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Seismic Vulnerability of Chittagong City and Some Mitigation Measures

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ABSTRACT: Recent repeated earthquakes in Chittagong region have generated a potential threat to the people of that locality. Chittagong is situated in a zone where a major earthquake may occur at any time. Its rapid urban growth is causing further deterioration and increasing the vulnerability of human lives, economy and infrastructures. If a large earthquake hit this city, it may cause heavy damage to its infrastructures and consequently the whole country may suffer. Hence, it is essential to develop an effective earthquake risk management plan, which requires long-term plan of action and involves multidisciplinary contribution. This paper tries to give some ideas about the potential threat and impact of hazards due to earthquake and the risks associated with it and thereby reduce the impacts through some relevant mitigation measures. It also focuses on the importance of organizational infrastructure that allows a good working partnership between academics, architectural and engineering practitioners, government regulators, financial institutions and social activists.

KEYWORDS: earthquake vulnerability, mitigation measures, risk management, urban growth

INTRODUCTION

Chittagong is the second largest city of Bangladesh. It is located in the southeastern part of the country and situated on the northern and western bank of the Karnaphuli River. It is also the country's largest port city, which contributes a lot in the economic development of the country. There are a number of divisional head quarters, important trade centers and commercial areas and many industries are located in this city. The country's biggest dam and hydropower plant in Kaptai is located not very far away from the city. But due to its geographical location, Chittagong city is located in a very disaster prone area. People of this area face different kinds of disasters like floods, cyclone and tornadoes at regular intervals. People are used to these kinds of hazards. Earthquake in Chittagong, even in Bangladesh has not yet been recognized as a serious natural disaster. So, people are not at all aware of it and also they are not prepared to face this hazard. Recent repeated earthquakes in greater Chittagong area (Ansary et al., 2001; Ansary and Sadek, 2006; Karim, 2003; Khan, 2003) have generated a potential threat and raised a great concern among the people of the country, especially among those around Chittagong region.

GEOLOGY OF THE AREA

Tectonically Chittagong occupies a part of western margin of Tripura-Chittagong Folded Belt (Alam et al, 1990). The trend of this folded belt is in the NNW-SSE direction, and folds are frequently dislocated or faulted (Matin et.al, 1983) longitudinally or transversely to the strike. Chittagong city is located in the plunging zone of the Sitakunda asymmetrical anticline (Muminullah, 1978). This anticline is stretched up to the Feni River from the city area. The axis of the fold is to the NNW-SSE direction, parallel to the general trend of regional strike, along the Chittagong-Dhaka Trunk Road.

The asymmetrical plunging anticline has steeper western flank and gently dipping eastern flank. The western flank merges abruptly into the alluvium due to a major fault parallel to the axis. The folded sediments are highly twisted and distorted in the plunge area around the city (Muminullah, 1978). There are major faults having evidence of vertical movements, and the minor faults having no evidence of vertical movement, but can be inferred from the lineament and orientation of the valleys. A regional fault in the west runs in the NNW-SSE direction, parallel to the strike fold and the Chittagong-Dhaka Trunk Road. This fault (Sitakunda fault) extends further south and cuts the hills around Marine Academy on the south-

ern bank of Karnaphuli River. Another fault, which runs parallel to Pass Road, is named as Tiger Pass fault. The Mio-Pliocene hills are elevated form the adjacent plains of fluvio-tidal complex due to this faulting. The trend of this fault is in the NW-SE direction and it cuts the regional fault in the west at an angle of 35^{0}. The other major fault named as Karnaphuli fault runs in the NW-SE direction, this fault has elevated the Marine Academy Hills from the adjacent Karnaphuli flood plains. The Karnaphuli River flows through a graben, restricted by the Tiger Pass fault and the Karnaphuli fault. Numerous lineaments and fractures have been developed across or parallel to the bedding plane during the development of the main faults.

The fluviotidal complex of the study area is formed of very recent non-cohesive, homogenous, saturated clayey silt and equi-granular fine sand deposited on Tertiary-Neocene bedrock. The engineering properties of the alluvial sequence indicate that the soil stratum has a very low unconfined compressive strength and moderately high liquid limit, a wide range of plasticity index and the ground water level is near the surface. The seismic properties of the vertical sedimentary sequence in the fluviotidal complex indicate that the soft alluvium may amplify some components of seismic energy (Helly et al., 1979).

SEISMICITY RECORDS OF CHITTAGONG

The study area is located in the Tripura-Chittagong Fold Belt (Alam et.al., 1990), where a thick sedimentary sequence deposited through Tertiary to Pleistocene age, which have been folded during the Himalayan orogenic movements (Krishnan, 1982). During this long geological time the area has experienced a varied environment due to the transgression and regression of sea. The area occupies most of the plunge area of Sitakunda Anticline and the plunge area is cut by Sitakunda fault, Tiger Pass fault and Karnaphuli fault. It is also observed that the older sediments are severely jointed and fractured indicating dissipation of accumulated energy. According to the Bangladesh national Building Code (1993), Chittagong City is located in Zone-2 with peak ground acceleration (PGA) value of 0.15g.

Chittagong has a long history of earthquakes. There are hundreds of evidences of earthquakes that jolted Chittagong and its surrounding areas. One of the largest earthquake in history occurred in 1762 at Arakan in the southern part of Chittagong division. Although the magnitude could not be recorded at that time but it caused heavy damages. It also triggered the earliest documented tsunami in the Bay of Bengal. Another big earthquake occurred in 1869 with a surface-wave magnitude of 7.5 at Cachar, Assam. This was also strongly felt in the whole Chittagong division. The 1912 Mandalay earthquake with a surface-wave magnitude of 7.9 was strongly felt in Chittagong. The 1950 Assam earthquake with a magnitude of 8.6 was also strongly felt in the city and its surrounding areas.

If we look at the recent time we find that since 1996 till to date, the Chittagong region, close to Myanmar border, has experienced more than 200 light and moderate earthquakes (Karmakar, 2003). The 1997 Jaintapur earthquake in the border of India and Bangladesh occurred with a magnitude of 5.6. It was felt mainly in Chittagong and also in Rangpur, Sylhet and Meghalya. In 21st November 1997, a magnitude 5.7 earthquake which occurred in the border of India and Bangladesh shook Chittagong city. This quake was felt throughout the country. But Chittagong had the most destructive effect. One five storied RCC building collapsed in this incident and 23 people were killed. On 22nd July, 1999 another earth-

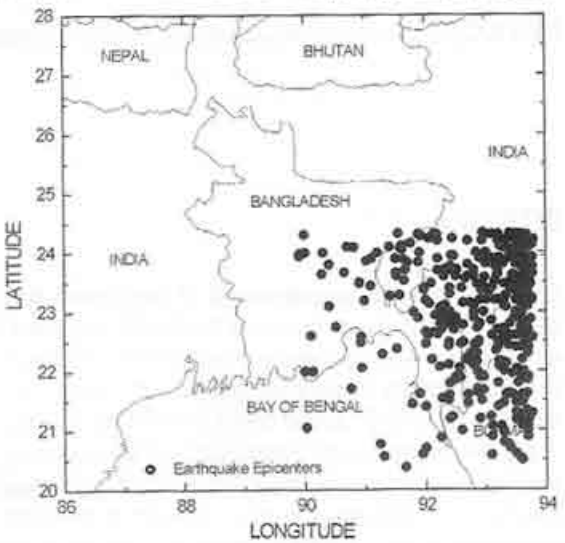


Figure 1: Earthquake epicentres within 200 km from

quake of magnitude 5.2 took place in Moheshkhali Island of Chittagong division. This quake was followed by few aftershocks and caused widespread damage in which at least six people were killed and more than five hundred were injured. Cracks were developed in the concrete structures of cyclone shelters and there was considerable damage of mud houses.

The recent earthquake that jolted Chittagong city and the adjoining hill districts occurred on 27th July, 2003. The magnitude of this earthquake was 5.6 (surface-wave magnitude). It's epicenter was at Kalabunia village of Barkal upazila of Rangamati district (Ansary and Sadek,

2006; Karim, 2003; Khan, 2003). Two people died and around three hundred people were injured. About 150 buildings including a school were damaged throughout the region, among them the Union Parishad building and the roof of a health complex collapsed. Five acres of land near Kalabunia village reportedly caved in. The shock was also strongly felt in the port city. During the quake power supply of some parts went out as a transformer exploded a sub-station at Madhunaghat, Chittagong. Cracks developed in several buildings, including Public Library, Chittagong Jail and Polytechnic Institute Building at Chittagong. Cracks also developed in buildings of Cox's Bazar, Moheshkhali, Kutubdia and Sonadia. Many mild aftershocks of different magnitude were felt in Barkal and Rangamati. Figure 1 show around 403 earthquakes which occurred within 200 km from Chittagong city for the last few hundred years.

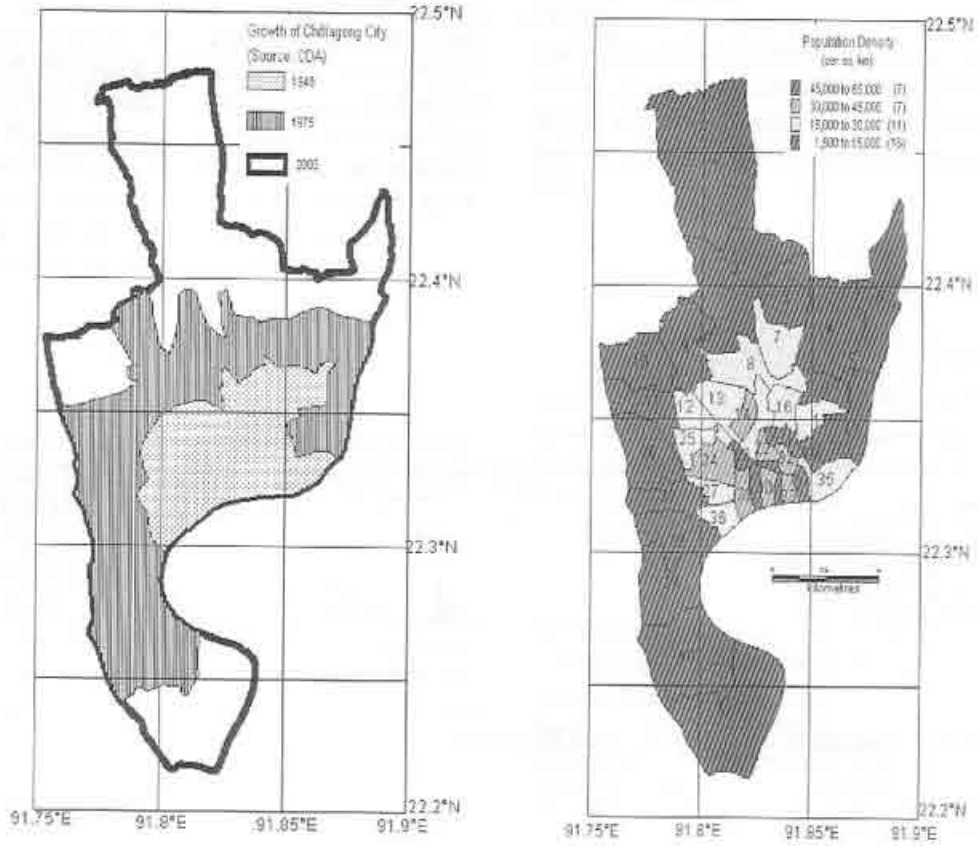


Figure 2: Growth of Chittagong city for the last few decades and population density

DEVELOPMENT TREND OF THE CITY

The risk associated with natural disasters is steadily increasing all over the world. But it is the urban center, which is more susceptible to natural hazard. Large-scale catastrophes from urban disasters have been graphically and tragically demonstrated in the recent years. In 1995 an earthquake in Kobe, Japan caused more than 6000 fatalities and over $US120 billion in economic losses. In 1999 an earthquake in Izmit, Turkey caused 20,000 fatalities and an estimated $20billion in economic loss. In 2001 an earthquake in Bhuj, India caused more than 16,000 casualties and in 2005, the Kashmir earthquake caused more than 80,000 casualties. Since cities are the main growth center in terms of population and economy, it is quite apparent that the losses will also be higher in cities than the rural areas. As Chittagong is the most important trade center for Bangladesh, the loss would be unimaginable if a large earthquake strikes this city. Figure 2 shows the growth of Chittagong for the last few decades and population density of the city. Failure to plan development in the poor and disaster prone country like Bangladesh will result in greater exposure to natural and manmade hazards for large number of people. Unplanned and rapid growths of its urban centers have made its cities the most vulnerable to potential earthquakes.

According to a census (BBS, 1991), 22% of the country's population is urban. The urban population has grown at a rate 4.67% per annum during 1981-91 (see Table 1). Although current trends indicate that urbanization is inevitable and unavoidable in the most developing countries, the rate of growth of the urban populations is too fast and exceeds the capacity of the infrastructure to absorb and support it. Chittagong is the second largest of our four metropolitan cities with a projected population of 2.4 million in the year 2011. Dhaka region emerged as the highest urbanized region since 1911 census. Chittagong region has been following Dhaka region since 1941. Significant upward growth trend of urban population was found in the regions of Chittagong as can be seen in Figure 3. Earlier less than 2 percent of the total population of Chittagong division lived in urban centers. But now more than 20% of the total populations of Chittagong division live in urban areas. The primary reasons for this fast growing trend of urbanization are largely attributed to the presence of seaport, divisional headquarters, industrial and commercial belts and educational institutions that attract people from different parts of the country for better employment, commerce and educational purposes.

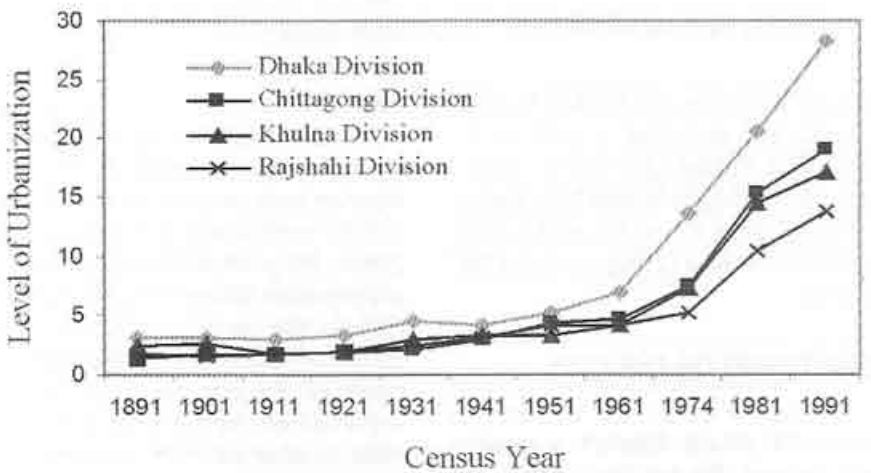
BUILDING INVENTORY OF CHITTAGONG CITY

Un-reinforced load-bearing wall type masonry buildings are most common in Chittagong and its surrounding areas. These are made of fired bricks with cement or lime mortar. They range from one to six storied. Roofing system of the buildings varies widely. Some of them have reinforced concrete roof, some have tiles or CI sheets and others have straw or bamboo. Masonry and reinforced concrete buildings don't have continuous lintel. Newer buildings are reinforced concrete (RC) frame structure types. RC frame structures are of various types. They generally consist of beam, column and slab. Some of them have columns and slabs but no beams. These

Table 1. Variations in the Level of Urbanization & National Share of Urban Population (1961-1991) of Chittagong Div
Source: *BBS, Urban Area Report, 1997*

Year	1961	1974	1981	1991
Total Population	10140	13876	16940	21865
Urban Population	569	1273	2994	4757
Level of Urbanization	5.61	9.17	17.67	21.76
National Share of Urban Population %	21.54	20.29	22.12	21.36

Figure 3: Trend of Urbanization in some major divisions of Bangladesh



frames are called flat plates. Flat plates are becoming popular day by day among the architects of Bangladesh, but this type of slab construction is not suitable for severe earthquake prone zone like Chittagong. There are also steel structure buildings, although little in number; they are mainly used for factory buildings. Wooden and bamboo made buildings are also there and these are safe against earthquakes. The numbers of houses using different kinds of roofs in Chittagong city are shown in Table 2.

Table 2. Number of houses with different roofing systems in Chittagong City
Source: *BBS, Community Series (Chittagong), 1992*

No. of Houses with Straw/ Bamboo roofs	*No. of Houses with Tiles/CI Sheet roofs*	*Total no. of Temporary houses*	*No. of Houses with Reinforced concrete roofs*	*Total no. of Houses*
75117	72445	147562	67357	214919
34.95	33.71	68.66	31.34	100%

The Chittagong city is in greater need for efficient and effective development planning and land use management as most of the city areas are unsuitable for development works. The best suitable zones around Station Road, Reazuddin Bazaar, Jubilee Road, Diwan Bazaar and Dampara areas are already occupied by unplanned dense settlements. Even before the last two decades people had the choice to stay around these places but presently the city is developing so fast that people have to move and live in the hazardous areas like Pachlais, Chandgaon, Agrabad, Nasirabad, Pahartali and Halishahar. Hilly areas are associated with landslide or mass movement and slope instability. Flat areas are hazardous because of low bearing capacity of soft soil deposit, which is very much susceptible to liquefaction. Besides this, some groups of people are involved in cutting of hills and construction of illegal houses. If there is a moderate tremor, it may cause massive landslides and those structures resting at the foothills will become simply death traps for the dwellers. But what Chittagong city makes most vulnerable against earthquake is the biggest unplanned development, haphazardly distributed throughout the whole city. Different land use categories are shown in Table 3. It is obvious that large unplanned residential areas, commercial and industrial areas and especially hilly areas are most vulnerable areas to earthquake. Architects, engineers and urban planners need to be cautious during finalizing a project location.

In Chittagong there are about 68.66% temporary houses (BBS, 1992). Most of these are safe against earthquake except those having roofs made of tiles. But the temporary houses are vulnerable against secondary hazard due to earthquake i.e. fire. Among the permanent houses masonry buildings more than two storied have greater possibilities to be damaged during an earthquake. The buildings without a continuous lintel are also vulnerable to earthquakes. Structural and architectural design of buildings requires special attention to be earthquake resistant.

Table 3. Different land use categories in Chittagong city
Source: *Land Use Survey, 1995*

Category of land use	*Land used (Acres)*	*Percentage*
Planned residential areas	1961.45	4.97
Unplanned residential areas	10378.62	26.29
Commercial areas	988.4	2.5
Industrial areas	3243.3	8.21
Cultivable land areas	10996.4	17.86
Hilly areas	5930.64	15.02
Tidal areas	2594.6	6.57
Unclassified areas	1899.7	4.81
Mixed areas	556	1.41
Other areas	926.65	2.35
Total	39475.75	100

A study on seismic vulnerability of buildings of five major cities of Bangladesh was recently conducted by the Department of Civil Engineering, BUET sponsored by CARE Bangladesh (Ansary and Choudhury, 2002). In this study the seismic damage prediction was made according to macro-seismic intensity scale. This assessment gives an idea of how many buildings are susceptible to earthquake hazard, the grade of damage they are to suffer and the number of possible injuries among the occupants of those buildings. Table 4 shows the seismic damage prediction of Chittagong city under earthquakes of different intensities. Figure 4 and 5 show distribution of buildings based on average of floor area and year of construction.

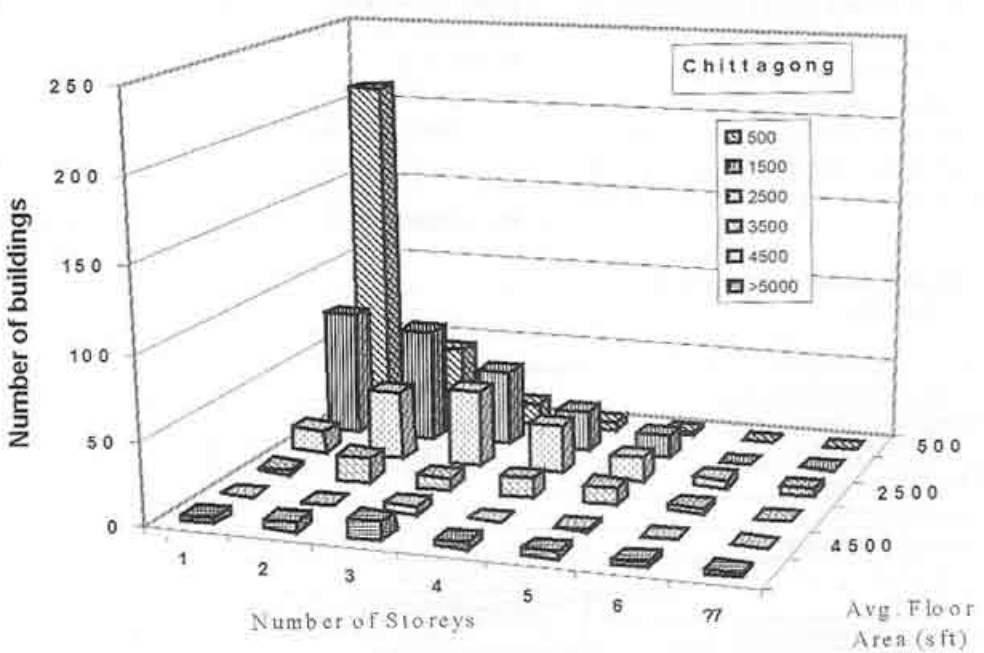
MITIGATION MEASURES TO REDUCE VULNERABILITY

The most cost effective actions to reduce the impact of earthquakes are those that reduce the vulnerabilities of cities. The solutions are mainly of two types: structural

Table 4. Vulnerability Assessment of Buildings of Chittagong of Bangladesh due to earthquakes of EMS intensities VI to X (after Ansary and Choudhury, 2002)

City	*Number of Buildings Surveyed*	*People living in those Buildings*	*Intensity*	*Intact*	*Slight Damage*	*Moderate Damage*	*Serious Damage*	*Partial Collapse*	*Collapse*	*% Affected Population*
Chittagong	756	27709	VI	300	380	76	0	0	0	61
			VII			79	1	0	0	62
			VIII			374	79	1	0	100
			IX				374	79	1	100
			X					374	79	100

Figure 4: Distribution of buildings based on average floor area and number of storeys



and nonstructural. The structural solutions include earthquake resistant design of new buildings, retrofitting existing vulnerable structures etc. The nonstructural solutions include incorporating risk considerations into urban planning processes, insurance coverage of existing structures, educating community etc. The structural solutions are elaborately discussed in a recently published earthquake resistant design manual (Ansary and Noor, 2006). This paper explains more elaborately on the different existing nonstructural solutions.

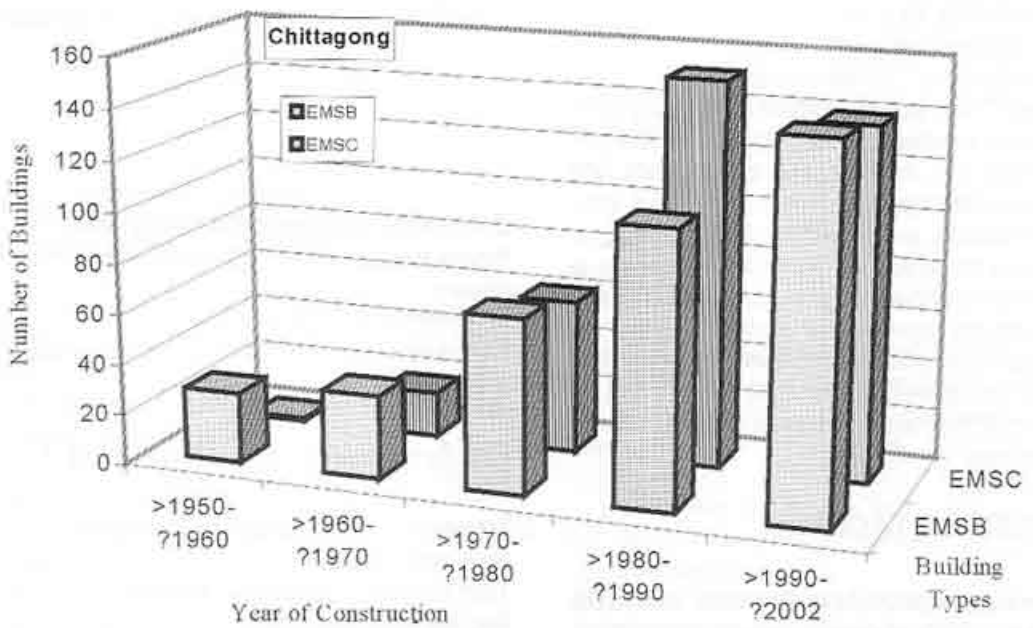
Despite making the cities prepare to respond to the emergency, the total impact of earthquakes is greatly dependent on the social, cultural and economic conditions of a community. It is not only a technical issue to be addressed by seismologists, architects and engineers; there are other aspects, which cannot be practically ignored. We need to focus on promoting preparedness and the inclusion of risk management in urban planning, raising public awareness of the existing risk and of affordable measures to reduce it, and incorporating the entire community in long-term risk management initiatives.

Public Education and Awareness

People can be educated about various hazards, its effects and mitigation measures through seminars, symposiums, and dramas. Some articles can be incorporated in primary level books to educate the children about earthquake and other hazards. Awareness to potential hazard and what to do if an adverse event occurs can help tremendously in responding to that event. Awareness program may be conducted in all the disaster prone areas through training to local people, women's group, sports club, elderly citizens, organizing interaction among the literate persons and supplying earthquake and fire safety tips and manual kits. School children program like debate, oratory, art and essay competition on the disaster-oriented themes may be organized to use children as the family motivators.

For the awareness program production of educational materials must be in local language, Bangla for the awareness program. Materials may be in the form of posters, leaflets, pamphlets, and booklets especially for the different target groups. The flow of updated information has to be maintained through the available local

Figure 5: Distribution of buildings based on year of construction



mass media like radio, television, newspapers and other publications. To encourage people to think, speak, write and work on disaster for the attitudinal change in society and institution building, incentives may be offered to the people of different level and organizations in the form of prizes, awards and seed money.

Building national capability in reducing risks it requires a clear plan for raising awareness and bottom-up approach to developing disaster management plans for all major urban centers of Bangladesh. Bangladesh Disaster Management Bureau, under the ministry of Relief and Disaster Management has gained sufficient knowledge and experience in flood, cyclone, tornado and draught. Now it has began its program to include earthquake in its program of disaster management. Bangladesh University of Engineering and Technology, Dhaka University, Bangladesh Earthquake Society and some international organization and NGOs are also working to increase awareness and promote earthquake disaster mitigation activities.

NGOs in Risk Management

Local non-governmental organizations (NGO) may play an important role in the reduction of earthquake risk in urban areas by complementing the work done by the local authorities. Since the long-term solutions of community problems should come from the government in the form of funding, regulations, and application of those regulations, it is indispensable to involve the government in risk management initiatives from the beginning to inform them about the problem and get their interest. But there are several shortcomings associated with working with the government. These problems include contradictory political and economic interests, conflicting priorities, and periodic changes. It is, therefore, vital to incorporate local non-governmental organizations to keep the focus, interest and motivation, and ensure that the process is not interrupted by the political and administrative changes. In most of the communities, the government has the means, authority and the organizational structure to implement risk management activities. However, the motivation, impartiality and continuity that an NGO could bring to the process should definitely speed up the work and increase its effectiveness.

RESPONSE AND RECOVERY

Government organizations have the primary roles in taking the responsibility of disaster and risk management. They have to make progress in improving their disaster response capabilities by institutionalize the application of disaster management in day-to-day operations of urban planning, construction monitoring and disaster preparedness. Pro-active actions of preparedness and mitigation are the only ways to reduce future losses. Moreover, discipline in the private and public institutions involved in risk management will reduce the volatility of losses, decrease the costs of operations and increase the efficiency and credibility of the organizations. It is important to share the experiences of mitigation, response and recovery processes that are followed in other earthquake affected countries such as Iran, Japan, Turkey and USA where they have well defined action plans against disasters. Sharing their strategies and risk management and considering the socio-economic condition of Bangladesh, the functions and responsibilities of respective governmental organizations and departments of Bangladesh (MoFDM, 2006) may be summarized as follows.

Disaster Management Bureau and Armed Forces Division

Prepare ward maps of all the localities of Chittagong Division for proper planning and regulations
Develop contingency plans
Prepare computer based geo-hazard maps
Set up emergency communications and early warning system
Operate 24 hours control room for emergency system
Develop Timely Warning Information System (TWIS)
Operate Disaster Service Management System (DSMS)

Health Services and BDRCS

Emergency response during earthquake
Prepare trained rescue squad for emergency
Control epidemiological outburst during disaster
Provide medical facility to emergency camps and relief shelters
Keep medical supplies ready
Provide training on First Aid Treatment to the local volunteer groups

Fire Service and Police Department

Prepare trained staffs for disaster emergency
Build rescue team
Train volunteers through Mock Exercise
Regulate hazardous materials
Manage required equipment and materials for emergency
Establish and protect temporary field hospitals

Provide security to the disaster affected areas
Take preventive measures against fire
Carry injured people for recovery treatment
Remove debris
Help distributing emergency supplies
Manage emergency service e.g. fire-brigade and ambulance

The City Corporation and Chittagong Development Authority

Enforce law and regulation for the implementation of earthquake safety measures in design and construction works
Adopt and enforce building codes for building design and construction
Use seismic information to prepare land use planning maps
Develop seismic zoning maps based on site amplification, liquefaction and landslides
Prepare inspection team for the construction works
Plan transportation and road networks for performing rescue operations speedily

Public Works Department

Retrofit the existing structures vulnerable to earthquake
Rehabilitate and reconstruct the damaged structures after disaster
Renovate public utility services like electricity, water supply, sewerage, telephone etc.
Demolish the hazardous structures

Besides these, it is also important to create a *Family Earthquake Plan* for home preparedness against earthquakes. This may include the followings.
Learn how to shut off gas, water, and electricity in case the lines are damaged
Check roofs, wall foundations for stability
Keep breakable and heavy objects on lower shelves
Put latches on cabinet doors to keep them closed during shaking
Know the safe spot in each room, (under sturdy tables, desks, or against inside walls)
Know the danger spots, (windows, mirrors, hanging objects, fireplaces and tall furniture)
Conduct practice drills e.g. physically placing children and themselves in safe place
Decide where the family members will reunite
Keep a list of emergency phone numbers
Develop a portable/auto survival kit

Safety Demand, Disaster Assistance, Insurance and Reinsurance

We have to change the culture of risk acceptance. It is very important to make the consumers aware of the earthquake threats so that they demand for safer housing. Economic consequences of any catastrophic event to the population depend on how the disaster assistance programs are formulated. Spread of risk through insurance and reinsurance can provide a community considerable relief in mitigating the economic disruption caused by the event. At the same time insurance company will compel the builders to build a safer house instead.

CONCLUSIONS

Recent repeated earthquakes have indicated that Chittagong and its surrounding hill districts are located at a moderately seismic zone. An earthquake of a larger magnitude (M>6.0) may attack this zone at any time. And if it does, it will pose greater threat to the urban centers of Chittagong. Especially the unplanned and hilly areas of the city will be affected heavily. Necessary steps should be immediately taken to face the seismic hazard in the area, especially at the port center. Seismic risks should be assessed correctly and subsequently mitigated to the extent feasible. Innovative and domestic disaster mitigation procedures should be adopted. Emphasis should be given for strengthening the most critical structures and lifeline facilities. A comprehensive disaster mitigation plan has to be developed and implemented as soon as possible. Political and institutional capacity needs to improve more than just the technical aspect. The effort will have to be multidisciplinary.

REFERENCES

Alam, M.K., Hasan, A.K.M., Khan, M.R. and Whitney, J.W. (1990). *Geological Map of Bangladesh*. Unpublished Report, Geological Survey of Bangladesh.

Ansary, M. A., Al-Hussaini, T. M., Sharfuddin, M. and Chaudhury, J. R., (2001). *1999 Moheskhali Earthquake: A Damage Study, Journal of Asiatic Society of Bangladesh (Science)*, No. 27(2), pp. 139-149, December, 2001.

Ansary, M.A. and Choudhury, J.R. (2002). *Seismic vulnerability of buildings of five major cities of Bangladesh.* BUET Research Report, Department of Civil Engg., BUET.

Ansary, M. A. and Sadek, A. (2006). *Assessment of 2003 Rangamati Earthquake, Bangladesh, 8th USNCEE*, held in April 18-21, 2006, San Francisco, USA.

Ansary, M.A. and Noor, M.A. [Editors] (2006). *Earthquake Resistant Design Manual*, APPL, Dhaka.

BBS (1997). *Bangladesh Population Census 1991*, Vol-3, (Urban Area Report), Dhaka: Statistics Division, Ministry of Planning, Govt. of Bangladesh, 1997.

BBS (1983). *Chittagong District Statistics*. Bureau of Statistics.

BBS (1991). *Statistical Year Book of Bangladesh*. Bangladesh Bureau of Statistics.

Helly, E.J., Lajoie, E.R., Spangle, W.E. and Blair, M.L. (1979). *Flatland Deposits of the San Francisco Bay Region, California-Their Geology and Engineering Properties and Their Importance to Comprehensive planning*. Geological Survey Professsional Paper 943, U.S. Covt. Printing Office, Washington, 1-88.

Karim, M.F. (2003). *Seismo-tectonic Evaluation of Barkal-Rangamati Earthquake, its Engineering Geological Significance and Some Disaster Management Strategies*. Seminar on 2003 Rangamati Earthquake, Dhaka, September 4, 2003.

Karmakar, S. (2003). *Trends in the frequency and magnitude of earthquake recorded at Chittagong and development of empirical formula for magnitude*. Seminar on Earthquake Monitoring and Loss Mitigation in Bangladesh, Dhaka, Bangladesh.

Khan, A.A. (2003). *Earthquake Scenario of Bangladesh in Reference to Kolabunia Earthquake of July 27, 2003-Vulnerability Assessment of Megacities*. Seminar on 2003 Rangamati Earthquake, Dhaka, September 4, 2003.

Krishnan, M.S. (1982). *Geology of India and Burma*. 6th Edn, CBS Publishers and Distributors, India.

Matin, M.A., Khan, M.A.M, Fariduddin, M., Boul, M.A., Hussain, M.M.T and Kononov, A.I. (1983). The Tectonic Map of Bangladesh-Past and Present. *Bangladesh Journal of Geology*, Vol. 2, 29-36.

MoFDM (2004). Standing Order on Earthquake Disasters, Ministry of Food and Disaster Mangement, January, 2004.

Muminullah, M. (1978). Geology of the Northern Part of Chittagong District Bangladesh. *Records of the Geological Survey of Bangladesh*, Vol. 11, Part 3, Dhaka, Govt. Press, 1-18.