Risk Due to Natural Disasters in Dhaka City and Measures for Mitigation

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Introduction

Islam Khan Chisti founded Dhaka in 1608 A.D. as the capital of the Bengal during the regime of Mughal Emperor Jahangir and it was at that time renamed Jahangirnagar. With the establishment of Mughal control over the region, Dhaka continued functioning as the capital of Bengal, Bihar, Orissa and retained the status till 1717. From 1717 to 1843, Dhaka had been the seat of the Naib-Nazim till the imposition of the British East India Company's administration, which led to the Sepoy Mutiny in 1857 and the formal establishment of British Rule. In 1905, Dhaka was made the capital of a new province comprising East Bengal and Assam. This was cut short by annulling the partition of Bengal in 1911. In 1947, the city emerged as the provincial capital of then East Pakistan and embraced the historic movements and finally the victory in the War of Liberation. After independence, Dhaka became the capital of Bangladesh in 1971.

The Dhaka City Corporation with an area of 360 sq. km. is divided into ninety wards. Each elects one Ward Commissioner and the ninety Ward Commissioners elect eighteen women Ward Commissioners raising their number to 108. A Mayor, who is directly elected by the citizens, heads the City Corporation. The 108 Ward Commissioners, under the captaincy of the Mayor are responsible for managing the municipal affairs and delivery of services to their electors. Decisions are taken in meetings of the City Corporation.

An analysis of Dhaka City's growth and population, occurrence of different natural disasters and disaster scenarios are presented in this paper. In addition, mitigation strategies for floods as well as for earthquakes and current efforts undertaken by different government and non-government organizations to mitigate earthquake disasters are discussed.

Dhaka's Growth and Population

Dhaka stands on the northern bank of the river Buriganga and about several kilometers above its confluence with the Dhaleswari River. The city, which started around the year 1600 AD on a small place on the bank of river Buriganga, continued to expand mainly in the northward direction along the table l and (Madhupur clay) during subsequent times. Beels and depressions on the east, west and south, which constitute flood plains of the Jamuna and Meghna rivers, restricted growth in these directions. The growth of the urbanized areas of Dhaka City through different periods is shown in Figure 1 (Siddiqui, 1990).

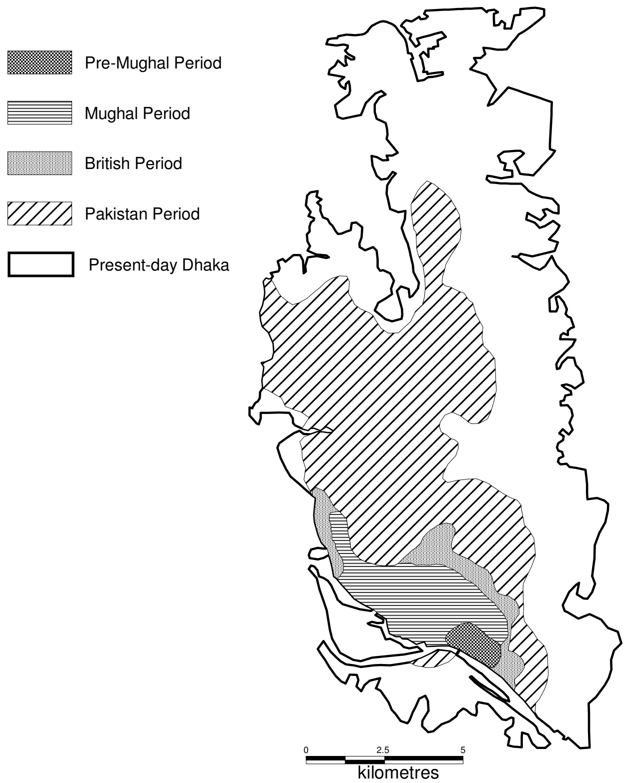

Fig. 1: Growth of Dhaka city through different periods.

Dhaka at present is one of the fastest growing cities in the world. The population of the Dhaka was around 0.9 million in 1700, around 0.2 million in 1800, around 0.1 million in 1900 and currently around 6 million within the City Corporation's boundary. In the last 40 years, the population of the city was almost doubled. According to a recent UNFPA report Dhaka Metropolitan area's present population is 12.3 million. The location as well as socio-political context of Dhaka favoured and shall favour rapid growth in the city's population. Better economic opportunities attracted people of all classes towards Dhaka. Rural poverty also pushed people to Dhaka for findings ways and means for survival.

In this study, initially thana (administrative unit) and later wards was adopted as the basic geographical reference (geo-code) for the earthquake loss model. Dhaka at present is divided into twenty-two thanas and ninety wards. Figure 2 presents population density map of these twenty-two thanas and also two other thanas, which are within the city areas but officially, fall in other district area. Figure 2 also presents the ward map of Dhaka City Corporation.

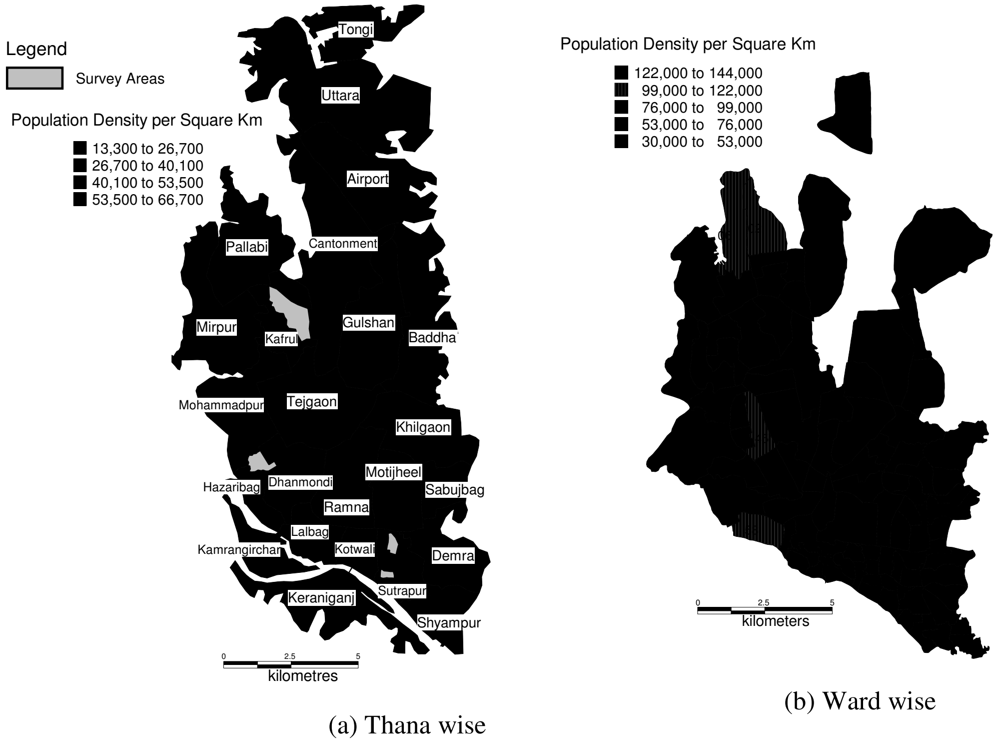

Fig. 2: Population density map of Dhaka.

Natural Disaster

From a natural hazard viewpoint, Dhaka is among the most vulnerable cities in the world. Floods, fires, earthquakes and tornadoes are among the major hazards (Mitchell, 1999). In this paper two major natural hazards such as floods and earthquakes are discussed.

Floods

Dhaka is surrounded by a network of rivers – the Turag on the west, the Buriganga on the south, the Balu on the east, and the Tongi Khal on the north (Figure 3). The historic cause of floods in Dhaka City is the rise in water levels of the rivers bordering the city. In addition, internal drainage congestion and un coordinated operation of flow regulation structures may make the flood situation worse (Faisal et al., 2003).

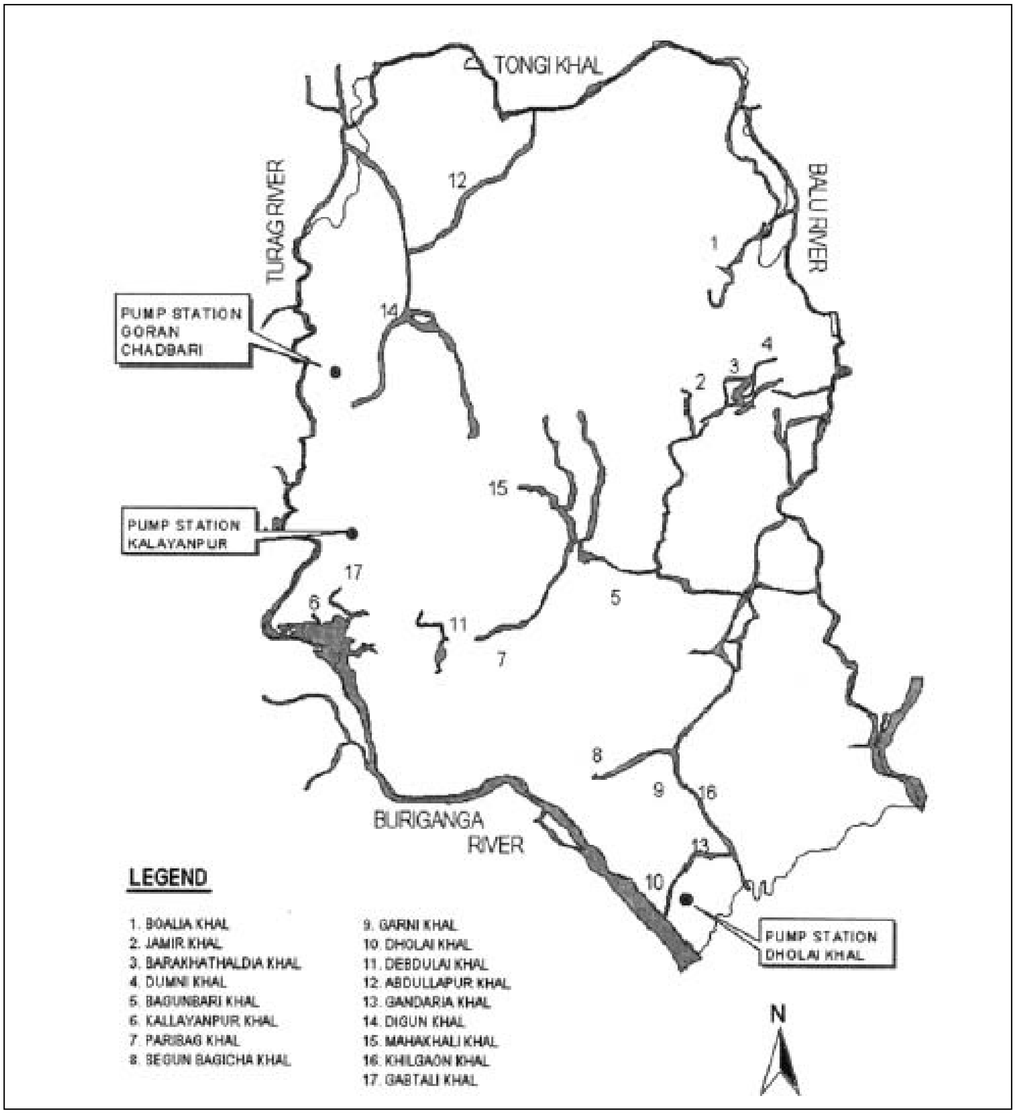

Fig. 3: Rivers and canals of Dhaka City.

Dhaka has experienced two major floods during the last decades. The 1998 flood has been one of the most devastating from duration point of view, whereas the water levels in the 1988 flood were among the highest in the last hundred years. After the 1988 flood, the western and southern parts of the city have been brought under flood protection by constructing the embankment and floodwalls as per Phase I of Dhaka Integrated Flood Protection Project (DIFPP). However, these structures could not provide 100% flood protection in 1998 due to the presence of a few openings in the form of surface and buried drains and discontinuity in floodwalls. Figure 4 shows the areas that were inundated during the flood of 1998. The eastern part of the city (to the east of Biswa Road) is not yet protected and all of it was inundated during the flood of 1998 as shown in Figure 4. This area largely comprises of low-lying floodplains that goes under water as the water level in the Balu River rises. However, growing population and land scarcity have forced many people to settle on this flood plain. Implementation of Phase II of DIFPP will provide flood protection to this part of the city.

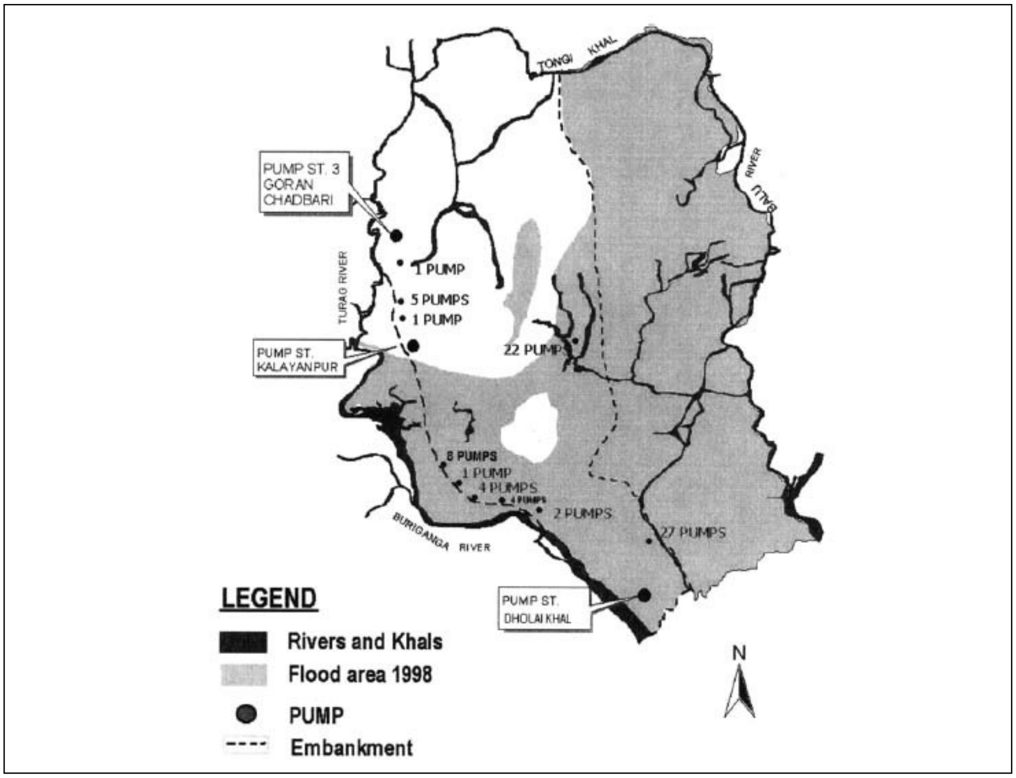

Fig. 4: Inundation pattern in Dhaka City during the flood of 1998.

Earthquakes

Seismic Source Zones and Seismicity

Seismic hazard is typically determined using a combination of seismological, morphological, geological and geotechnical investigations, combined with the history of earthquakes in the region. Bolt (1987) analyzed different seismic sources in and around Bangladesh during the feasibility stage of Jamuna bridge project. Bolt identified four major sources of earthquakes: (i) Assam fault zone, (ii) Tripura fault zone, (iii) Sub-Dauki fault zone and (iv) Bogra fault zone. Figure 5 shows some of the active faults, which are situated in and around Bangladesh.

Reliable historical data for seismic activity affecting Bangladesh is available only for the last 450 years (Gupta et al., 1986). Recently developed earthquake catalogue for Bangladesh and surrounding area (Sharfuddin, 2001) showed that sixty-six earthquakes with $M_s \geq 4.0$ occurred from 1885 to 1995 within a 200 km radius of Dhaka city. The most prominent historical earthquakes affecting Dhaka is listed in Table 1.

Bangladesh National Building Code (1993) placed Dhaka in Seismic Zone 2 with PGA value of 0.15g (where g is acceleration due to gravity). The seismic zones mentioned in national code were not based on analytical assessment of seismic hazard and were mainly based on the

Table 1: Magnitude, EMS intensities and distances of some major historical earthquakes around Dhaka.

Name of the earthquake	Magnitude	Intensity at Dhaka	Distance (km)
1869 Cachar	7.5	V	250
1885 Bengal	7.0	VII	170
1897 Great Indian	8.7	VIII+	230
1918 Srimangal	7.6	VI	150
1930 Dhubri	7.1	V+	250

location of historical data. An updated seismic zoning map based on analytical study was recently developed (Sharfuddin, 2001) which has been presented in Figure 6. This zoning map was based on consistent ground motion criterion such as equal peak ground acceleration levels with a return period of 200 years. Based on the philosophy behind the seismic zoning and experience from recent earthquakes, it can reasonably be assumed that a major earthquake event in Dhaka region is capable of higher damage than that assumed in the existing zoning map (BNBC, 1993).

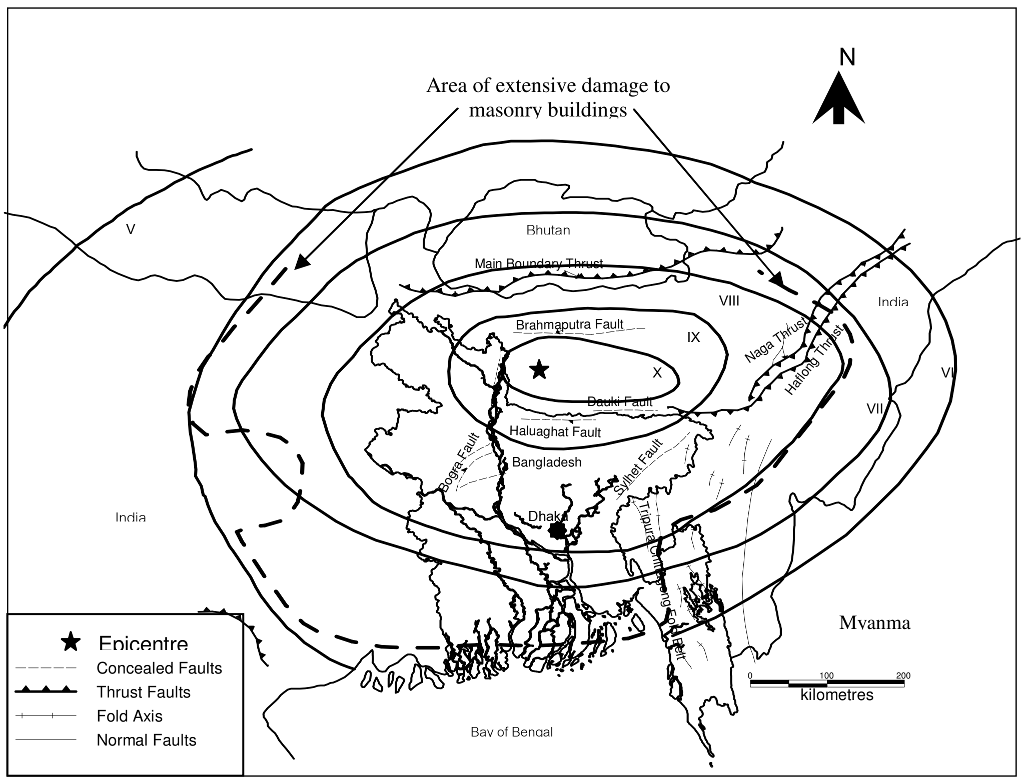

Fig. 5: Active fault locations and isoseismal map of 1897 Great Indian earthquake

Earthquake Scenarios and Associated Probabilities

Due to the non-availability of seismo-tectonic data on lineaments and their level of activity, scenario events were estimated using earthquake catalogues. The earthquake history of Dhaka presented in Table 1 shows evidence of damaging earthquakes at frequent intervals; there were already a few earthquakes with intensity V+ damage during the last 200 years. Based on historical data, it is conceivable that the Dhaka region may experience earthquakes with damage greater than intensity VIII, the level assumed based on 1897 Great Indian earthquake (Oldham, 1899). In this study, an earthquake of maximum EMS intensity (Grunthal, 1998) VIII was used for damage estimation.

Intensity attenuation law developed recently for Bangladesh and surrounding region (Equation 1) by Ansary and Sabri (2002) was used for estimating intensities of sixty-six earthquakes within a 200 km radius of Dhaka and Gutenberg-Richter recurrence relationship was developed to estimate the probabilities for different intensity earthquakes. The probability of exceedance in a design life of 50 years for EMS intensity VIII was 57 %.

$$I = 8.378 + 1.283(M_s) - 0.0007483(R) - 4.9(\log R) \pm 0.93P \qquad (1)$$

Building Inventory Survey and Results

The detailed building inventory survey was discussed in a separate paper (Ansary and Meguro, 2003). Here some salient features relevant to this study are presented.

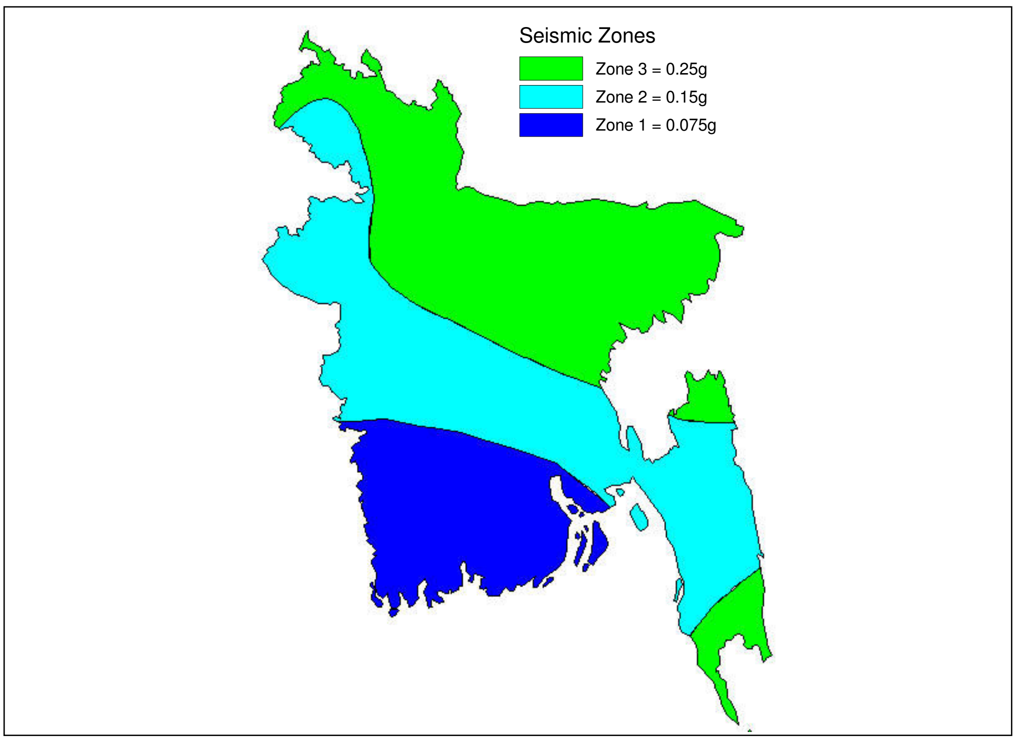

Fig. 6: Updated seismic zonation map of Bangladesh.

Selection of Sample Sites

Dhaka City Corporation is currently divided into ninety wards. Among these, eight wards (ward number 73, 74 and 77 of Sutrapur thana; ward number 47, 48 and 49 of Dhanmondi thana; ward numbers 14 and 16 of Kafrul thana) were selected based on their settlement age and locations. These are widely apart and represent the different settlement pattern of the city. Figure 2 shows the location of these wards in Dhaka city. The main target was estimating the likely building damage due to the scenario earthquakes with a certain level of ground shaking: how the buildings are constructed and the likely response of the buildings to such shaking. The building inventory survey covered mostly urban and partly semi-urban in nature. It also covered the commercial and the industrial (light industry) areas.

Building Typology and Classification

The building inventory survey helped to classify all buildings in Dhaka into five types based on their definition in European Macroseismic Scale (Grunthal, 1998). Table 2 shows the description of each typology.

Table 2: Definition of building typologies in Dhaka.

No.	Types	Description
1	EMSB1	1-storied brick masonry of fired bricks with cement or lime mortar; roof is either of GI sheet or other materials.
2	EMSB2	2-storied or taller brick masonry of fired bricks with cement or lime mortar; roof is generally made of RCC slab. Some weak and old reinforced concrete frame.
3	EMSC	Reinforced concrete frame with low ductility; designed for vertical load only.
4	EMSD	Reinforced concrete frame with moderate ductility; designed for both vertical and horizontal loads.
5	EMSF	Mainly bamboo, wooden and steel structures.

Number of Stories and Building Area

A majority (60% at Dhanmondi, 46% at Kafrul and 63% at Sutrapur) of the existing buildings is 2-5 storied and about 40% (37% at Dhanmondi, 46% at Kafrul and 34% at Sutrapur) is single-storied. Figure 7 shows the distribution of buildings in the three thanas according to number of stories and floor space.

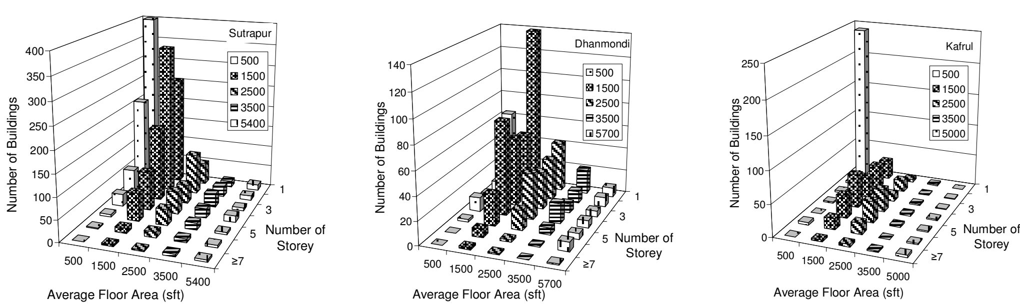

Fig. 7: Distribution of building types according to number of stories and floor space in three. thanas.

In the residential areas, RAJUK or Rajdhani Unnayan Kartripakha (Capital Development Authority) generally do not allow structures beyond 6 stories. But from Figure 7, it can be seen that in Dhanmondi and Sutrapur areas less than 1 % is taller than 6-storied. Some of them may be approved by RAJUK and the owner may extend some beyond the approved plan. Each year at least 10 to 20 such structures collapse in Dhaka due to one reason or other. In the newly developed Kafrul area, the percentage is higher (around 2.1%), as there are many Government constructed high-rise housing complexes and offices.

In Dhanmondi area, the average house sizes are comparatively larger than Sutrapur and Kafrul areas, where residents are comparatively affluent. In Sutrapur (which is an old settlement), the house sizes may also be decreasing due to division of the original plot among successors of the original owner. Similar process has also started in Dhanmondi area recently, due to the local custom of succession of property and due to higher price of land there. Most of the old houses are demolished and the developers are constructing luxurious apartment buildings. The building inventory data obtained for the three thanas together with BBS (2001) data were utilized for estimation of housing units and their story-wise distribution, for the rest of the twenty-one thanas.

Disaster Scenario

For floods, the damages due to 1998 flood are presented and for earthquakes, damages due to a scenario earthquake are presented below.

Floods

In 1998, several floods passed through the country since early July. The flood situation started to worsen in the beginning of July due to heavy rainfall in the entire catchment area of the Ganges-Brahmaputra-Meghna system (Islam et al., 2003). Compared to the normal rainfall in the July–August period, the rainfall was 40% higher in July and 35% higher in August. As a result, water levels in all major rivers showed a significant rise.

The water levels in the rivers surrounding Dhaka approach the respective danger levels in the second half of July but cross the danger levels in mid-August. Peak flows occur typically in the last week of August and the first two weeks of September and flood water recedes in the last ten-days of September (Figure 8). The floods of 1987 and 1988 followed this pattern. However, during the flood of 1998, water levels crossed the danger levels almost a month earlier and stayed there until the last week of September. The main difference between the floods of 1988 and 1998 as seen in Figure 8, is that the former peaked very quickly in mid-August and had duration of about four weeks. The latter showed a smaller early peak, which prevailed until the arrival of a second peak in the second week of September. Finally the water levels receded in the last week of September. Thus the duration of 1998 flood was more than two months making it the longest flood in the history of Dhaka City. In terms of flood height, 1988 flood peaks were higher compared to the peaks of 1998.

Major Findings from the Analysis of the 1998 Flood

Based on the analysis of the 1998 flood as presented above, a number of important findings are listed below in relation to flood mitigation in both the western and eastern parts of the city.

Box 1 Damages to important infrastructure of Dhaka City during the flood of 1998

Housing: According to a field survey carried by the Center for Urban Studies, Dhaka, approximately 262,000 houses of various types were damaged worth Taka 2.3 billion (Islam, 1998).

Roads: About 1000 km of road surface was damaged within the DCC area (Siddique and Chowdhury, 1998).

Water supply: According to the Dhaka Water and Sanitation Authority (DWASA), out of 235 deep tube wells, 12 went under water and had to be cleaned and restored after the flood. DWASA also had a plan to repair, clean and disinfect some 600 km of water supply mains. Additionally, 400 km of sewerage lines and 11 sewer lift pumps needed rehabilitation. Estimated cost of these activities was $10 million (Faisal, 1998).

Drainage: A total of 223 km of box culvert, open drain and storm drain were reported to have silted up or damaged. About 510 km of tank sewer and sewerage line, 6 pump stations and 10 sewerage lift stations were affected (Siddique, 1998).

Power: According to the Dhaka Electric Supply Authority (DESA), 500 transformers, 300 km of wire and 600 poles for 11 KV lines were damaged due to flood. Another 40 km of existing lines and 200 poles needed repair (Faisal, 1998).

Box 1. Damages to important infrastructure of Dhaka City during the flood of 1998 (Islam et al., 2003)

Findings for the Western Part of Dhaka

The western part of Dhaka City is largely protected by the embankment constructed after 1988 flood as per Phase I of DIFPP. Even then, about 20% of this part of the city was inundated in 1998 due to the following reasons:

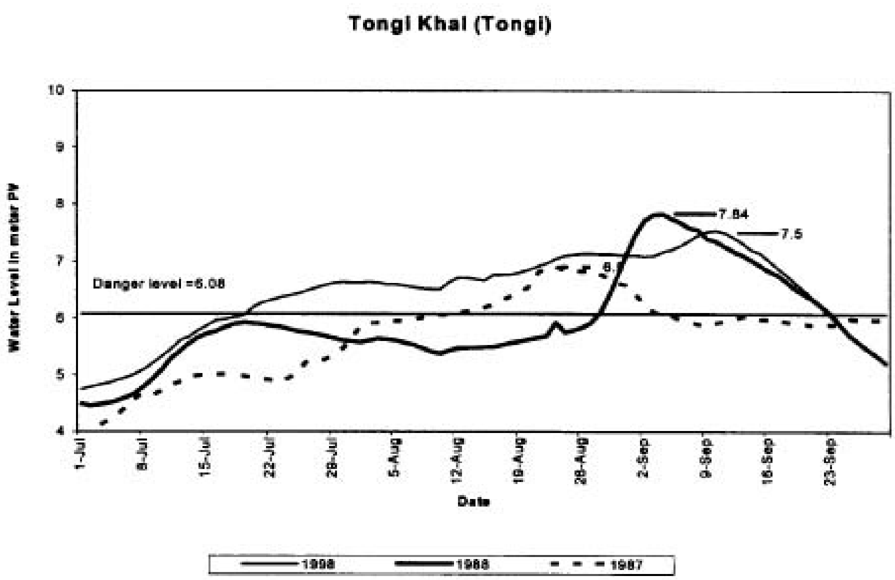

Fig. 8: Flood hydrographs for the Tongi Khal

i. Hydraulic leakage through un-gated drainage pipes and culverts;

ii. Delayed closure of the regulator gates at Rampura Bridge;

iii. Inadequate pumping from the retention storage;

iv. Leakage through incomplete segments of the floodwall along the Buriganga River;

v. Significantly reduced drainage capacity due to accumulation of solid waste and silt;

vi. Lack of coordination between organizations responsible for flood control and drainage;

vii. Partial completion of DIFPP.

It may be mentioned here that the embankment along the Turag River played a crucial role in protecting the western part of the city during 1998 flood even though its construction was not completed as per design. Specifically, the *berm* on the countryside was not constructed and the crest width was found to be less than the design width in some parts of the embankment. As a result, there was a serious threat of seepage failure of the embankment, which was countered by holding water on the countryside with the help of sandbags.

Findings for the Eastern Part of Dhaka

The eastern part of Dhaka is flooded annually, as it is largely an unprotected lowlying flood plain. Anticipation of construction of the embankment along the Balu River had already triggered rapid urbanization in this part with little supervision from the city planning authority. Many structures are being built with low plinth level, which will be inundated in case of a major flood. The city planners must adopt and enforce proper land use plans in this area to prevent major economic loss and human sufferings in future. A very important aspect of the land use plan for Dhaka East would be the open areas to be developed as retention ponds to prevent massive water logging. Unless these areas are identified and preserved now, these will be taken up by urban developers and the city authority may have to buy these areas back at a much higher price compared to their present value.

Earthquakes

Microzonation

For the present analysis, a GIS based map of Dhaka was developed based on 1:20000 scales Survey of Bangladesh map published in 2001. For the GIS analysis MapInfo software was used. Figure 9 shows the geological map of Dhaka based on the above GIS map. The Madhupur clay and old natural levee areas (termed as Madhupur Clay) were assumed to be non-liquefiable and the rest of the area, i.e., flood plain, active natural levee and abandoned channel areas (termed as Flood Plain) were assumed to be liquefiable. For the earthquake loss estimation this simplified map has been used.

Figure 10 presents site amplification and liquefaction potential maps of Dhaka, which have been developed very recently by Ansary (2003). The site amplification map has three zones with the following characteristics: zone 1 with resonant frequency of less than 3 Hz and mean ground motion amplification of 2.5; zone 2 corresponds to resonance frequencies in a band of 3 to 5 Hz having a ground motion amplification of 1.8; zone 3 corresponds to resonance frequency greater than 5 Hz and mean ground motion amplification of 1.8 Hz. The liquefaction map has two zones: a zone with liquefaction possibility and the other with no liquefaction possibility.

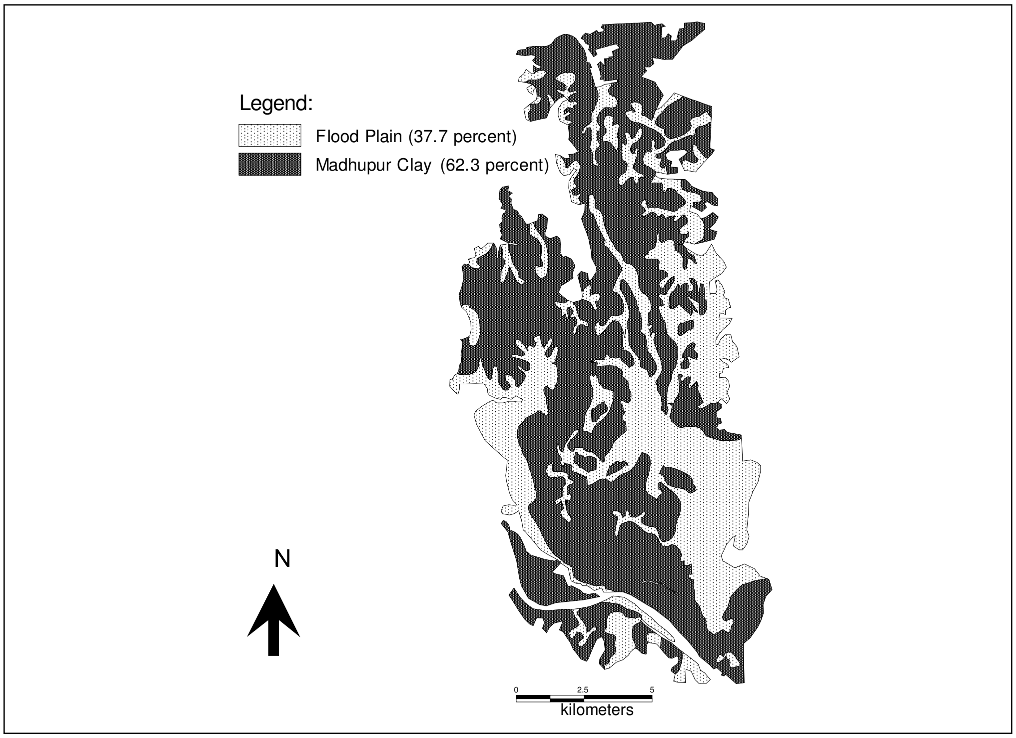

Fig. 9: Geological map of Dhaka.

Vulnerability Function

In this study, fragility curves for the buildings in Dhaka were prepared by calibrating the existing fragility curves for Indian buildings prepared by Arya (2000) and for Nepalese buildings prepared by Bothara et al. (2000). There exist a number of fragility curves for different types of structure and different earthquake intensities but according to the authors' experience, the Indian and Nepalese curves are most suitable for Bangladeshi structures. Figure 11 present the fragility curves for EMSB1, EMSB2, EMSC, EMSD and EMSF type structures.

Neither Arya (2000) nor Bothara et al (2000) mentioned the types of damages (i.e., collapsed or heavily or moderately damaged) to be estimated using those fragility curves. Segawa et al. (2002) used those curves after some calibration and quoted those curves to be developed for heavily damaged structures. For this study, based on some previous findings from damaging earthquakes in India (Arya, 2000; Jain et al., 2002; NSET and DEQ-UOQ, 2000), it was assumed that complete (damage grade G5) and partial collapse (damage grade G4) structures comprise 25% of EMSB and EMSC damage, heavily damaged structures (damage grade G3) comprise 40% of EMSB and EMSC damage, moderately damaged structures (damage grade G2) comprise 15% of all type total damage and low damaged structures (damage grade G1) comprise 20% of all type total damage.

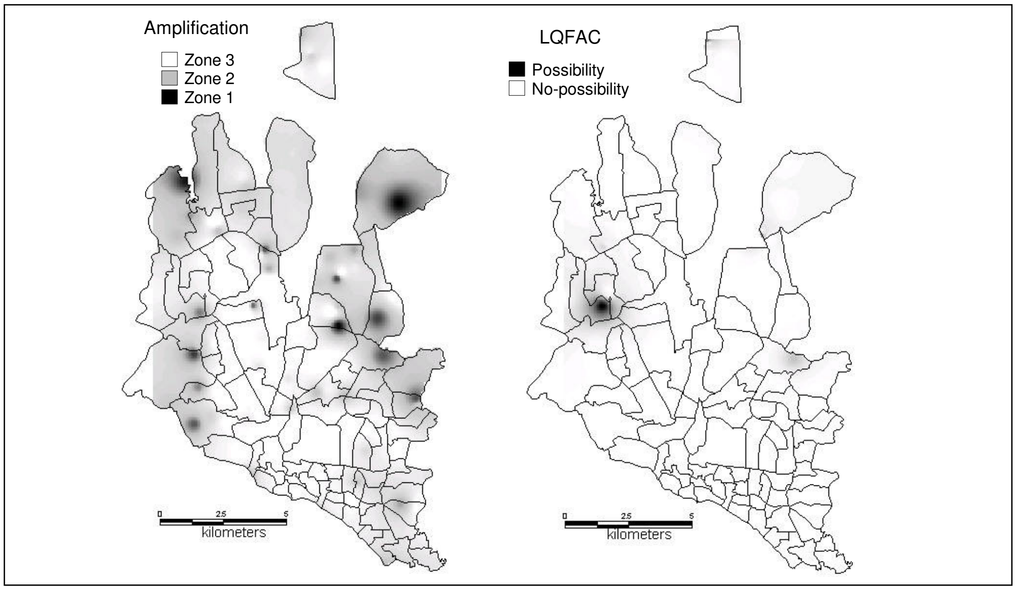

Fig. 10: Seismic microzonation maps for Dhaka.

Building Damage

The intensity variation map is the same as the geological map of Dhaka as presented in Figure 9. Maximum intensity of the scenario earthquakes was assigned to the flood plain area (37.7 %) and one degree less intensity was assigned to the rest of the area with Madhupur clay (62.3 %). Damage ratios for each thana were obtained for the scenario earthquake with maximum intensity of VIII using the intensity variation as defined earlier and the fragility curves of Figure 11. In total, on an average 28% of buildings were estimated to be damaged by intensity VIII earthquake. On the other hand, for intensity VIII earthquake, thana wise damage distribution varies between 16 to 40%. Figure 12 presents thanawise damage ratios for intensity VIII earthquake. Thanas, which are situated in southeastern part of Dhaka showed greater building damage ratio, this result is consistent with the existing soil condition in those areas.

It is interesting to note that during the 2001 Bhuj earthquake (maximum EMS intensity X), over 980,000 masonry structures experienced medium to severe damage and 230,000 were collapsed in Gujarat (Jain et al., 2002). Total death toll was around 15,000 and injuries were 170,000. The Bhuj city (EMS intensity IX) located 70 km from the epicenter with a population of only 150,000 experienced around 10,000 deaths, 90% of masonry structures of old Bhuj collapsed and most of the reinforced concrete structures were badly damaged. Even many mid to highrise buildings of Ahmedabad (EMS intensity VII), a city 300 km away experienced collapse and heavy damages. Since Dhaka is a much larger city and the building stock is larger than Ahmedabad and Bhuj, the expected damage will be consequently much higher.

Human Casualty

In order to assess the human casualty levels due to the earthquake, the estimates of average fatality and injury levels were estimated using a mortality prediction model for different categories of structures derived these figures. This prediction model is based on investigation of casualty due to several major earthquakes that occurred during this century (Coburn et al., 1992). The total number of people that may be killed due to damage of each building type can be represented by:

$$Ks_b = D_b * [M1_b * M2_b * M3_b * M4_b] \quad (2)$$

Where, D_b is the total number of damaged structures of building type *b*, M1 is the occupant density and M2 to M4 are conditional probability factors to modify the potential casualty figures. The factor M1 represents the population per building. For this investigation, M1 was taken as 5 (BBS, 2001). M2 is the occupancy of buildings at the time of earthquake. The occupancy cycle proposed by Coburn and Spence (1992) was used. Depending on the time of the earthquake, the occupancy rate can been found from this figure. M3 is the proportion of occupants who are trapped by collapse of buildings. This depends on the type of building. M4 is the proportion of occupants who are either killed or injured in the earthquake. It was observed that collapsed multi-storied masonry and reinforced concrete buildings lead to death of a large number of trapped occupants, while collapsed masonry buildings lead to death of relatively small number of trapped occupants.

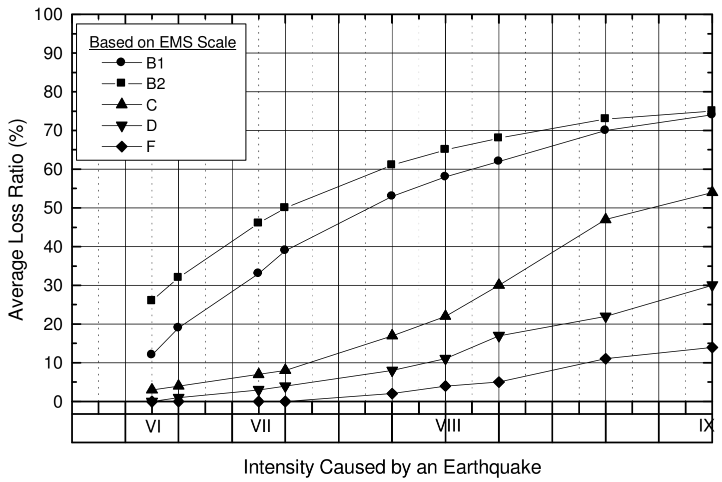

Fig. 11: Fragility curves for different building types based on EMS intensity.

The Dhaka building inventory, census information, earthquake hazard and vulnerability data and the mortality information were combined to estimate the number of possible injuries and the corresponding deaths that may occur due to earthquakes of different strengths. The occurrence of an earthquake of EMS Intensity VIII at Dhaka may lead to massive loss of life and damage of buildings. Depending on the time of the day, from 22000 to 28000 people may perish due to structural collapse and damage in the earthquake. The numbers of serious injuries may also range from 86000 to 107000, possibly placing a very severe strain on the emergency relief and health-care infrastructure.

Mitigations of Floods

Some mitigation strategies for floods and earthquakes are discussed below.

Long-Term Strategies for Flood Mitigation

Some of the shortcomings of the current flood management practices have to be addressed immediately to protect Dhaka City from flooding. As short-term measures, all hydraulic leakage must be sealed off, badly silted-up drains must be cleaned and encroachment of retention ponds must be stopped (Islam et al., 2003). But to ensure long-term flood protection for Dhaka City, the most important step is to complete Phase II of DIFPP. After the 1998 flood, this plan has been expanded into a multi-objective project where the flood protection embankment will also house a four-lane road (Dhaka City eastern Bypass) and a railway track. Figure 13 shows the proposed cross-section of the multipurpose embankment along the Balu River. The following structural and non-structural measures are recommended as long-term measures for flood mitigation.

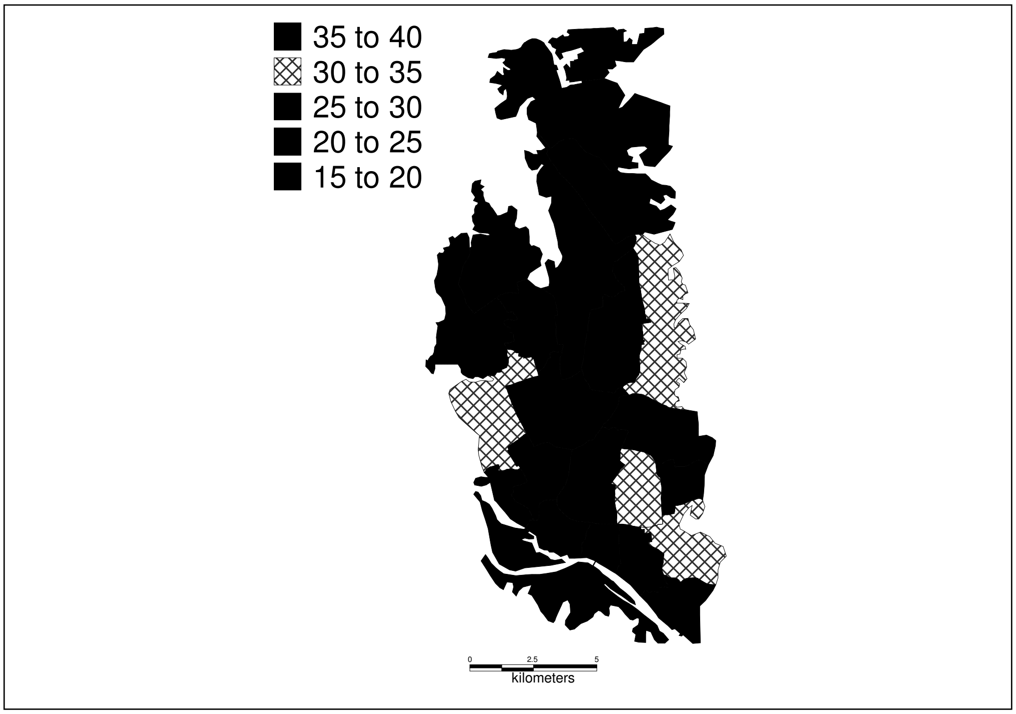

Fig. 12: Thanawise average damage ratio of buildings for a scenario earthquake of intensity VIII.

Structural Measures

i. Complete Phase II of DIFPP and ensure total flood protection for Dhaka City;

ii. Install and operate adequate number of pumps (supported by corresponding retention ponds) and maintain these in good condition;

iii. Maintain all existing and future flood control structures, reinforce weak points, provide bank protection where necessary;

iv. Maintain the internal drainage network in good condition; and,

v. Develop operating rules for all the regulators and establish close collaboration with the flood forecasting and warning agencies.

Non-Structural Measures

i. Protect existing retention ponds in the western part of Dhaka and set aside

sufficient land for retention ponds in the eastern part of Dhaka;

ii. Improve the flood forecasting and warning system, provide forecast in terms of potential area of inundation;

iii. Build public awareness on flood preparedness through NGOs and the media;

iv. Undertake awareness campaigns to prevent indiscriminate disposal of garbage in the surface and subsurface drains of the city;

v. Streamline institutional bottlenecks and assign all flood-related responsibilities to DWASA and BWDB as appropriate;

vi. Introduce rules and regulations for proper land use in the eastern part of Dhaka;

vii. Introduce mandatory flood proofing for new buildings in the eastern part of Dhaka;

viii. Provide flood warning and flood shelter;

ix. Ensure cost sharing by GOB and floodplain dwellers.

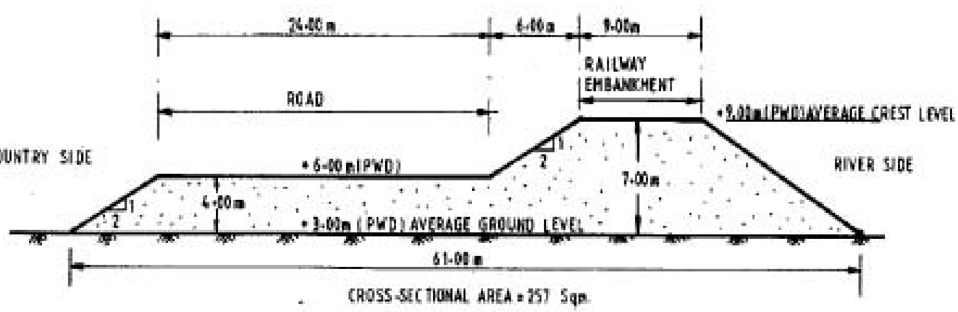

Fig. 13: Cross-section of the multipurpose embankment along the Balu River.

Long-Term Strategies for Earthquake Risk Mitigation

Bangladesh achieved remarkable success in managing frequently occurring hazards such as cyclones and floods. The country has a well-organized Cyclone Preparedness Programme (CPP), which boasts a volunteer list of around 36000 who may be mobilized along the 700 km long coastal belt within a few hours. Some other countries prone to cyclones and storm surges are trying to emulate CPP. To cope with the earthquake disaster a similar Earthquake Preparedness Programme (EPP) needs to be implemented.

For earthquake disaster mitigation professional as well as government solution is required. Architects, engineers, geologists, planners etc. will provide technical aspects and NGOs, mass media and social scientists will provide social aspects of professional solution. Builders, financial institutions, land developer would be required to support professional solution. Government agencies can help to implement professional solution through policymaking and policy enforcement. Government solution should clearly point out regulatory jurisdiction of each organization. For earthquake disaster mitigation following pre and post measures should be undertaken on an urgent basis.

Awareness and capacity building

- Increase public awareness through education (school children), earthquake drills, interactive website, mass-media, publication, training etc.
- Training of building inspectors, community leaders, construction workers and masons.
- Updating earthquake engineering course curriculum.

Earthquake engineering research

- Installation of free field accelerographs and seismographs for engineering and seismology studies.
- Seismic hazard assessment based on free field data and source models.
- Vulnerability assessments of structures using structural analysis and nondestructive testing. Develop laboratory and testing facilities.
- Development of indigenous and cheap retrofitting measures.
- Microzonation of urban areas based on different soil effects.
- Updating building code.

Earthquake resistant construction

- Legal enforcement of building code.
- Proper use of ductile steel and lateral force resisting systems.
- Building insurance to promote earthquake resistant construction.
- Retrofitting critical structures such as schools, hospitals and fire offices.
- Urban and regional planning to mitigate earthquake effects.

Post-earthquake response

- Develop automatic safety shutdown system for electricity, gas, telephone and water supply system whenever the ground shaking exceeds a certain limit.
- Develop facilities for post earthquake search and rescue operation.
- Local people and organizations most effectively do rescue of victims because they are able to carry this out more quickly than outside agencies. Community based voluntary group should be trained who can actively participate in rescue operation just after an earthquake disaster.
- Prepare contingency plans.
- Coordination among different interest groups those will be involved in the post earthquake rescue effort.
- Arrangement of emergency medical treatment facilities for injured people.

Current Efforts

In the following paragraphs a brief summary of activities undertaken by different organizations of Bangladesh to mitigate earthquake disaster are presented.

Bangladesh University of Engineering & Technology (BUET)

Department of Civil Engineering, BUET offers postgraduate courses on Earthquake Engineering, Soil Dynamics, Structural Dynamics and Vibration Analysis. Until 1996, their existed only two postgraduate theses linked with Earthquake Engineering. But after 1996, six more postgraduate theses related to this field were completed. Currently two students are pursuing their PhD and four more students are pursuing for their Master's thesis in the Department in Earthquake Engineering field.

Department of Civil Engineering, BUET is working as a consultant to the 4.8 km long Jamuna Multipurpose Bridge to monitor the seismic instruments that the Department's faculty members helped to be installed in July 2003. In addition to the seismic instrumentation of the bridge, there is a borehole accelerograph at 57 m depth and seven free-field seismic instruments at Bogra, Natore, east and west end of the bridge, Mymensingh, Gazipur and Dhaka.

In April 2002, BUET put forward a proposal for the establishment of a National Center for Earthquake Engineering (NCEE) and included it in BUET's next five-year plan for implementation. In March 2003, an MOU was signed between NCEE and ICUS, University of Tokyo. Recently, a linkage is established between Virginia Polytechnic Institute, USA and NCEE with USAID funding.

After the recent Bangladeshi earthquakes several BUET team performed field surveys (Ansary et al., 2001, Ansary et al., 2003). The first author also visited earthquake-affected parts of Gujarat state of India as mentioned earlier with GERIT (Mistry et al., 2001) under the joint sponsorship of EMI-WSSI. The author has also contributed two reports one on unreinforced masonry and the other on mud houses to the EERI's World Housing Encyclopedia Project.

Government Agencies

Disaster Management Bureau (DMB) was established with the help of UNDP and UNICEF in 1993. Although initially it was established to manage flood and cyclone, after the 1997 earthquakes in Chittagong and Sylhet region, Bureau started to train different government officials and volunteers about pre and post-earthquake preparedness and management techniques. For the last couple of years, Bureau conducted fifty or more earthquake training workshops in different regions of Bangladesh. In 2002, it also published a Disaster Management Training Manual. The second part of the manual has a complete chapter on Earthquake Training Module and Public Awareness Guidelines.

The Ministry of Disaster Management & Relief (MDMR) is currently working as the government coordinator for all activities regarding earthquake. Recently, they asked all the concerned ministries, departments and armed forces division to submit Contingency Plan regarding earthquake. The Ministry also compiled a list of available rescue and recovery equipment available in the country. MDMR is currently taking preparation to hold a mock drill in the mid week of December 2003. It will be held in the Dhupkhola field at the old part of Dhaka city, where the current population density exceeds 70000 per sq. km.

The second phase (2003-2008) of Program for Enhancement of Emergency Response (PEER), a USAID funded international project includes Bangladesh with the existing four other PEER affiliated countries – India, Indonesia, Nepal and Philippines. The program aims to strengthen and institutionalize capacities in emergency and disaster response of the member countries. An MOU in this regard will soon be signed between PEER and Ministry of Disaster Management & Relief (MDMR).

In 2001 Bangladesh Meteorological Department (BMD) initiated a project to establish four broadband seismic stations at Rangpur, Sylhet, Dhaka and Chittagong cities.

Public Works Department (PWD) is responsible for constructing all the government buildings of the country. For the last two years, the Department arranged several in-house workshops to train their engineers about earthquake resistant design. Also the engineers of this organization have started to use seismic codes in designing buildings.

Bangladesh Armed Forces Division (AFD) played a significant role in all past disaster management in the light of the tasks assigned in the "Standing Order on Disaster, 1999" circulated by MDMR. Recently, Bangladesh Armed Forces, in consonance with the national initiative, chalked out a contingency plan for Dhaka city (Rasul, 2003). According to the AFD's contingency plan, the city is divided into eight sectors with predefined tasks after an earthquake. AFD will also activate "Disaster Management and Relief Monitoring Cell" at Prime Minister's Office after an earthquake.

Geological Survey of Bangladesh (GSB) is the oldest organization in the country involved with the development of seismic zonation maps. The organization was instrumental in developing the 1972 and 1979 seismic zonation maps (Choudhury, 1993). But unlike its predecessor the Geological Survey of India (GSI) under the British rule, it did not initiate any research in earthquake field. Currently it depends on USGS and GSI for earthquake source information.

Bangladesh Earthquake Society

Bangladesh Earthquake Society (BES), a non-government voluntary organization was established on April 2002 and was registered on January 2003. The first election of the society was held on August 2003 and a 12 member executive committee (EC) was elected. The EC members consist of engineers, geologists, NGO activists and government administrators.

BES also organized two national level workshops and held four monthly seminars so far. The first workshop was jointly organized with RAJUK [Capital Development Authority] on August 21, 2003 to train the engineers of Bangladesh about the earthquake resistant design. The second workshop was organized together with Disaster Management Bureau (DMB), Ministry of Disaster Management and Relief on September 4, 2003 to sum up the findings of 2003 Rangamati Earthquake. Both the workshops put forward a set of recommendations to be implemented either by the government or by the NGOs with the help of donor agencies. The second workshop was the first of its kind where architects, armed forces personnel, engineers, geologists, NGO activists and government officials presented their papers. In March 2003, an MOU was signed between BES and ICUS, University of Tokyo.

Non-government Organization

CARE-Bangladesh is involved in the disaster related field of Bangladesh for the last thirty years. But only after the 2001 Gujarat Earthquake, it focused its attention in earthquake disaster. Some recent activities of CARE are: Circulation of pamphlets among the general masses on communities' role before, during and after an earthquake; development of seismic risk scenarios for different cities of Bangladesh; planning to circulate IAEE's manual for the seismic design of non-engineered construction in Bengali; arranging different earthquake sensitization seminars and workshops in different parts of Bangladesh.

Bangladesh Red Crescent Society (BDRCS) also arranged a seminar to discuss their role before, during and after an earthquake in line with MDMR's policy in September 2003. Similarly some NGOs and societies such as ActionAID, CARITAS, EPRC, FBAST, GJKS, JUUAB, SAFE and SDF organized seminars and workshops on earthquake risk mitigation in different cities of Bangladesh.

Other Organizations

Bangladesh Insurance Academy (BIA) conducted the first workshop on catastrophic risk management in 1998. The second workshop on similar topic was just held on November 2003.

Recently, BRAC University together with ADPC, Bangkok organized a two weeklong workshop on Earthquake Vulnerability Reduction in Cities (EVRC3).

Conscience for Existence, a student organization of BUET worked at the community level of one of the wards of Dhaka city (Ratan et al., 2003). Recently, the group organized an exhibition to share their experience of the survey carried out in the community level of the old Dhaka.

Department of Civil Engineering, Chittagong University of Engineering & Technology (CUET) established an Earthquake Research Centre in 2001. It started a joint research together with the University of Macedonia, Skopje. Under the agreement faculty members of CUET are regularly trained in Skopje.

Geohazards Research Group (GRG) of the Department of Geology of Dhaka University in cooperation with Lamont-Doherty Earth Laboratory of the University of Columbia, USA installed a broadband seismometer in Dhaka (Khan, 2003) and several GPS devices at some places of Bangladesh recently. The Department also got funding from Ministry of Science & Technology (MOST) to carry out research in the field of earthquake hazard assessment for 2003-2004. Recently, Dhaka University administration has started to assess the vulnerability of their existing buildings and halls to prioritize their retrofitting measures.

Institute of Engineers Bangladesh (IEB) organized several seminars on earthquakes. Currently it is offering some courses on earthquake resistant design together with Engineering Staff College, Bangladesh.

Institute of Diploma Engineers Bangladesh (IDEB) also offered several courses on earthquake vulnerability and seismic design of structures.

Real Estate and Housing Association of Bangladesh (REHAB) also conducted one seminar after the 2001 Bhuj Earthquake.

Department of Civil Engineering of SUST and BUET under the guidance of the first author is currently working to develop seismic microzonation map of Sylhet. Also building data survey for particular wards of Sylhet were carried out.

In 2002, UNDP submitted a Comprehensive Disaster Management Program (CDMP) proposal to the forum of donor agencies. It got donor communities approval in early 2003. The sub-program 4 (a)-ii of the PCP contains an urban risk research component on urban earthquakes. The objective is to facilitate an expansion of mitigating programs through initiating studies to obtain in-depth knowledge about the earthquake threat and related risks in the urban areas recommending mitigation measures for selected cities of Bangladesh.

Mass Media

Mass media such as newspapers and television networks played a vital role during the recent 2003 Rangamati Earthquake. They covered and broadcasted as much information as they could collect from the affected areas of Barkal, a remote hilly town. The journalists followed the different expert team who visited the earthquake-hit areas and published their findings in the National Dailies and showed live footage in the Television News. Currently newspapers have taken initiative to regularly publish news of earthquakes and interviews of local earthquake experts and their research activities, which will certainly enhance public awareness level.

Conclusions

Originally designed to be home to a million people before the country's independence in 1971, Dhaka has since grown into a chaotic megacity of 12 million. In addition, Dhaka is burdened with haphazard and unplanned development. Also, significant flood and earthquake risk exist for the City. Under Flood Action Plan, the Western part of the City has become free from flood risk; the Eastern part is still vulnerable to floods. Although there is no potential seismic source zone of major earthquake near Dhaka City, the occurrence of a similar earthquake of 1897 with intensity between VII to VIII in Dhaka may cause havoc for the City as well as the country itself. The recent actions undertaken by government and non-government organizations to reduce earthquake risks are praiseworthy.

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