EMBANKMENT FAILURE

Although dams have very good safety record, failures do occasionally occur. Such events always generate a "Post-mortem" study to determine the cause of failure and to help us avoid similar events in the future. Studies of dam failures also have provided insight into other geotechnical problems.

A study by Biswas and Chatterje (1971) examined more than 300 dam failures throughout the world and found the following causes:

- 35 percent were a direct result of floods that exceeds the spillway capacity, and thus were due to inaccurate hydrology.
- 25 percent were due to geotechnical problems, such as seepage, piping, high pore water pressures, inadequate seepage cutoff, fault movement, excessive settlement, or landslides.
- The remaining 40 percent were from a variety of problems, including the use of poor construction materials or practices, wave action, acts of war, and poor maintenance.

The most common causes of failure in levees include:

- Overtopping by floodwaters, which leads to rapid erosion
- Uncontrolled seepage through or breadth the levee, leading to a piping failure
- Landslides in the levee slopes

There are a lot of examples of embankment failure in the world. Some histories of crucial embankment failure are illustrated in Table 4.

All these problems can be avoided through the proper analysis, design, and construction. This is why modern engineered levees rarely fail. Unfortunately, many miles of unengineered levees still exist, and the cost of retrofitting or replacing them is enormous. Thus, the primary task for the geotechnical engineers is to identify the most hazardous ones and reinforce them first.

Table 4: Some Historical embankment failure in the world

| Name of dam | Country | Time when failure occurred | Causalities | Causes of failure |
|---|---|---|---|---|
| South Fork Dam | Johnstown, Pennsylvania, USA | 1889 | 2,209 | Overtopping |
| St. Francis Dam | California, USA | 1928 | 500 | Landslide |
| Malpasset Dam | France | 1959 | 421 | Geological failure |
| Vaiont Dam | Italy | 1963 | 2,600 | Landslide |
| Lower San Fernando Dam | California, USA | 1971 | - | Liquefaction |
| Buffalo Creek Dam | West Virginia, USA | 1972 | 125 | Overtopping |
| Teton Dam | Idaho, USA | 1976 | - | Piping |
| Levee of USA | New Orleans and Southeast Louisiana | 2005 | 1,118 | Overtopping |

## 1.7 EMBANKMENT FAILURE IN BANGLADESH

Most of the people living in the southern part of Bangladesh have seen the devastating and destructive scenarios of cyclone SIDR. But in Cyclone Aila, damage has been increased due to the breaching of the coastal polders.

Figure 8: Damage of embankment due to the cyclone Aila in Satkhira district by the side of the Kapatakha river

The authority has to face difficult situation to tackle the effect of Aila. The polders of coastal belt in Bangladesh have been damaged due to the attack of storm surge. As a result, many villages have been inundated. Agricultural lands have been severely affected by the intrusion of saline water. Most of the coastal areas were under water. As a result, people could not communicate each other due to flooding. Due to breaching of embankments the relief works have been hampered. Some photographs of Embankment damage from the coastal areas in Bangladesh after the cyclone Aila are shown in Figure 9.

## 1.8 ACTION PLAN FOR UPCOMING CLIMATE CHANGE

In 2005, the GoB has developed the National Adaptation programme of Action (NAPA) after extensive consultations with communities across the country, professional groups; and other members of civil society. The process has been taken forward, including through the adaptation of the Bangladesh Climate change Strategy and action plan (BCCSAP) in 2008, which is the main basis of Bangladesh's efforts to combat climate change over the next ten years. The following action plans have been taken to combat the upcoming climate change:

- Repair and maintenance of existing flood embankments
- Repair and maintenance of existing cyclone shelters
- Repair and maintenance of existing coastal polders
- Adaptation against floods
- Adaptation against future cyclones and storm-surges
- Planning, design and construction of river training works

To mitigate the problem after disaster following suggestion are provided (BCCSAP, 2008).

- Survey of the condition of coastal polders and preparation of GIS maps with present coverage of areas protected by these polders.
- Repair, reconstruction and maintenance of existing coastal polder based on future projected sea level rises and storm surges.
- Reconstruction and repair of polders/embankments to design height and section

Specific recommendations due to cyclone Aila:

- Quantify and periodically update the assessment of risk.
- Implement more effective mechanisms for coordination and operation.
- Upgrade engineering design procedures of embankment construction and practice to place greater emphasis on safety.
- Engage independent experts in high level reviews of all critical life safety structures, including cyclone and flood protection system.
- Correct the system's deficiencies by establishing mechanisms to incorporate changing information, making the embankment survivable if overtopped, strengthening the affected embankment.

## 1.9 CONCLUSIONS

Although Bangladesh is not responsible for the top most country of GHG emission, some effective steps have been taken under the Kyoto Protocol. To fight against climate change as well as tropical cyclone, sustainable infrastructures should be constructed. The coastal polders, which are fully and partially damaged, may be repaired and reconstructed by appropriate design. Geotechnical investigation of the damaged embankment is required for the diagnosis of embankment failure as well as proper design. As a result, soil samples of embankment and foundation may be collected. Without the laboratory test of the soil sample it should not be possible to control seepage. Design of embankment section may be executed considering the storm surge height. Proper monitoring is also crucial for stable embankment construction. The embankment layers may be compacted on the basis of laboratory soil test data.

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# PART-VI

# WORKSHOPS, SEMINARS AND MEETINGS

**Prepared By**

Md. Saidur Rahman
Sharmin Ara
Mehedi Ahmed Ansary

**BANGLADESH NETWORK OFFICE FOR URBAN SAFETY (BNUS), BUET, DHAKA**

**SAARC Training Course on**

**EARTHQUAKE RISK MITIGATION**

March 30-April 4, 2009

At Centre for Continued Education, IIT Roorkee, Roorkee

Organised by

SAARC Disaster Management Centre, New Delhi, and Centre of Excellence in Disaster Mitigation Management, IIT Roorkee

BNUS members Ms. Afifa Imtiaz, Ms. Israt Jahan and Mr. Yusuf Reza participated.


Group Photo of SAARC training program at IIT, Roorke

Paper Presentation of Afifa Imteaz


Inaugural session of the program


Participants of the Training

Taking certificate and crest

## SAARC Training Program on

## CLIMATE CHANGE ADAPTATION AND DISASTER RISK REDUCTION IN SOUTH ASIA

July 9-July 15, 2009

Inaugural session: Senate Hall auditorium, University of Dhaka

Training Sessions: Centre of Excellence, 2nd Floor Lecture Room

The Dean of the Faculty of Earth and Environmental sciences, university of Dhaka and the SAARC Disaster Management Centre, New Delhi arranged the seven days SAARC Training on Climate Change Adaptation and disaster Risk Reduction in South Asia from July 9 to July 15, 2009. The purpose of this workshop is to share the knowledge about the climate change phenomena south Asian countries. The sustainable solution of climate change Adaptation and Disaster Risk Reduction have been dicussed. We, three stuff of BNUS (Israt Jahan Sheuly, Md. Saidur Rahman, Salahuddin Rizvi), participated the seven days Training course from July 8 to July 15. This course is very significant for our capacity build up along with analysis the climate change Phenomena in the South Asian Countries. In this course Dr. Shahnaz Hussain co-ordinated and Dr. Amanat Ullah Khan was the moderator. The various Topics on Climate Change this course have been presented by the Climate Change expert in Bangladesh and other countries. The Causes of Climate change along with the adaptation and the Risk Reduction through sustainable solution have been discussed. There was open discussion session for pointing out the current problem and their possibility of solution. From open discussion it has been noticed that every country having some different problem of climate change. Bangladesh and Myanmar is severely affected by the Cyclone and flood. Pakistan, Nepal, India and Bhutan are vulnerable severely due to landslide. Maldives is vulnerable due to the Sea level Rise and inundation. Drought is common to every country in South Asia. Myanmar is also severely affected by the cyclone. Drough and Landslides are big problem in Srilanka. The following topics have been discussed on the course:

Climate change and growing vulnerability of Natural Disaster in South Asia

Global Climate Change scenario

Climate Change projection in South Asia by IPCC

Critical Climate change issues and associated disaster in South Asia

Global Disaster Trends

Climate change impact in Agriculture and Food Security

Climate change impact in water resources

Climate change impact in different communities

Linking climate change adaptation and disaster risk reduction

Tacking Global Climate Change: Challenges of Regional and International Cooperation and Networking

Adaptation of regional Climate models in generating climate change scenarios

Climate change adaptation in south Asia

Adaptation and Disaster Risk reduction in South Asia: Bridging gaps between communities and climate change issues

Funding for Climate Change Adaptation

Sustainable development in a changing Climate Change

Climate Change and coastal Ecosystem

Impact of Climate Change on Sea level rise in Bangladesh

A few aspects of climate change, impacts and adaptation in Bangladesh

Climate Change impacts in agriculture

Climate change impact in Human Health

Structural Strengthening of Houses and Infrastructure

Tools, Techniques, and Practices for integration of Disaster Risk Reduction into Climate Change Adaptation

Adapting to flood and Risks-case studies

Adaptation to Cyclone Risk-case studies

Mindset Change for adaptation to Climate Change in Bangladesh

Adaptation to GLOF-Case Studies

Rain Water Harvesting in climate change Adaptation-Maldives

Climate Change implication on Forest and Biodiversity

Adaptation To coastal Erosion

Good Climate Change Adaptation practices in Bangladesh

Climate change Knowledge enhancement in Disaster Risk Reduction

Geo-Hazard data and information available to response the climate change

Gender Dimension in Disaster management adjusting with Floods & Cyclones


Eight SAARC countries of the program

Participants of the program

Presentation of the program

SAARC participants with BNUS staff

Taking Certificate from the Honorable Minister, Dr. Muhammad Abdur Razzaque , Ministry of Food and Disaster Management.

Two young researchers with Dr. Amanat Ullah Khan

**WORKSHOP ON**

**Disaster Risk Reduction through Schools**

National Convention-2009

August 3-August 4, 2009

At National Museum and Public Library

Session-1: People Assembly: Voice from the Grass roots

Session-2: Interactive Session

Video presentation; “Cyclone Sidr and the Disaster Preparedness of Students”

“The Culture of Disaster Risk Reduction and Resilient through the Eyes of Children”-Moderator: M A Al-Mamun Mazumdar, Project Manager, Sap Bangladseh

Session-3:

National Consultation on “Integrating Disaster Risk Reduction and Climate Change Education in National Policy Vision”

Session-4:

Video Presentation-“Lamia’s Story”

Describing Grassroots Reality:

Presentation on the summary of the National consultation

**Parallel Programmes:**

Exhibition on the Publication and materials on Disaster Risk reduction- Public Library

Photography and Exhibition on paintings by the children

Two days long Film festival (Documentary Feature film Presentation on Disaster and Climate change)-Central Public Library

Session-5: Life Experience in Disaster Preperedness

Session-6: Natonal consultation on "Disaster Resilient and Climate Literate Future Generation"

Session-7:

Documentary –"Lamia's Story"

"Policy Convergence in the light of grassroots experience"

"The implication of Mass Media in Disaster Risk

Some pictures from the workshop

## Regional Workshop on Reducing Earthquake Risk through Comprehensive Preparedness and Mitigation planning

December 10 -12, 2009

BNUS Director Prof. Mehedi Ahmed Ansary and all BNUS members participated in this workshop and worked as Rapporteurs for different sessions.

ERRP Regional Program in collaboration with Disaster Management Bureau, Government of Bangladesh, SAARC-DMC, ADRC and WSSI has organized 3 day long (December 10 -12, 2009) "Regional Workshop on Reducing Earthquake Risk through Comprehensive Preparedness and Mitigation planning *(Lessons and recommendation in context of South Asia)"*

The program has been successfully inaugurated on the scheduled day. The welcome speech was given by Mr. Sohel Khan and was followed by Dr. D. D. Joshi from SAARC Disaster Management Center (SDMC). Mr. Khan gave a brief on ERRP (Earthquake Risk Reduction and Recovery Program) that's: ERRP (Earthquake Risk Reduction and Recovery Program) covers five countries: Bangladesh, Bhutan, India, Pakistan and Nepal with the main objectives of exchange of information, experience sharing and sharing of knowledge and was started in 2008 by UNDP with the support of Japan. Dr. Joshi introduced SDMC, its objectives and activities in disaster management.

Mr. Koresawa, Executive Director, ADRC also gave the opening address discussing on main objective of the center, its recent activities with findings and its future initiatives. He declared on the upcoming disaster risk reduction conference in Kobe Japan, from 17-19, January 2010.

The special guest chairs were honored by Mr. Stefan Priesner, Country Director, UNDP Bangladesh and H.E. Mr. Tamotsu Shinotsuka, Ambassador, Embassy of Japan in Bangladesh. Mr. Priesner addressed Bangladesh as a leader in DRR and other countries learn the Disaster Management Techniques from here.

Mr. Dipankar Talukder, state minister, CHT Affairs, GoB was the guest of honor and he recommended laws and by laws must be relevant and govt. agencies must be strengthened to enforce the implement of law.

Finally Dr. Md. Abdur Razzak, Minister, MoFDM, Govt. of Bangladesh honorable chief guest discussed on the disaster scenario in South-Asia and officially inaugurated the workshop.

Researcher of BNUS (Israt Janan Sheuly, Md. Saidur Rahman, Ripon Hore) were got the opportunity to participate in this two day long workshop. They also act as rapporteur of the workshop.

**TECHNICAL SESSION**

- The technical session was chaired by Mr. Shankar Prashad Koirala, Joint Secretary, Ministry of Home affairs, Govt. of Nepal.
- In this session Dr. D.D. Joshi of SDMC elucidates and rendered an excellent presentation on Earthquake Risk and Vulnerability in South Asia.

### CASE STUDY PRESENTATION

After that some case studies were presented.

- At first Earthquake Risk Reduction Initiatives Particular focuses on Preparedness and Response Planning by Mr. Maksud Kamal, CDMP, GoB and UNDP.
- Then “Post 2005 Earthquake Experience (Recovery and Preparedness): Incorporating Risk Reduction in Planning” by Mr. Tariq Rafique, Pakistan
- “Lessons from the Reconstruction of Houses in Aech after the December 26, 2004 Tsunami” by Mr. Teddy Boen, Senior Advisor, WSSI.

### COUNTRY REPRESENTATIONS

**Country Representations** on Experience and lessons of ERRP at the country level were done for Bangladesh, Bhutan, Nepal and Pakistan by the respective country representative.

### GROUP DISCUSSION

The participants in the workshop were distributed into 3 Groups to participate in group discussion on three major issues.

**Group 1** discussed on **Strengthening of city/ municipality planning, implementation of effective ERR**, which was chaired by Mr. Farhad Uddin, Director General, DMB, GoB and Moderated by Prof. Dr. Mehedi Ahmed Ansary, Director,WSSI.

Three **case studies** have been presented there.

- Mr. Yoshihiro Imai, ADRC presented on **Disaster Prevention in Japan and City Planning**.
- Mr. Suraya Shrestha, NEST, ADPC presented on Efforts and lessons of **Urban Earthquake Risk Management in Nepal**
- Mr. Anisur Rahman, ADPC presented on **Measures for Strengthening of City Level Planning for Effective implementation of ERRP: a case study of Bangladesh**.

**Group 2** discussed on **Financing for sustainable Earthquake Risk Reduction and Mitigation at pre and post disaster stage**, chaired by Mr. Md. Abdul Wazed, Joint Secretary, MoFDM, GoB and moderated by Mr. Vijaya Singh, ARR, UNDP-Nepal.

Three **case studies** have been presented there.

- **Earthquake Insurance in Japan - Strong tool for Risk Management by** Yoshiaki Ogane, Senior Researcher, ADRC
- **Financing for Sustainable Disaster Risk Reduction in Pakistan** by Raja Sajjad Khan, Director, State Disaster Management Authority, Azad Jammu & Kashmir
- **Financing for sustainable Earthquake Risk Reduction and Response** by Mohammad Abu Sadeque, Deputy Secretary, MoFDM

**Group 3** discussed on **Monitoring and Evaluation of ERR initiatives at the national and regional level,** chaired by Mr. Phuntsho Wangdi, Director, SQCA, Ministry of Works and Human Settlement, Govt of Bhutan and moderated by N.M.S.I Arambepola, Director, UDRM, ADPC.

Two **case studies** have been presented there

- Yuki Matsuka, UNSIDR presented on **Monitoring and Evaluation of ERR initiatives: HFA Monitor System and Indicators**.
- N.M.S.I Arambepola, Director, UDRM, ADPC presented on **Monitoring & Evaluation of ERR initiatives at City/municipality levels and Regional/National levels.**

With the group discussions in three different parallel sessions the day 1 activities were successfully concluded and the outcomes from group discussions were presented on the next day.

The second day introduced with the Group presentation on the recommendations found from of first day group discussion by the group leaders.

**Recommendations from Group1**

- Involvement of local authorities in implementation of ERR through city plannig
- Earthquake risk assessment should conclude with earthquake risk reduction.
- All municipalities should have upgraded master plan considering ERR
- Exchange of information among the municipal authorities

- City authorities should consider liquefaction susceptible zones in land use planning.

**Recommendations from Group 2**

- Investment in DRR has to be increased
- Capacity for DRM (Disaster Risk Management) planning for national, local and regional level has to be increased
- Ensure Sustainability of DRM financing. (out side government financing)
- Insurance for ERR need to be explored and confirmed. (high rise building, private companies etc)
- Strengthening Existing Environment Impact Assessment Process (DRR Sensitive).
- Development of DRM National Action Plan.

**Recommendations from Group 3**

- Group 3 strongly & unanimously recommends the current Forum to request Regional Office for ERRP, to organize a Regional Meeting of National Project Managers responsible for the implementation of National ERRP, to draw up appropriate national and regional indicators to measure progress of ERR initiatives closely following the principles and features HFA template indicators.
- National Governments to take an active lead Roles to ensure that indicators developed within their ERR framework for measuring national ERR initiatives are resolutely adopted and enforced. To ensure that progress on ERR initiatives are effectively (honestly) measured against adopted indicators by the government, civil societies / NGOs will be empowered to check / scrutinize to authenticity of such actions taken.
- At the regional level, a central agency such as SDMC will be mandated to coordinate the collection and review of nationally adopted indicators and arrange a vote for acceptance by other member states / nations before the indicator/s in the subject can be accepted as a regional indicator.

**PRESENTATIONS**

Afterward Teddy Boen presents on **Vulnerability of Non-engineered masonry houses and common retrofitting practices for preparedness (reference to South and South East Asia).**

Then Mr. Hiroshi Imai gave a presentation on **Retrofitting of Vulnerable Structure: Case analysis of Pull down Experiment to review the seismic performance of existing masonry building held in Nepal** and Mr. Masato Ohori, ADRC commented on the pull down demonstration.

Then Dr. D.D. Joshi of SDMC renders a presentation on **Report on the Digital Vulnerability Atlas project**.

Mr. Sohel Khan presented on **Review of "Call for action" recommended in ERRP Conference in India and proposed next steps**.

**Formation of Community based Urban Volunteers** by Major Motiur Rahman, Director, Training and Planning, Bangladesh Fire Service and Civil Defense.

### PANEL DISCUSSION

The last session of the workshop was Panel discussion of experts on "Mainstreaming of ERR into Development Planning".

### PHOTOGRAPHS OF ERRP WORKSHOP AT HOTEL LAKE SHORE

Photo1: Inauguration Session of the Workshop

Photo2: Posters Displayed at the Workshop

Photo3: Dr. Mehedi Ahmed Ansary at the Workshop

Photo4: Participators of the ERRP Workshop

Photo 5: Researcher of BNUS

Photo 6: Teddy Boen Giving Presentation on Vulnerability of Non-Engineered Building

Photo 7: One of the Participants Presenting Group Discussion on Selected Topic

Photo 8: Panel Discussion of the Workshop

## Visit of Dr. Shinji Tanaka at Bangladesh Network Office for Urban Safety (BNUS)

*Dr. Shinji Tanaka from Transportation Engineering division of Asian Institute of Technology (AIT), Thailand, visited Bangladesh Network Office for Urban Safety (BNUS), BUET, Dhaka on 7 December, 2009. Dr. Mofiuzur Rahman of Department of Civil Engineering, BUET accompanied him. Prof. M. A. Ansary (Director, BNUS) briefed on various Research works and BNUS activities which were executed at different times. BNUS researchers Ms. Israt Jahan and Md. Saidur Rahman assisted Professor Ansary in explaining the tasks completed by BNUS.*

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| *Group Photos with Dr. M.A. Ansary, Dr. Shinji Tanaka and Dr. Mafuzur Rahman* | *Dr. M.A. Ansary representing the BNUS activities* | *A gift presented to Dr. Shinji Tanaka by Prof. M.A. Ansary* |

*Prof. Dr. M. A. ansary demonstrated briefly the Earthquake Evacuation Plan for Old Dhaka, Microzonation Map of Cox's Bazar city, Earthquake Recording Instruments at various locations in Bangladesh, The occurrence of cyclone (Sidr and Aila) and Climate Change Scenarios in Bangladesh and so on. He also showed interest for research in transportation sector. Dr. Tanaka appreciated the performed activities and inspired for further efficient curriculum in future. Finally, Dr. Ansary presented a gift to Dr. Shinji Tanaka for visiting to BNUS office in Bangladesh University of Engineering and Technogy (BUET).*

# One Day Workshop on Fire Hazard in Bangladesh and Remedial Measures February 10, 2010

Held at ITN Centre, BUET
Organizers: Tokyo University of Science, Japan, Bangladesh Fire Service and BNUS, BUET
Some Photographs and Participant list is attached.

Fire Workshop
Date: 10 February 2010
ITN Conference Room
BUET, Dhaka

| Sl. No. | Name | Designation / Organisation | Signature |
|---|---|---|---|
| 1. | KOBAYASHI Kyoichi | Tokyo University of Science | 小林恭一 |
| 2. | TAIKI TOMATSU | NIHON SEKKEI Inc. TOKYO UNIVERSITY of Science. | [illegible] |
| 3. | YUKIO NISHIDA | TOKYO University of Science | 西田幸夫 |
| 4. | SANDIB BARUA | Tokyo University of Science | [illegible] |
| 5. | Yukio YAMAUCHI | Tokyo University of Science | Yukio Yamauchi |
| 6. | KAZI Golam Nasir | Deputy Chief Architect Department of Architecture | [illegible] |
| 7. | ENGR. M.A. AWAL | MANAGING DIRECTOR THE STRUCTURAL ENGINEERS LTD | [illegible] |
| 8. | MD. SIRAJUL ISLAM | Chief Town Planner Dhaka City Corporation | [illegible] |
| 9. | MD. Mohsin uddin | Security offcer D. C. C. | [illegible] |
| 10. | Dr. Farooque Ahmed | Professor, BUET | [illegible] |
| 11. | Mosleh Uddin Ahmed | Executive Engineer (O&M) Public Works Dept. (PWD) Dhaka | [illegible] 10.2.10 |
| 12. | Md. Nafizur Rahman | Research Architect Housing and Building Research Institute | [illegible] 10.02-10 |
| 13. | Engr. Saiful Islam | Managing Director Nuteech Construction Chemical Co. Ltd. | [illegible] 10.02.10 |
| 14. | Md. Mosharraf Rahman | Consulting Engineer Fosroc Chemical | [illegible] 10.02.2010 |

| Sl. No. | Name | Designation / Organisation | Signature |
|---|---|---|---|
| 15. | Aklima Khatun | Head of Compliance cell BKMEA | Aklima |
| 16. | Dr. Md. Abdur Rouf | Professor, BUET | MRouf |
| 17. | M.A. Mannan. | Asstt. Secy. [illegible] (BGMEA) | [illegible] |
| 18. | A.K.M. Shahjada | Dy. Secretary (TT) BGMEA (Safety cell) | [illegible] 10/02/10 |
| 19. | Md. Zahurul Amin | Asstt. Director Fire Prevention Fire Service and Civil Defence | [illegible] 10/02/10 |
| 20. | Maj Motiur Rahman | Director (TPD) | [illegible] |
| 21. | Prof. MA Ansary | BNUS, BUET | [illegible] |
| 22. | Prof AMM Safiullah | VC, BUET | — |
| 23. | Brig. General Nain | DG, FSCD | — |
| 24. | Md. Akhlaqur Rahman | Program Officer, ActionAid | [illegible] |
| 25. | Shakib Nabi | ActionAid | [illegible] |
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