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Earthquake and Physical Vulnerability Assessment of Existing Buildngs in Urban Areas

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Abstract

Earthquakes is difficult to deal with because of it's multiple impacts on human lives. It has a major ability to degrade an urban physical structure with geological components. The objective of this thesis is to assess the seismic vulnerability including building's physical conditions so that earthquake-prone buildings can be identified and plans to increase awareness among the users can be easily organized. In order to fulfil the objective, seismic vulnerability of Reinforced Cement Concrete (RCC) structures has been evaluated in the study area using the Turkish method as proposed by the Turkey government and the Japan International Cooperation Agency (JICA). 240 different reinforced concrete residential buildings were assessed using a checklist. The physical fragility was estimated by an on-site assessment to calculate the Earthquake Risk Score (E.R.S) value of each building. The survey findings were examined by SPSS software with factor analysis. The results revealed that only ten out of 240 structures were considered as high risk, whereas 84 structures were of moderate risk. It is proposed that more methodical evaluations were suggested for such structures before confirming the building as earthquake risk.

Keywords: Earthquake, Dhaka, Vulnerability, Assessment, Turkish method

INTRODUCTION

Earthquakes are natural catastrophe under which disasters are mainly caused by demolition or collapse of man-made structure and which can be violent enough to kill thousands of people. It is one kind of applied force which is affected directly to the building as whole partially and indirectly. Earthquake destruction depends on many variables such as intensity, vibration period, the strength and speed of the energy, frequency, geological and soil condition, construction system etc. It is estimated that 500, 000 or so detectable earthquakes that occur worldwide each year, more than 150,000 temblors strong enough to be felt by humans and about 700 shocks have this capability to cause damage when centred in a populated area [1].

For example, Haiti (North America) was struck with an earthquake of 7.0M magnitude on January10, 2010, rendering around 1.5 million people homeless and killing more than 230,000 people [2]. These numbers were far more than the causalities caused by the earthquake of same magnitude in San Francisco,1989 (63 died and 3,757 injured) [3]. The reasons beyond such surprising difference were densely distribution of buildings. Most of the buildings did not built according to the standards and those were destroyable in the grip of a strong earthquake. In this study, a vulnerability assessment process has been categorized for earthquake hazard in densely populated residential areas. The proposed evaluation model mainly focused on structural condition of houses. The proposed methodology has been implemented for Dhaka, which is one of the metropolitans of Bangladesh. The analysis results can be used in an urban community for earthquake awareness and mitigation process.

AIM OF THE STUDY

The cause, effect and possibility of earthquakes in Dhaka city were investigated in this research. This research also examined the current earthquake risk of three wards, among 91 wards in Dhaka and increased the understanding of the natural hazards by analyzing the previous documents of the city and a visual examination of buildings.

Objectives

- To classify the causes and effects that best describe for mass destruction during earthquake.
- To recognize the earthquake risk in densely populated residential area of Dhaka city.
- To identify appropriate methods of seismic vulnerability assessment.

Background of the Study

What is an Earthquake?

An Earthquake is the series of vibrations caused by the seismic waves which is spread out from fracture (known as active fault in the Earth's crust) in a rapid movements,. When some form of stored energy is suddenly release in the earth crust it causes seismic waves [4], usually when masses of rock push into each other or pull apart suddenly fracture and slip.

From the fault location, different types of waves and velocities travel different paths in all direction before reaching a building's site and exposing the local ground to various motions [5]. In various cases, additional shocks may occur before or after the earthquake. The magnitude and intensity of a shaking is determined by various scales, like Richter scale, the moment magnitude scale and the modified Mercalli scale.

Causes of earthquake

Four parts of the earth are: the internal core, outer core, mantle and crust (*Fig. 1*). A thin layer on the ground of the earth is made by the crust and top of the mantle. The layer is split into tectonic plates covering the surface of the earth. These plates moves and slide each other smoothly. The plate boundaries are made up of many faults and these faults are the result of most earthquakes worldwide. The edges of the plate are rough and they held each other while the other plate continues to move. Finally, when the plate is shifted far enough, the edges unstick on one of the faults and an earthquake occurs [6].

Effects of Earthquake

It is important to recognize that the structural damage can result from various seismic impacts in a comprehensive design strategy. The effects of earthquakes include the following;

Ground Shaking: Earthquakes primarily damage homes and other rigid constructions to more or less severe effects. The severity of regional effects depends on the size of the earthquake, the distance from the epicenter and the geological conditions of the area. All the structures on the surface react in different degrees to this vibration when earth shakes.

Landslides: Landslides and serious storms can create a significant geological hazard, leading to slope instability.

Soil Liquefaction: Soil liquefaction occurs if water steeped with granular material (for example sand) shortly loses its power because of the ground shaking and becomes liquid from solid. Soil liquefaction could lead the buildings to sink into softened deposits [7].

Fires: The damage to electric power or gas line can lead to fires during earthquakes. In case of a rupture of water supply and pressure loss, the spread of a fire after it is began can also be hard to prevent.

Tsunamis: Tsunamis also known as a seismic sea waves are generally produced when destructive plate boundaries abruptly move and overlying water vertically displaced. Tsunamis have a tiny offshore amplitude and a very lengthy wavelength, which typically swells slightly above the ocean surface and can travel at speeds of more than 700 km per hour [8].

Human Impacts: Earthquakes may result in illness, absence of essential necessities, loss of life, damage to general properties, destabilization of road, bridge and other essential infrastructure and therefore with serious potential of affecting any rescue activities.

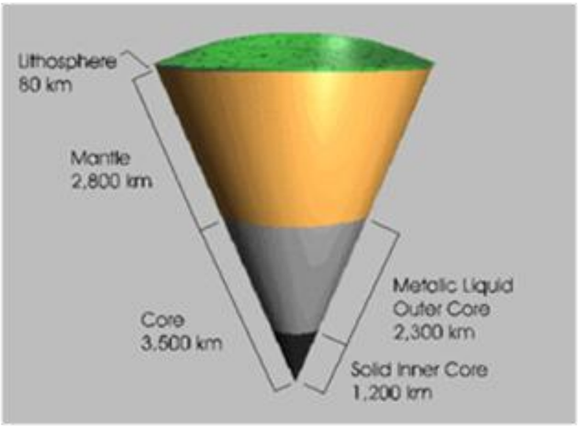


Figure 1: Four Major Layers of Earth *(18)*

Effects of Earthquake Vulnerability in Densely Populated Residential Areas (Bangladesh)

Bangladesh is tectonically located at the intersection of three tectonic plates (*Fig. 2*) -the Indian plate, the Eurasian plate and the Burmese micro plate [9].

The Indian plate moves 6 cm / year in the north-east direction and sub ducting under the Eurasian plate (45 mm / year) and the Burmese plate (35 mm / year) in the north and east respectively [10]. Due to the geotechnical setup, major cities of Bangladesh including Dhaka are very susceptible to an earthquake.

There are active regional faults that can cause moderate to large earthquakes in and around Bangladesh. Table 1 presents five active tectonics blocks with maximum magnitudes of earthquake in Bangladesh.

Figure 2: Tectonic Structure of Bangladesh *(16)*

Table 1: Magnitude Level in Tectonic Blocks [11]

No.	Table Tectonic block	Maximum magnitue
1.	Bogra fault zone	7.0
2.	Tripura fault zone	7.0
3.	Assam fault zone	8.5
4.	Shilong plateau	7.0
5.	Sub Dauki fault zone	7.0

Earthquake Threats in Urban Area of Bangladesh (Dhaka City)

Dhaka is the most susceptible city of the world in earthquake, followed by Tehran according to a research of the United Nation in 1999 ([12]. Dhaka includes into zone II of the seismic zoning map where the seismic faults are 50 to 500 km away from this city [6].

UNDP 2009 research indicates that there were over 7.2 million individuals in the Dhaka City Corporation where an average of 61,000 individuals lived in per square kilometer. The Commission found that the number of the buildings in the capital at that time was about 325,000, of which half were at least 30 years old [13] and also about 90% buildings in the capital were non-engineered [12]. In Dhaka, 70-80% of concrete constructions will collapse and 30.00 000 people will die if a 7-8 degree Richter scale earthquake occurs [14].

Factors of Earthquake Vulnarability

Risk assessment studies that consider the threat of earthquakes are mainly based on building physical vulnerability. According to a German earthquake expert Dr.-Ing. Dorka, the Turkish seismic risk assessment method may apply to a developing country such as Bangladesh, in which standard building codes are not followed properly [15]. This study focuses on a level 1 Turkish seismic risk assessment procedure for low to medium rise RCC (Reinforced Cement Concrete) buildings in different areas of Dhaka city. The buildings are ranked into four categories as ‘no risk’, ‘low’, ‘moderate’ and “high risk”.

Study Area

The study areas are ward no.60, 51 and 46 of Dhaka City Corporation located along the Buriganga River in central Bangladesh between latitude 23.7104-N and longitudes 90.40744-E [16]. As of 2016, the population in Dhaka and its neighbouring region was 18 million, with an approximate population of about 8.5 million in the town itself, covering a total area of 306.4 sq. Kilometers [17]. Among the 91 wards, the ward no. 46 (Mohammadpur area), 51 (Kalabagan area) and 60 (Old town) were chosen as the examination territory (*Fig. 3*).

METHODOLOGY

The Walkdown Assessment Procedure

The walkdown assessment procedure (Turkish method) consists of recording the building’s various exterior features.

Figure 3: Location Map of Study Area in Dhaka City *(9)*

The building features followed by Albayrak et al. [18], considered for the level 1 seismic risk assessment survey, are described below:

Building age

Number of stories (1 to 9)

Presence of soft stories (Yes/No)

Presence of short column (Yes/No)

Presence of heavey overhang (Yes/No)

Pounding between adjacent buildings (Yes/No)

Topographic effect (Yes/No)

Visual construction quality (Good/Moderate/Poor)

Local soil condition (Stiff/Soft)

The Bangladesh National Building code, prepared in 1993, recognizes these facts and places Dhaka in a moderate seismic zone with zone coefficient (Z) of 0.15. The expected intensity of the earthquake in Dhaka city is around VIII (Modified Mercalli Intensity Scale), which can be assumed to correspond to a peak ground acceleration (PGA) of 0.2 g to 0.25 g. According to the seismic zoning map of building code (1993), the PGA is approximately 0.15 g on very firm soil for Dhaka city (Zone II), considering site effects it can be 0.20g or more. Corresponding peak ground velocity (PGV) can be taken as between 40cm/sec to 50 cm/sec [19]. Base score values are categorized into six individual cases according to storey number and PGV values presented in Table 2. According to Table 3, if E.R.S. < 30 than High Risk, 30 < E.R.S < 70 than Moderate Risk, 70 < E.R.S < 100 than Low Risk and E.R.S.>100 are classified in the No Risk group [18].

Earthquake Risk Score (E.R.S) can be calculated by Equation (1).

E.R.S = Base Score (B.S.) + ∑ [Score Reduction Value (S.R.V) x Vulnerability Parameter Multiply (V.P.M)] (1)

Table 2: **Base Scores and Vulnerability Scores of Risk Factors [18]**

Risk Factors						
Number of storey	**Base score (B.S)**		**Soft storey ***	**Heavy overhang ***	**Short column ***	**Pounding effect ***
1-2-3	**130**	**Score Reduction Value (S.R.V)**	**-5**	**-5**	**-5**	**0**
4-5	**120**		**-10**	**-10**	**-5**	**-2**
6	**110**		**-15**	**-15**	**-5**	**-3**
7	**100**		**-20**	**-15**	**-10**	**-5**
8 or more	**90**		**-25**	**-20**	**-10**	**-5**

Risk Factors							
Number of storey	**Topographic effect ***	**Visual construction quality ****	**Age of building**				
			Construction year				
			2007-	**2000-2006**	**1997-1999**	**1976-1996**	**-1975**
1-2-3	**0**	**-5**	**0**	**0**	**-3**	**-5**	**-10**
4-5	**0**	**-5**	**0**	**0**	**-10**	**-15**	**-15**
6	**0**	**-10**	**0**	**0**	**-15**	**-20**	**-25**
7	**-2**	**-10**	**0**	**-3**	**-20**	**-25**	**-30**
8-9	**-2**	**-15**	**0**	**-3**	**-25**	**-30**	**-35**

* V.P.M = 1 if the risk factor exists; otherwise 0.

** V.P.M = 2 if the visual construction quality is "poor", V.P.M=1 if it is "moderate", V.P.M=0 for "good" condition

Table 3: **Earthquake Risk Score (E.R.S) [18]**

	Earthquake Risk Score			
	E.R.S.<30	*30<E.R.S.<70*	*70<E.R.S.<100*	*100<E.R.S.*
Risk status	High	Moderate	Low	No risk

Survey Data Collection and Analysis

Building samples from three selected wards were surveyed by walk down procedure with a checklist form to collect all the information needed for analysis and results. In order to determine the conveniences of the proposed risk assessment method, a total of 240 sample houses in Dhaka city have been performed. Necessary secondary data were collected from Dhaka city corporation. Once the required data collected, the existing dataset was tabulated for analysis in SPSS and Microsoft excel to formulate the input.

RESULTS AND DISCUSSION

Vulnerability Factors

Overall, 240 concrete structures are evaluated for building age, building storey, soft story, short column, heavy overhangs, pounding effects and the visual quality of structures presented in Table 4 and 5, in the chosen area of Dhaka city. Soft storey (77%) is important as a factor of vulnerability in the study region. It was also shown in the assessment that good and poor construction conditions are around 36% and 10% respectively (Fig. 4). On the other side, the chosen structures contain 162 heavy overhang structures. In this study, short column and pounding effect are the smallest amount of structures discovered out of all considered vulnerability variables.

Table 4: Earthquake Risk – Number of Buildings with Age and Storey

Ward No.	**Building Age**					
	10<Years		***11-20 Years***	***21-30 Years***	***>30 Years***	***Total***
60	33		35	12	0	80
51	24		35	16	5	80
46	21		39	19	1	80
Total	78		109	47	6	240
%	32.5%		45.42%	19.58%	2.5%	100%
Ward No.	**Story Number**					
	1-2-3 Story	***4-5 Story***	***6 Story***	***7 Story***	***8+ Story***	***Total***
60	4	34	28	14	0	80
51	4	29	28	10	9	80
46	2	38	35	4	1	80
Total	10	101	91	28	10	240
%	4.17%	42.08%	37.92%	11.66%	4.17%	100%

Table 5: Earthquake Risk – Number of Buildings with Vulnerable Parameters

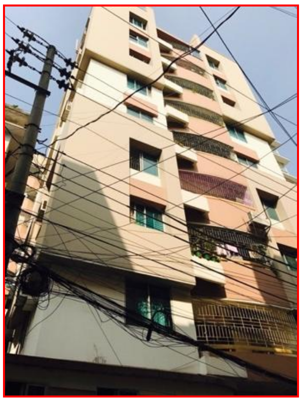
Ward No.	**Soft Storey**		**Short Column**		**Heavy Overhang**		**Pounding Effect**	
	Yes	***No***	***Yes***	***No***	***Yes***	***No***	***Yes***	***No***
60	59	21	18	62	57	23	47	33
51	62	18	8	72	59	21	31	49
46	63	17	3	77	46	34	55	25
Total	184	56	29	211	162	78	133	107
%	76.67%	23.33%	12.08%	87.92%	67.5%	32.5%	55.42%	44.58%

Ward No.	Visual Construction Quality		
	Good	***Moderate***	***Poor***
60	20	52	8
51	31	39	10
46	35	40	5
Total	86	131	23
%	35.83%	54.58%	9.58%

Earthquake Risk Score (E.R.S)

After finalizing the survey, total 240 representative residential buildings of selected wards were analyzed using Turkish method.

Case Study 1: The Following 9 stories R.C. building is shown in *"Fig. 5"* for determining the Earthquake risk score.



A sample building in the selected area of Dhaka city *(Site survey: December 2016)*

Table 6: Calculation of Earthquake Risk Score

Variables	**House No. 01**	
	Status	***Score***
Storey number	9	90
Building age	12	-3
Soft storey	Yes	-25
Heavy overhang	Yes	-20
Short column	No	0
Pounding effect	No	0
Visual construction quality	Good	-15
Result	Moderate risk	42

E.R.S = Base Score (B.S.) +∑ [Score Reduction Value (S.R.V) x Vulnerability Parameter Multiply (V.P.M)] (1)

=90 + ∑ [(-3) +(-25x1) +(-20x1) +0+0 +(-15x0)]

= 90 + (-48)

= 42 (Moderate Risk)

In Table 7, the result shows that 146 buildings out of 240 (61%) are classified as 'no Risk' to 'low risk' while only ten (4%) buildings are scored less than 30 which fall under 'high risk'. About 35% of buildings are in 'moderate risk' zone which may also require further investigation. Thus, ward no.51 has maximum number of high risk buildings where ward no.46 has highest number of 'no to low risk' buildings.

Table 7: Earthquake Risk- Number of Buildings

Ward No.	**Earthquake Risk Score**			
	E.R.S.<30 ***High***	***30<E.R.S.<70*** ***Moderate***	***70<E.R.S.<100*** ***Low***	***100<E.R.S.*** ***No risk***
60	4	24	43	9
51	5	39	29	7
46	1	21	47	11
Total	10	84	119	27
%	4%	35%	50%	11%

CONCLUSIONS

There is not an similarly susceptible earthquake in the infrastructure of various fields. In order to determine structures susceptible and prepare plans for renovation, the vulnerability of structures has been evaluated. To fulfil the objective of this research, the building's vulnerability has been evaluated to identify the vulnerable buildings to proposed restoration technique to the building users. The findings indicate that only ten buildings out of 240 are considered as high risk, compared to 84 buildings with moderate risk, so further methodical evaluations for such constructions are proposed before the danger of the earthquake is verified. While not each of the susceptible building can be abandoned, potential structures should be constructed according to land use planning and a strict building code, to mitigate the earthquake vulnerability of the region. These works should be helpful in particular for planning capital investments before catastrophes.

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