Assessing the Seismic Vulnerability of Buildings and Residents of Uttara in Dhaka City Using RADIUS

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Introduction

Bangladesh is not free from any possibilities of severe earthquake. It is already divided into three earthquake zones of different intensities. Risk is high in those of urban areas having built environments rather than rural areas. Day by day, the urban areas are growing with multistoried buildings. 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. Some researchers suspected that if an earthquake with magnitude 6.5 occurs, about 60% buildings of Dhaka city will be demolished (The Daily Star, 2008). The earthquake risk at any location depends on the seismic hazard as well as the vulnerability of its structures. The seismic hazard evaluation considers the likelihood of earthquake of a particular magnitude or intensity affecting a site, and the evaluation of seismic risk in any city requires proper consideration of the strength of likely earthquakes in future. The seismic hazard for Bangladesh has recently been quantified (Sharfuddin, 2001). The seismic vulnerability, on the other hand, depends on the construction practice in the city and is related to quality of building stock (Islam, 2005). Vulnerability is defined as the degree of loss to a given element or set of elements resulting from the occurrence of a natural disaster (Marfai and Njagih, n.a). For a densely populated city like Dhaka, the condition is more at risk as the buildings of the capital are constructed following the local practices and are not much resistant to a strong natural hazard. Moreover, small to medium intensity earthquake shook the capital several times in this year. Uttara is primarily a residential suburb, and is divided into several "sectors". The residents are generally from an (upper & higher-middle-class) or middle-class background, who favor its distance from the congestion and pollution of Dhaka city. Indeed, well into the 1990s, Uttara retained its quiet, leafy suburban character. In recent years, with the increasing influx of people moving in from the city, Uttara has evolved into a bustling town, similar to other areas of Dhaka such as Gulshan or Dhanmondi (BBS, 2006). Though earthquake activity is characterized by small to medium intensity but the reports of great historic earthquakes and the recent frequency of seismic occurrences indicate that it is necessary to address the seismic risks of buildings especially in Dhaka. This paper aims to assess the vulnerability of buildings and population using RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters). This tool was designed to promote worldwide activities for the reduction of urban seismic risks mainly in the developing countries. Thus, the final outcome of this paper will point toward the applicability of RADIUS as a tool for seismic risk assessment.

Major Earthquakes Affecting Bangladesh

The major earthquakes that affected Bangladesh and adjoining areas of South Asian countries (Source: Alam, 2003) are listed below:

- 2nd April 1762 – Near Chambal (Southern Chittagong Division).
- 30th June 1868 – Near Sylhet, (Northern Chittagong Division).

- 10th January 1869 – Cachar Earthquake (Dhaka Division), Bangladesh.
- 14th July, 1885 – Near Dhaka (Dhaka Division).
- 12th June 1897– The Great Indian Earthquake, the epicenter was at 230 km from Dhaka.
- 8th July, 1918 – Near Kishoregonj (Northern Dhaka Division)
- 9th September 1923 – West of Durgapur, Dhaka Division.
- 2nd July 1930 – Dhubri Earthquake, the epicenter was at 250 kms from Dhaka City.
- 15th January 1934 – Bihar-Nepal Earthquake, the epicenter was at 510 kms from Dhaka City.
- 24th December 1944 – Near Sylhet (Northern Chittagong Division).
- 19th May 1945 – Near Mohanganj, Dhaka-Chittagong Division border.
- 10th December 1949 – North of Saidpur (Rajshahi Division).
- 15th August 1950 – Assam Earthquake. The epicenter was at 780 kms from Dhaka City.
- 24th December 1950 – Near Baniyachung (Northern Chittagong Division).
- 12th June 1956 –Near Netrakona (Northern Dhaka Division).
- 21st June 1963 –Near Netrakona (Northern Dhaka Division).
- 12th May 1977 – Bangladesh-Myanmar border (Chittagong Division).
- 6th February 1988 –Near Sylhet (Northern Chittagong Division).
- 12th June 1989 – Bay of Bengal, Khulna Division.
- 8th May 1997 – Indo-Bangladesh border region(Chittagong Division).
- 21st November 1997 – Southern Mizoram, India, often called as Bandarban Earthquake, 22.21N, 92.7E. In Chittagong, a five-storied building collapsed.23 people were killed and another 200 were injured in Chittagong.
- 22nd July, 1999 –Maheshkhali Island (Chittagong Division).
- 31st December 1999 – Kutubdia Island (Chittagong Division).
- 19th December, 2001 –Dhaka Area (Dhaka Division).
- 27th July, 2003-Rangamati (Chittagong Hill Tracts).

Table1: Significant seismic sources and maximum likely earthquake magnitude in Bangladesh

Location	Maximum Likely Earthquake
Assam Fault	8.0
Tripura Fault Zone	7.0
Sub-Dauki Fault Zone	7.3
Bogra Fault Zone	7.0

Source: Bolt, 1987

Objectives of the Research

The main objective of the research is to assess the building vulnerability for seismic risks and estimate the population casualty using RADIUS software.

Methodology

For accomplishing comprehensive seismic vulnerability assessment of buildings and population of Uttara, Geographical Information System (GIS) provides a perfect environment for research. GIS has the capability to store, manipulate, analyze and display the large amount of required spatial and tabular data. This paper aims to assess the vulnerability of buildings and population casualty using GIS and RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters) software. This tool was designed to promote worldwide activities for the reduction of urban seismic risks mainly in the developing countries. Most of the existing risk management techniques and methodologies have been designed in developed countries and, as such, cannot be transferred directly to developing countries. This methodology has been developed through actual projects in such cities as Quito, Ecuador, and Kathmandu, Nepal. The major parameters for this study are:

- Ground condition (Soil type)
- Shape of the target region by meshes
- Mesh weight
- Total buildings, building types and their distribution
- Total Population and distribution
- Choice of scenario earthquake and its parameters
- Number of storey

The schematic diagram of RADIUS methodology is given in the figure below:

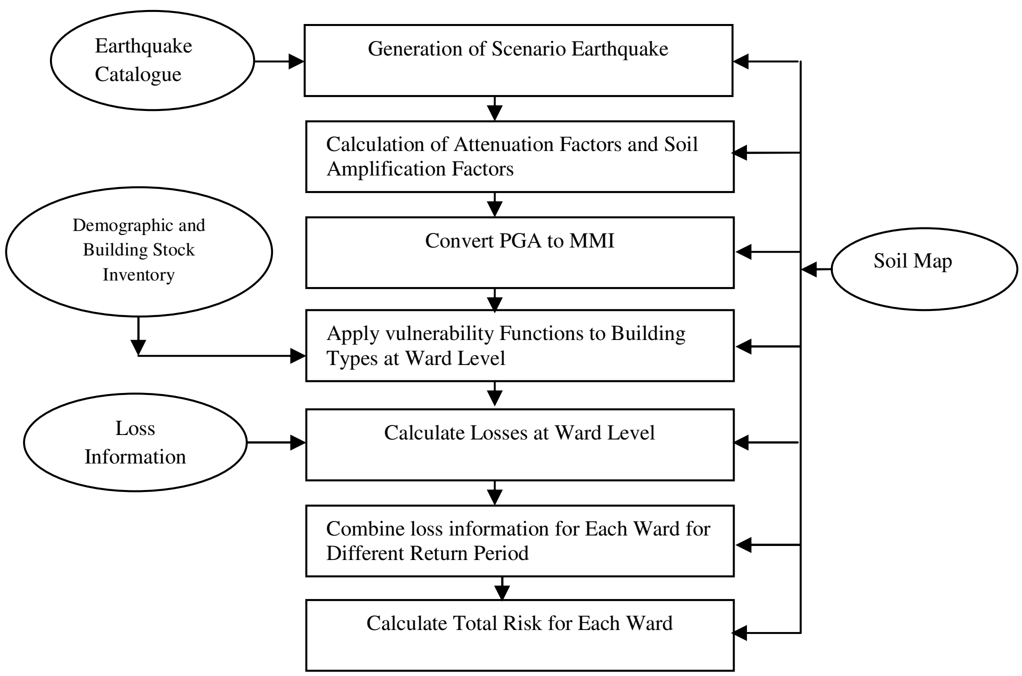


Fig. 1: RADIUS Methodology for Building Loss Estimation (Brijesh, 2004)

Figure 1 shows the flow chart of Radius methodology. This methodology divides the building class into 10 categories based on their material type, construction type, seismic code, occupancy type and number of stories (Villacis and Cardona, 1999). This classification is based on the common building type in Latin American cities. The number of each type of building in each mesh is estimated by density of buildings with a weight called "Mesh weight".

Building Damage Estimation

Physical vulnerability is defined as the degree of loss to a given element or set of elements at risk resulting from the occurrence of natural phenomenon of a given magnitude. Earthquake vulnerability of a building is defined as the amount of expected damage induced to it by a particular level of earthquake intensity (UNDP, 2004). Vulnerability is a function of magnitude of an event and the type of elements at risk. There are different types of vulnerabilities, such as physical, social and economic. Especially the social vulnerability like population changes is constant through time. It can be in the form of urban expansion or change in population (Van Westen, 2001). For example in a seismic event, the vulnerability derived from the magnitude of earthquake and the elements, which are at risk. These elements define weight of vulnerability. The more elements are at risk, the higher will be the vulnerability. Both qualitative and quantitative assessment of vulnerability of buildings can be performed. The vulnerability assessment is to identify the vulnerable conditions of buildings that are exposed to natural hazards. It describes as the probability of failure of a structure under different levels of ground shaking. Vulnerability is calculated on the basis of acceleration or MMI based on a damage observed during a historical earthquake (Brijesh, 2004).

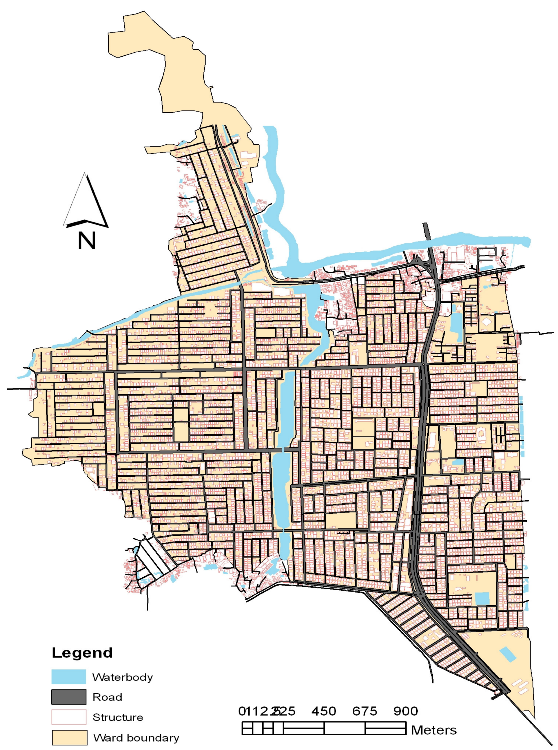


Fig. 2: Map of the study area.

The Study area is situated in ward 1 of Dhaka city and consists of about 9839 buildings. Each building consists of a specific or multiple uses but the dominant one is the residential use. The soil type is soft throughout the ward and mesh weight ranges from very high to low calculated on the basis of percentage of residential buildings in each mesh. The total population of the ward is 345097 according to BBS, 2001. The study area contains informal constructions and multistoried buildings too. So, there exist several building classes according to floor size and use. The study area is filled with a good number of educational and commercial structures. For estimating the damage of buildings of the study area, the area is divided into some grids commonly known as mesh in RADIUS. Uttara is partitioned into 35 meshes which cover the study area and size of the each mesh is 0.5 sq. km. For building damage estimation, the Kobe earthquake (1995) is selected as scenario earthquake. It occurred in Japan with an intensity of 7.2 in the Richter scale. All the buildings are classified according to the RADIUS classification. The RADIUS classification is shown in Table 2.

Table 2: RADIUS classification for building classes

Explanation of Building Classes	
RES1---	Informal construction - mainly slums, row housing etc. made from unfired bricks, mud mortar, loosely tied walls and roofs.
RES2---	URM-RC composite construction - sub-standard construction, not complying with the local code provisions. Height up to 3 stories. URM is Un-Reinforced Masonry and RC is Reinforced Concrete building
RES3---	URM-RC composite construction - old, deteriorated construction, not complying with the latest code provisions. Height 4 - 6 stories.
RES4---	Engineered RC construction - newly constructed multi-storied buildings, for residential and commercial purposes.
EDU1---	School buildings, up to 2 stories. usually percentage should be very small
EDU2---	School buildings, greater than 2 stories usually percentage should be very small
MED1---	Low to medium rise hospitals and institutions usually percentage should be very small
MED2---	High rise hospitals and institutions usually percentage should be very small
COM----	Shopping Centers
IND -----	Industrial facilities, both low and high risk

The buildings of Uttara were selected from each mesh and the data from attribute table was used to categorize the structures according to RADIUS classification. There was no category of institutions or service centers so that percent is included in the MED1 and MED2 classes. The classification was first done using the options of 'Select by attributes' in GIS. Then the data prepared was given as input to the building inventory of RADIUS.

Radius Environment for Earthquake Analysis

A scenario earthquake is a prime requisite in case of building and population vulnerability analysis using RADIUS. This is chosen either from any historical earthquake or defined by the user. Table 3 shows the experience of an earthquake in Japan.

Table 3: Scenario for building damage analysis.

Fault Location	Epicentral Distance (in Km)	Richter Scale Magnitude	Time	Year
Kobe earthquake, Japan	1	7.2	5:46	1995

For RADIUS analysis, total study area is organized into 0.5 sq.km. grids and the buildings are classified according to the building classification suggested for RADIUS analysis. Besides, it is very important to ensure the proper shape of the study area by generating mesh and redefining mesh areas. Before this step of data preparation, GIS is used to prepare the base map containing mesh regions which can be used for RADIUS technique. Then from the grids obtained, the arbitrary mesh setup of RADIUS is redefined. Figure 3 shows the shape of a mesh area.

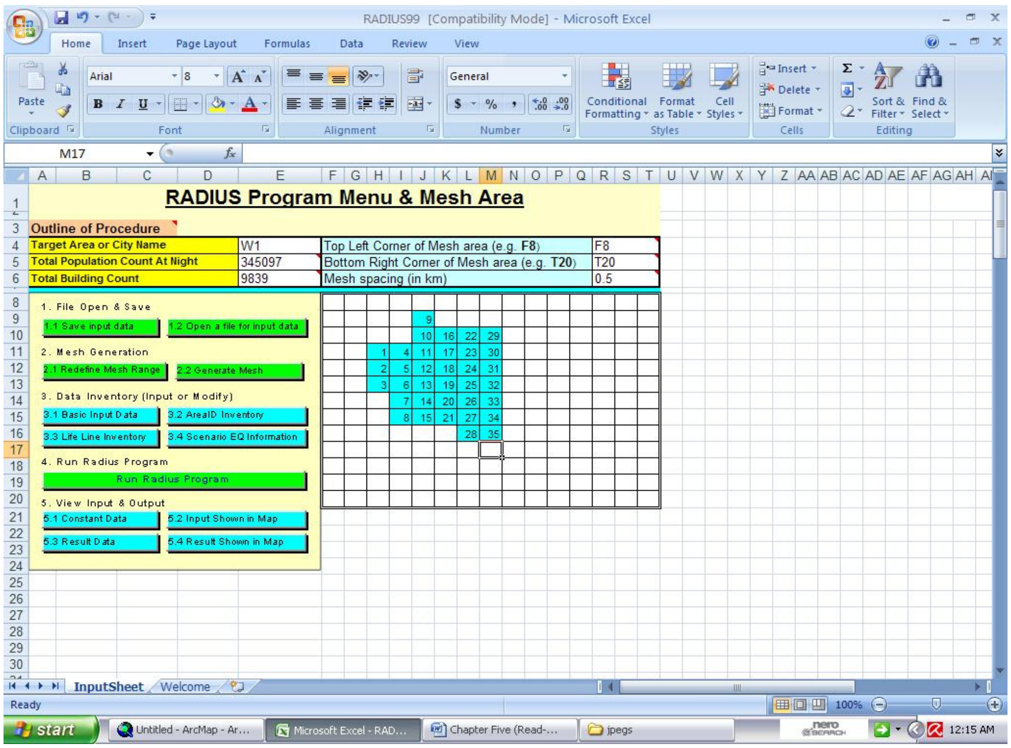


Fig. 3: RADIUS interface

For analysis in RADIUS, the total area for vulnerability analysis is divided into mesh areas like A3, A4, A5, B4, C5 etc. The base map is divided into grids in GIS and the shape of the target area is redefined by generating new mesh in the RADIUS interface. The building count, damage and casualties are shown in the output for mesh regions separately.

In the data preparation stage, mesh ID, area names, mesh weights, and local soil type was checked and used for developing the database of the basic input data. After that in the area inventory, 10 separate classes of buildings for every mesh were given as input. But before that step for convenience in calculations, ArcGIS platform has been used to count the building classes from the attribute data of the buildings of Uttara prepared by DAP. The building density in different meshes is indicated in the map below:

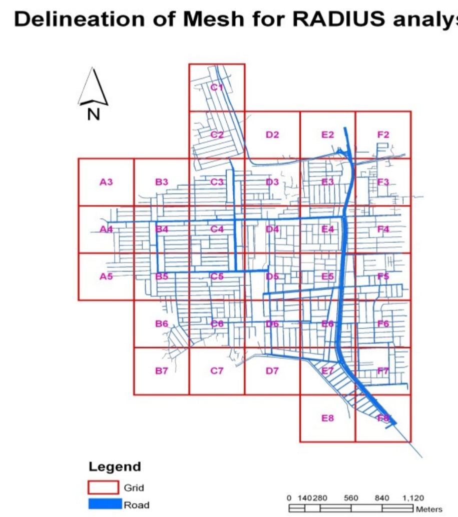


Fig. 4: Partitioned meshes in GIS environment

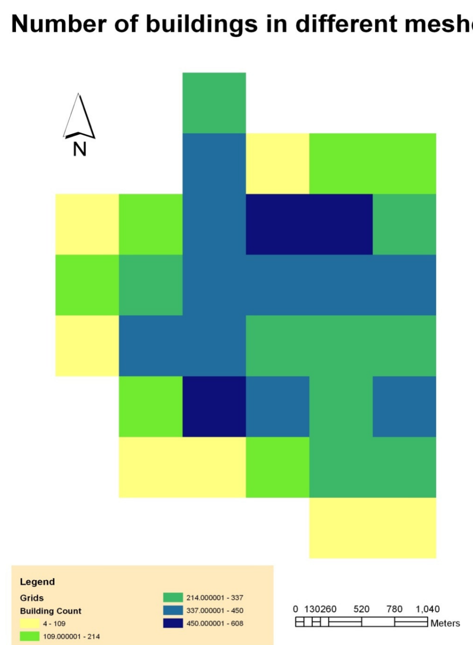


Fig. 5: Density of buildings at different places of Uttara

As Uttara is a planned residential area, no mesh was found devoid of a single residential structure. Thus, there was no mesh having no weight or 0 values and the distribution started from low weight to very high weight as per density of residential buildings. The mesh distribution map represents that the grids A3, B5, B6, B7, C1, C2, D4 and E8 has the highest density of residential buildings and it is greater than 90% of the total buildings. 42.86% of the area is calculated as high density residential area which means that 80% or more buildings are residential in it. 31.43% area has average density of residential structures and a single mesh was found having low density.

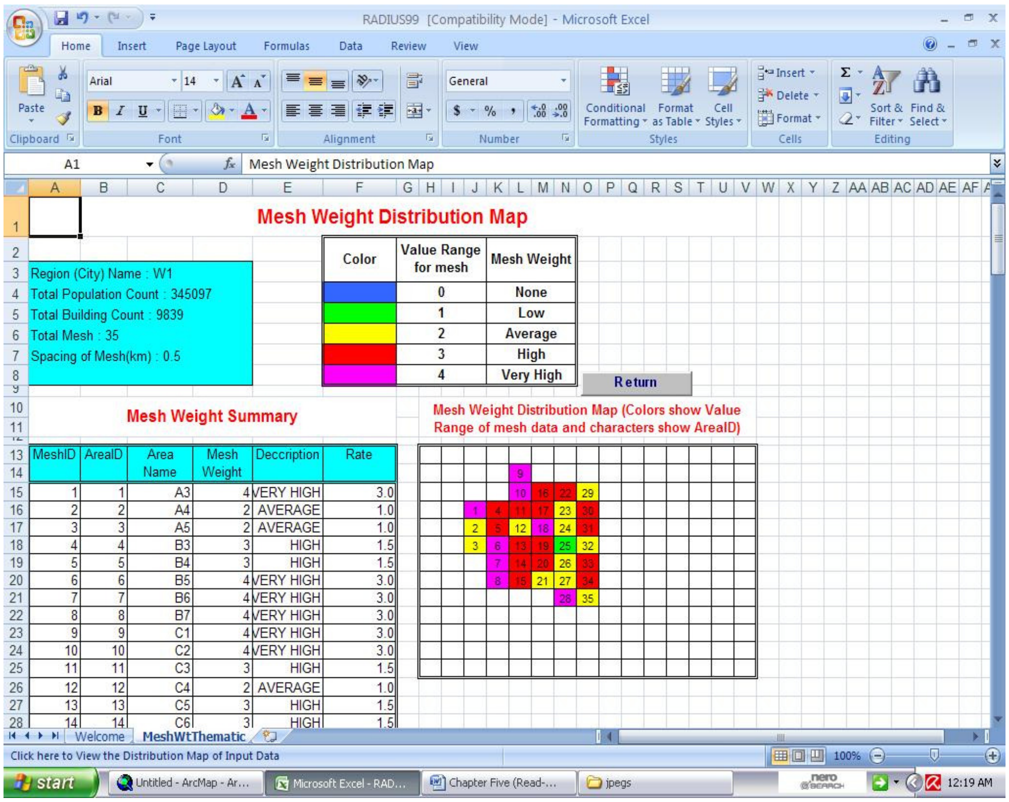


Fig. 6: Window of RADIUS showing the mesh weight distribution

After fulfilling the data requisite for analysis in RADIUS, the program was run and the results obtained are the inputs shown in map for soil type, mesh weight, Building counts, Day population and night population. Moreover, the main results are presented in a tabular form in the excel sheet and the results of MMI, Damaged buildings, Ratio of damaged buildings and Casualties (Death and Injury) are presented using thematic maps.

It was found that out of a total of 9839 buildings, about 6214 buildings will be partially or fully damaged if the intensity is 7.2 in Richter scale. That is, 63.2% buildings of the total number will be damaged and vulnerable to a seismic hazard with parameters similar to Kobe earthquake. Building damage is greatly influenced by the soil quality (Ranjan, 2005). Due to this fact, in many cases the one-storey buildings are damaged to a greater extent than the tall structures.

The four residential classes along with the other classes of buildings are damaged different proportion. The highest building damage was found in the class Res1 which is above 45% and it was followed by Res3 which has 30.41% of its structures damaged. About 14.5% of the buildings of Res2 category are found vulnerable in this scenario of earthquake. The rest of the classes like EDU1, MED1, COM, IND etc. are present in small number in the ward and for this reason the damage percentage is also small ranging from 0.2% to 2.36%. The mesh A3 has the highest number of buildings damaged which is 286 out of 394. On the other hand, 72.3% coverage of the 35 meshes will have more than 60% of its buildings damaged. In general, if an earthquake similar to scenario earthquake hits the study area, then the damage scenario will be like this and no single mesh would be found where there will be building damage of less than 50% of the total.

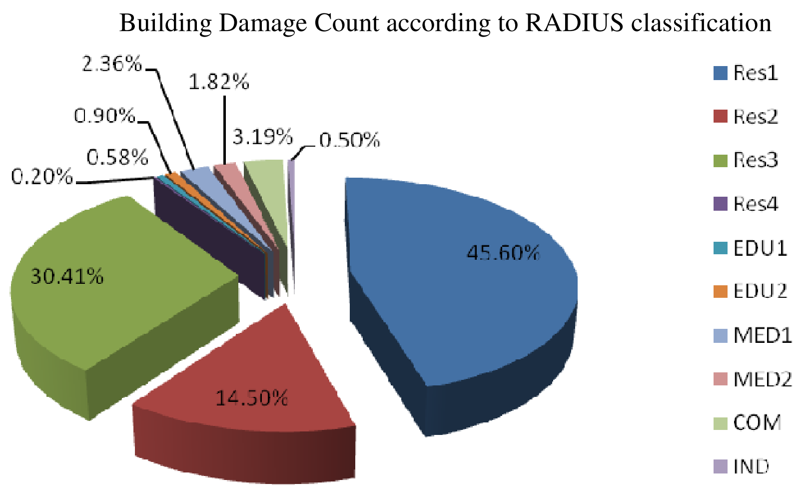
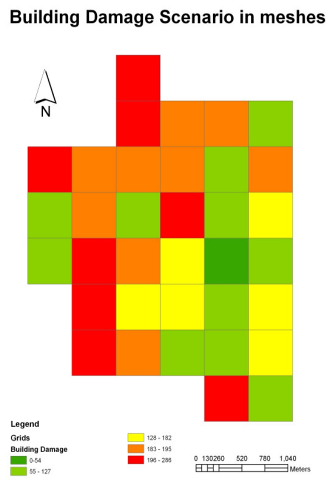


Fig. 7: Building Damage according to building classes

This indicates the vulnerability of Uttara in case of any moderate or severe earthquake. It is estimated that more than half of the total structures will be damaged and lead to a severe consequence of casualty which increases proportionally with the damage. Figures 8 and 9 show the damage scenario in case of an earthquake.



F 8: Number of Buildings damaged in each meshes

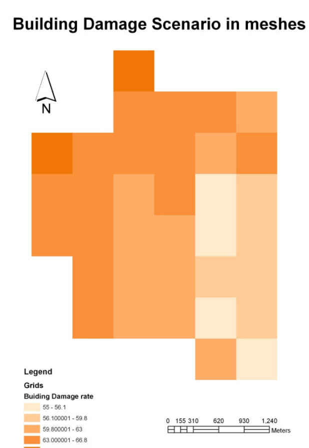


Fig. 9: Building Damage Ratio

The building damage ratio is defined as the percent of number of damaged buildings to the existing total number of buildings. Here, the damage ratio is categorized into 5 divisions and symbolized with light to dark shades of color. The lowest ratio is 55 and the highest ratio is 72.5. In this building damage ratio, the class wise ratio of damage like the MDR of Res1, EDU1, COM etc are displayed in the tables of the result sheet.

The population distribution is uneven everywhere and it varies largely with the day and night timings. This is mainly because during daytime, people from residential areas commute to work in other places within or outside the city. Again, there are some people who are involved in wage earning activities within the residential area and come from other places, where house rent and other expenses is comparatively low. Thus, because of this temporary displacement of population, the population count is conducted at two times within the 24 hour duration. The total population at day time was found to be 353994 and the total population at night is 345,097. Some meshes indicate that there is an increase in population during day and some meshes have decreased population at night. Figures 10 and 11 show the population during the day and night.

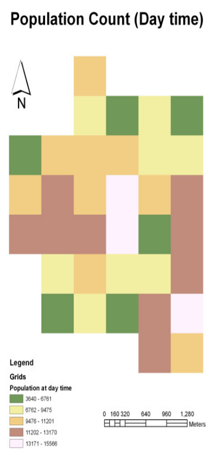


Fig. 10: Population during day

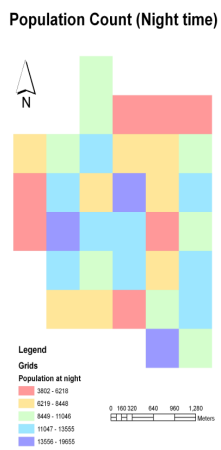


Fig. 11: Population during night

For the analysis of population casualty distribution in every mesh, same scenario of earthquake is used. The scenario earthquake was set up with day time parameter and the combined results of death and injuries in the study area are described with the graph (Figure 12). Here, the highest number of injuries is found in the grids B5, D4 and E8. The rest of the meshes have injuries from 1000 to 5000. The grids B5, D4 and E8 have 63.9%, 65.4% and 62.1% of their buildings damaged so the relationship of structural damage and population casualty is again proved but with a new technique RADIUS. Again, the death count is proportionally higher in the grids A3, B5, B6, D4 and E8, where the building damage is high too as per previous discussion.

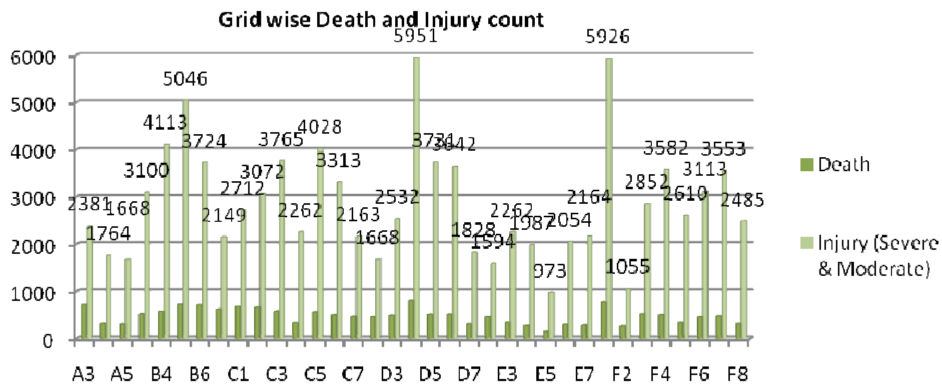


Fig. 12: Population Casualty Graph

A total of 16788 people are vulnerable to death and 100823 may be injured if any seismic hazard similar to the scenario earthquake chosen for this study strikes Uttara. Figure 13 shows the number of severely and moderately injured people in each mesh when the earthquake intensity is 7.2.

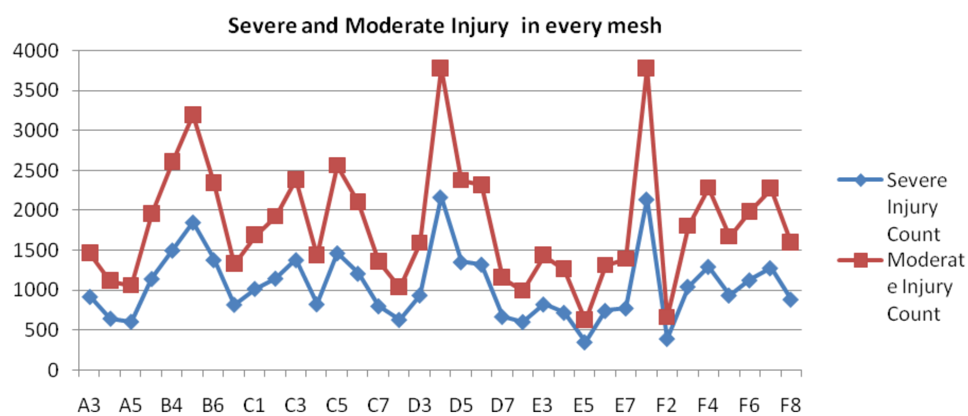
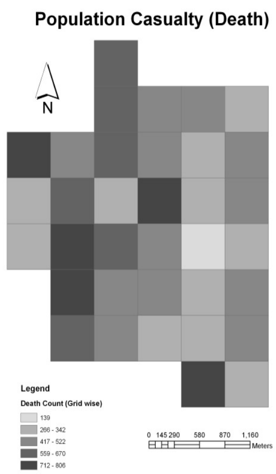


Fig. 13: Comparison between severe and moderate injury

From Figure 13, a relationship between severe and moderate injuries can be established which can be stated as the number of injuries in both the cases increase and decrease proportionally. This can be verified by the pattern of the two lines in Figures 14 and 15. The two lines are identical and the mesh for sever injuries are less, the moderate injuries are less too and vice versa. The percent of population casualty in total is 34.1 which is more or less half of the damage of buildings that may be faced if the situation matches with the scenario earthquake. So the population vulnerability is related with the building vulnerability in the study area.



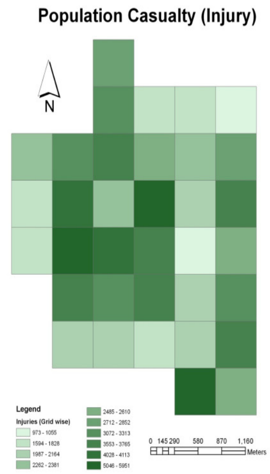
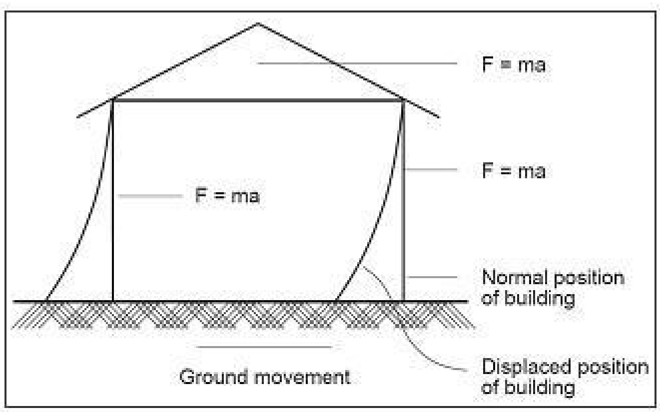


Fig. 14: Population casualty (Death) Fig. 15: Estimated population injuries

Discussion

The primary effect of an earthquake is the shaking of buildings and infrastructure and the buildings are shaken in all possible directions during an earthquake (Brijesh, 2006). Thus, the building joints are loosened and it leads to subsequent damage or collapse. Since earthquakes are ground movements (which, in effect cause the ground to move under a building), the forces that occur in a building come from inertia of its own mass (IAEE, 1986). Hence, heavy buildings have more inertia force i.e., seismic load on the building. But, there other factor which lead to small informal settlement to be damaged more than the heavy structures. Figure 16 shows the failure mechanism of buildings.



Source: (IAEE, 1986)

Fig. 16: Failure mechanism of Building.

Dhaka City Corporation has literally no protection mechanism against a strong earthquake. Preparation for seismic hazard mitigation should be started from the root level (ward). Clarification of the role of community in disaster prevention efforts, such as first aid, evacuation and information collection and dissemination is also a prime requisite. The Dhaka City Corporation must have enough capacity for emergency response, such as supply of food, water, medicine, tools for preliminary rescue operations and electricity-supplying generators and designated evacuation routes and sites. For undertaking immediate actions by both national and local governments, the factors to be considered are:

- Government recognition of the earthquake management;
- Education and information for the citizens; and
- Accumulation of research and development works.

Disaster management plans is required to be formulated from the ward level under the guidance of National Disaster Management Committee so that emergency response and disaster prevention is covered. Utilization of the community resources along with the relevant organizations has to be such that it supports the rescue activities to the fullest extent. In order to protect life and property of the local people in times of an earthquake, all disaster-related organizations from national to community levels should take measures at full efforts. Community people have to be organized and mobilized on voluntary basis to assist Community Authority and Local Health Personnel. Establishment of Mass Casualty Management (MCM) system as a part of systematic response Casualties which should consist of four vital elements: community-based response activity, Advance Medical Posts (AMPs) at sites, Hospital care and Transportation. Recommendation and instruction of evacuation shall be made by NDMC, District Municipality and Fire Fighting Department. Staffs should be allocated for the operation and maintenance of the evacuation place. Building construction rules and proper setback should be maintained for building construction. DCC is responsible for running the emergency operation during an earthquake incident and ensuring dissemination of authentic information to mass media. Besides, it should undertake urban crisis planning *(evacuation areas, pre-positioning of essential elements for response & recovery)***.** DMB should function on coordination mechanism at national level under various disaster management committees.

At the same time, individual local resident has to get a concept of self-protection, obtain enough knowledge of earthquake, accumulate training, learn counter measures of disaster by experience and implement these activities at home, in the community and workplaces, etc. Community level organizations should be developed with the local individuals and authorities involved for disaster preparedness and emergency response. In order to get a more detailed and realistic damage map, the depreciation factor applied to buildings should also be applied to contents since some could be highly depreciated. When assessing damage due to seismic hazards of higher than 9 on Mercalli scale, the cost of the content should be taken into consideration. Efforts should be made to collect detailed information about the buildings within Dhaka, Sylhet and Chittagong cities. Then using RADIUS methodology, results of hypothetical seismic actions can be developed and GIS can be used for handling spatial data and presenting the damage scenarios. The disaster database can provide a strong platform in preparedness actions as seismic events are very much accidental.

The outcomes from RADIUS analysis in this paper can be summed up as the structural damage is proportion to the population casualty of Uttara (2:1) which resembles the opinion of Brijesh (2004), where he stated a relation exists between structural damage and population casualty. Ground condition is highly responsible for building damage and that’s why the Res 1 class is the most vulnerable structure class in the study area though it contains a significant percent of high rise apartments.

The probable building damage is 63.2% using RADIUS and according to Ministry of Food and Disaster Management in its National Earthquake Contingency Plan stated that, almost 40% of the buildings of Dhaka city will be damaged if an earthquake of 7.5 magnitude hits the city (MoFDM, 2009).

Conclusion

For urban planning, risk assessment related to different types of hazards with time is very important. In this exercise, vulnerability to seismic hazards was assessed based on different building categories and previous earthquake scenario. From the results, several conclusions are arrived at: Particular attention to the topography and soil condition is very important in order to generate a valid and detailed seismic vulnerability or hazard map. Building cost is an important factor in building damage assessment as it results in subsequent economic loss. GIS technology represented a great advantage in this study, especially for damage calculation, vulnerability analysis and presentation of the final results obtained from RADIUS.

RADIUS methodology was designed to prepare action plans to reduce seismic risks of urban areas. So, the task of preparing action plans and addressing the seismic risks in future have become simple. According to Brijesh 2004, "RADIUS method gives preliminary loss estimation of earthquake. This method is very simple and it uses the common building types for building classifications. Therefore, it is very easy to implement this methodology in developing countries. The drawback of this methodology is that it is not possible to identify the vulnerable area. The methodology only gives the result in the form of percentage of building damage. The quantification of damage is also not possible by using this methodology. This methodology does not consider the complex structural aspect of the building vulnerability." There is no such software developed to address the conditions of the developing countries. In Bangladesh, absence of detailed database and suitable program is a hindrance for proper assessment of risks and vulnerability due to a hazard. So, new programs should be designed for analysis of hazards in this subcontinent which can provide more detailed output of risk assessment. An economic impact study can be conducted to assess the potential and social loss due to an earthquake. The outcome should indicate whether structural upgradation of relevant structures is required. Besides, development of a national index can help to increase preparedness.

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