1st Croatian Conference on Earthquake Engineering
1CroCEE
22-24 March 2021 Zagreb, Croatia

DOI: https://doi.org/10.5592/CO/1CroCEE.2021.199

Evaluating earthquake vulnerability using Analytical Hierarchy Process (AHP) and social appraisal of retrofitting in Lalmatia, Dhaka

Tanzila Aktar Shawon[1], Akter Mahmud[2], Mohammad Mizanur Rahman[3], Michio Ubaura[4], Masudur Rashied[5]

[1] *Postgraduate Research Student*, Department of Urban and Regional Planning, Jahangirnagar University, Bangladesh, *shawonurp17ju44@gmail.com*

[2] *Professor*, Department of Urban and Regional Planning, Jahangirnagar University, Bangladesh, *aktermahmud@yahoo.com*

[3] *Assistant Professor*, Department of Urban and Regional Planning, Jahangirnagar University, Bangladesh, *mizanurp@gmail.com*

[4] *Professor*, Department of Architecture and Building Science, Tohoku University, Japan, *ubaura@tohoku.ac.jp*

[5] *Junior Research Consultant* (URP), SATREPS-TSUIB Project, Housing and Building Research Institute (HBRI), Bangladesh, *masudurrashied@outlook.com*

Abstract

Bangladesh is one of the most earthquake vulnerable countries in the world. As Bangladesh is located near to the boundary of two active plates (Indian plate in the west and Eurasian plate in the east and north) the country has invariably been under threat of an earthquake that may be so harmful that may kill people to less than a moment. With the frequency of earthquakes on the increase, it is natural for people to be scared as specialists consider them to be warning of what lies ahead. Vulnerability of Lalmatia against earthquakes is stressed using Analytical Hierarchy Process (AHP) and multi-criterion analysis in this study. The APH allows decision-makers to model a complex problem in a hierarchical structure showing the relationship of the goal, objectives (criteria), sub-objectives, and alternatives. In this method six affecting factors against earthquake vulnerability in five subcategories has been considered as like as construction year, population, road width, building use, area of parcel and building vulnerability. The Analytical Hierarchical Process (AHP) model is also applying for determining the weight and priority of the vulnerability factors contribution to the lives of individuals. This research finally reveals some buildings that are "very high" vulnerable and refers to detail assessment for first step plan and some buildings are "high" vulnerable and also refers to detail assessment in the second step plan. Rest of the buildings are considered less vulnerable for the screening process. The retrofitting of structural components is conducted for not only an individual component or groups of components. The good performance of the entire structural system must be ensured. Retrofitting strategy is determined based on the results of technical assessment. The indicators and model of this study has contributed in the vulnerability assessment as well as initiate mitigation efforts against earthquake of Dhaka city.

Key words: Analytical Hierarchy process (AHP), assessment, earthquake, retrofit, social appraisal, vulnerability

1 Introduction

Bangladesh is vulnerable to earthquake because of the existence of several fault lines and tectonic plate boundaries [1]. Previous experience of earthquake and rapid urbanization, high population growth rate, high density and development of economic arrangements increasing the vulnerability for earthquake [1]. Dhaka, the capital city of Bangladesh with estimated population in 2020 of roughly 2.1 million [2] and a population density of 44,500 people/km^2 [2], resulting in significant pressures in city. With high density this megacity continues to expand with extremely ill planned and increasing earthquake vulnerability. The infrastructures and the life safety in Dhaka against seismic hazard are now a burning concern as the Earthquake Disaster Risk Index has placed Dhaka among the 20 most vulnerable cities in the world [3].

Dhaka is developing fast and without proper guidance, we may see more cases like the June 1, 2010 Begunbari building collapse, where buildings are constructed on marshy land or during an earthquake where soil liquefaction may devastate the city [4]. The meteorological department of Bangladesh University of Engineering and Technology (BUET) detected at least 90 earthquakes taking place in the country between May 2007 and July 2008, nine of them above five on the Richter scale and epicenters of 95 percent being within a 600 km radius of Dhaka city [5]. CDMP [6, 7, 8] assessed earthquake risk assessment of Dhaka city for earthquake of 7.5 Mw magnitude generating from Madhupur fault. According to the assessment, out of total 3,26,000 buildings, approximately 270,604 buildings will be at least moderately damaged which comprises over 89 % of total building stock. Besides 238,164 buildings will be damaged beyond repair. Around 260,788 and 182,450 people will die respectively for an earthquake taking place at 2:00 AM and 2:00 PM. Around 1,527,668 people will be displaced aftermaths an earthquake [6, 7, 8].

A survey was conducted by Asian Disaster Preparedness Center (ADPC) [9] between Feb 2008 and Aug 2009 under the governments Comprehensive Disaster Management Program (CDMP). A survey said, some 1, 30,000 people could be killed right away if an earthquake of 7.5 magnitude, originating from the Madhupur blind fault, strikes capital Dhaka in the daytime. A quake measuring 8 Richter scale from the plate boundary fault-2, close to Chittagong, will kill around 69,900 people in the capital in the daytime, while 13,600 will need hospitalization, and 61288 first aid [10]. So, Bangladesh and capital city are highly vulnerable to earthquake and considering these views in mind, the study was conducted to find out the existing building's earthquake vulnerability in Lalmatia and also to know the people's perception about the willingness of building owner to retrofit the existing buildings.

2 Aim and objectives

The main aim of this research is to assess the earthquake vulnerability, and the willingness to pay by the landowner to retrofit the existing buildings of Lalmatia area, Dhaka city. The following objectives have been taken to implement this aim:
- To assess the earthquake vulnerability in the existing buildings.
- To investigate the willingness of building owner to retrofit the existing buildings.

3 Survey parameters

The parameters that are selected in Level-1 survey for representing building vulnerability are the following:
- General Information: Type of building, Number of stories, Year of construction, Number of occupants, Maintenance record.
- Presence of a Soft Story: Yes or No
- Presence of Heavy Overhangs: Yes or No
- Apparent Building Quality: Good, Moderate or Poor
- Pounding Between Adjacent Buildings: Yes or No
- Presence of a Short Columns: Yes or No

4 The Analytical Hierarchy Process

The APH allows decision-makers to model a complex problem in a hierarchical structure showing the relationship of the goal, objectives (criteria), sub-objectives, and alternatives. Uncertainties and other influencing factors can also be included. It is not only supporting decision makers by enabling them to structure complexity and exercise judgement, but also allows them to incorporate both objective and subjective considerations in the decision process [11]. Applying the APH procedure involves three basic steps:
- Decomposition, or the hierarchy construction;
- Comparative judgements or defining and executing data collection to obtain pair wise comparison data on elements of the hierarchical structure; and
- Synthesis of priorities, or constructing an overall priority rating [12].

AHP can provide an analytical process that is able to combine and consolidate the evaluations of the alternatives and criteria by either an individual or group involved in the decision-making task [13]. Vulnerability of Lalmatia against earthquake stressed using Analytical Hierarchy Process and multi-criterion analysis in this study is followed. As indicated in table 1 six parameters were selected to do vulnerability assessment. Furthermore, the identified six factors are categorized into five sub categories. Table 1 shows factors affecting the vulnerability against earthquake.

Table 1. Factors Affecting Vulnerability along Their Weight (Source: Developed by authors, 2019)

Main Criteria	Following Criteria	Vulnerability				
		Very High	High	Medium	Low	Very Low
Building Vulnerability by Turkish Method	Weight	9	7	5	3	2
	0.1-0.2	▪				
	0.21-0.40		▪			
	0.41-0.60			▪		
	0.61-0.80				▪	
	0.81-1					▪
Construction Year of Building	Before 1970	▪				
	1970-1980		▪			
	1981-1990			▪		
	1991-2000				▪	
	2001-2010					▪
Population per Building	91 and more	▪				
	90-71		▪			
	70-40			▪		
	40-21				▪	
	20-0					▪
Area of Parcel	Less than 100 m2	▪				
	101-250 m2		▪			
	251-500 m2			▪		
	501-1000 m2				▪	
	More than 1000 m2					▪
Road Width	Less than 10′	▪				
	10′-20′		▪			
	21′-30′			▪		
	More than 30′				▪	
Building Use	Residential		▪			
	Educational			▪		
	Commercial				▪	
	Service Facilities					▪
	Official					▪

5 Existing conditions of the building in Lalmatia

There are different types of buildings structure in Lalmatia area like RCC, masonry and semi-pucca building. The masonry structures are more vulnerable during earthquake. There are different building stories in Lalmatia area. Five to six stories buildings are more (31.3 %) than other stories in the study area. It is found that, there are some buildings aged above 30 years. In Lalmatia area, the highest amount of buildings constructed around 1985 to 1995 (almost 957 buildings constructed). Figure 1 shows that after 2005, construction and reconstruction of buildings is increasing most. Between 2005 to 2014, almost 47.8 % buildings are constructed. Before 2005 building construction was more in 1985 to 1995. Again, construction of structures is increasing in last ten years. The use of the buildings is divided into some exact ranges that define the actual utilize of the building. In Lalmatia area most of the building is used as residential purpose. Some other type of building uses a like commercial, community services and mixed use also founds.

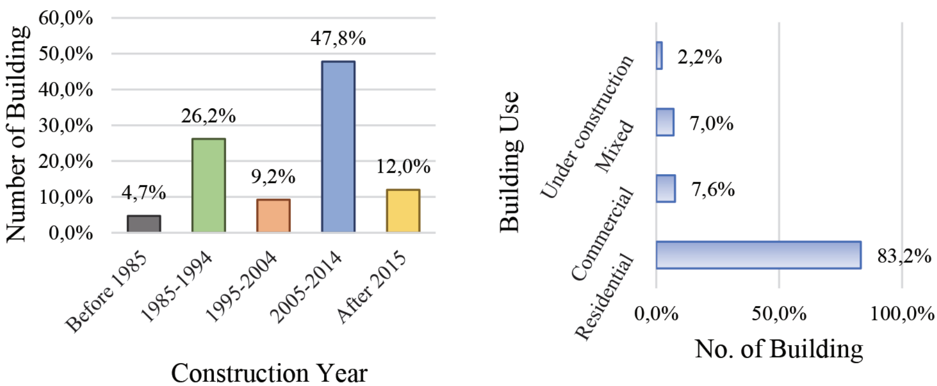

Figure 1. a) Construction Year of Building, b) Percentage of Building Use (Source: Field survey, 2019)

Among the surveyed buildings under this research, about 38 % of buildings in Lalmatia were found with heavy overhangs (Figure 1). Heavy overhang in buildings was found in most of the upper floor from two to three feet. The number of buildings with short column 4 % was found in the study area (Figure 2). Due to increase in stiffness, the columns share more flexural moment, and this causes the increase in share forces. Therefore, these columns typically sustain serious damage throughout strong earthquake. Nowadays the ground story (Figure 3) is left open for the purpose of parking in large number i.e., columns in the ground story do not have any partition walls (RCC) between them. The percentage of soft story buildings is less than the buildings without soft story. Almost 38 % buildings having soft story. It is found that, majority of the apparent building quality is good in Lalmatia area, and it is almost 59.2 %. It is found from field survey that the majority of the buildings has pounding possibility (59.8 %) (Figure 4).

Figure 2. Presence of Heavy Overhang

Figure 3. Presence of Short Column (Source: Field survey, 2019)

Figure 4. Presence of Soft Story

Figure 5. Pounding between Adjacent Building

6 Calculation step for different factors

A comparison matrix (table 2) has been developed to determine the weight of each factor. Calculation step includes the following:

Step 1: Calculating the weighted sum vector: matrix is multiplied the pairwise comparisons (table 2) by the column vector "local priority," and a new vector obtained in this way is called the Weighted Sum Vector (WSV).

Table 2. Pair-Wise Comparison of Six Vulnerability Factors (Source: Developed by authors, 2019)

Pair-wise comparison matrix (A1)						
Criteria	BV	CY	Popn	AoP	RW	LU
Building Vulnerability by Turkish Method (BV)	1	7	7	7	7	7
Construction Year of Building (CY)	0.143	1	2	4	6	7
Population per Building (Popn)	0.143	0.5	1	2	4	5
Area of Parcel (AoP)	0.143	0.25	0.5	1	2	3
Road Width (RW)	0.143	0.167	0.25	0.5	1	2
Land Use (LU)	0.143	0.143	0.2	0.333	0.5	1
Sum	1.71471	9.06	10.95	14.833	20.5	25

The above equation revealed that the highest weight belongs to building vulnerability by Turkish method and the rest of factors depend on the other used building material.

Step 2: Calculating the inconsistency vector: the elements of weighted sum vector are divided by relative priority vector and the result is Inconsistency Vector (IV) (table 3).

Step 3: Obtaining λ_{max}: mean of inconsistency vector elements gives the value of λ_{max} (table 3).

Table 3. Criteria Weight Calculation (Source: Developed by authors, 2019)

Normalized Pair-wise comparison matrix							A2	A3 = ∑A1· A2	A3 ÷ A2
Criteria	BV	CY	Popn	AoP	RW	LU	Criteria Weight		
BV	0.583	0.773	0.639	0.472	0.342	0.28	0.515	3.912	7.599
CY	0.083	0.110	0.183	0.270	0.293	0.28	0.203	1.350	6.645
Popn	0.083	0.055	0.091	0.135	0.195	0.20	0.127	0.810	6.401
AoP	0.083	0.028	0.046	0.067	0.098	0.12	0.074	0.459	6.238
RW	0.083	0.018	0.023	0.034	0.049	0.08	0.048	0.292	6.100
LU	0.083	0.016	0.018	0.022	0.024	0.04	0.034	0.210	6.181
Average									6.527

Step 4: Calculating the inconsistency index: inconsistency index is defined by (1) where n is the number of alternatives in the problem:

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{0.527}{5} = 0.105 \quad (1)$$

Step 5: Calculation of inconsistency ratio: a mechanism which has been determined to consider the consistency in the analysis is calculating inconsistency ratio (CR) obtained from inconsistency index divided by random index by (2). If this ratio is less than or equal to 0.1, the consistency is accepted.

$$CR = \frac{CI}{RI} = \frac{0.105}{1.24} = 0.085 \tag{2}$$

Where,
CI - Consistency Index,
RI - Random Consistency Index,
n - Number of Attributes,
λ_{max} - Weighted Matrix

RI indicates the random index in the above equation which is derived from the following table (table 4).

Table 4. Random Index (RI), [14]

n	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

If CR (adaptive ratio) is equal or smaller than 0.1, it means there is a concordance in judgments and if CR greater than 0.1, the judgments should be reconsidered. In the present study the CR is estimated as 0.085 meaning there is a concordance in judgments. So, the weighted value of different factors imputed with the degree of priority of different structures. Then value of individual structure needs to normalize.

7 Evaluation of the overall vulnerability

To evaluate the overall vulnerability, the weights for the criteria is calculated using AHP method and then vulnerability map of Lalmatia is prepared based on vulnerability level. With the value of Turkish Method at the time of AHP model the range of vulnerability levels are depended on huge population, very high construction age, narrow road and building use is residential. AHP consider all multiple aspects that can affect any building vulnerability and weighted with seismic buildings related factors and present the vulnerability category.

Table 5. Vulnerability Score of Very High Vulnerable Building by AHP Method (Source: Developed by authors, 2019)

Uniq_id	No of stories	Vulnerability score by Turkish method	CY	Popn	AoP	RW	LU	Score
761	6	0.19	1990	55	46.87	22	R	42
1571	6	0.20	1998	52	322.13	22	R	36
1406	10	0.20	1990	76	118.97	22	R	42
1532	6	0.19	1990	54	283.68	26	R	40
970	5	0.18	1990	37	106.43	22	R	38

According to AHP method, by giving a priority on very high vulnerable and high vulnerable building (Turkish method) represents the three priority ranking. In case of very high vulnerable buildings (total buildings 5), 2 buildings get first priority (Uniq_id 761 and 1406), 1 get second and 2 gets third priority (Uniq_id 1571 and 970). In case of high vulnerable building (total buildings 21), 13 buildings get first priority, 5 gets second and 3 gets third priority. This priority list represents priority-based retrofitting.
AHP method is used only for very high vulnerable building and a high vulnerable building in Lalmatia area. Map 2 represent the very high vulnerable building priority and map 3 represent the high vulnerable building priority. Based on AHP results, it was concluded that, 5 building of very high vulnerable get most priority for retrofitting. And then 21 buildings get priority for retrofitting.

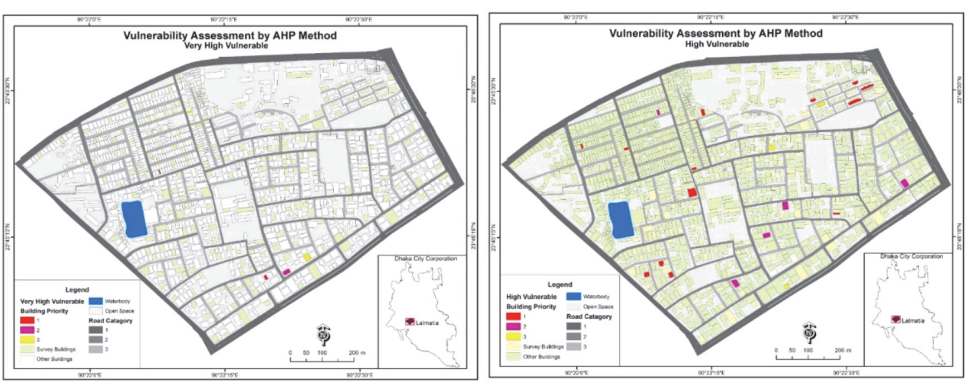

Figure 6. Vulnerability Assessment Map by AHP Method (Source: Developed by authors, 2019)

8 Willingness to pay for retrofit

Some people want to retrofit by thyself in Lalmatia area. Some people have already started to retrofit. Several people believe that developer can't work properly. That's why small size of respondent is agreed to retrofitting by developer. Responses show that awareness but that willingness to participate in a retrofit project is modest and is limited. Survey result shows that majority of the respondent are not agreed to retrofit for above mentioned prioritized 26 buildings. About 92 % respondent are not agreed to pay for retrofit. Only 8 % respondent are agreed to retrofitting.

The major barrier to building retrofit is the direct economic loss to the building owner. The findings revealed that more owners will adopt adequate mitigation measures, if the initial cost of implementation can be reduced through the provision of financial and market-based incentives such as low interest loans and tax deductibles. Provision of these incentives would reduce the owners' initial retrofit and building maintenance costs, thus strengthening their ability to adopt appropriate seismic mitigation measures.

9 Retrofit plan based on vulnerability

Based on findings by applying AHP method, can make short term and medium-term plan (table 7) for retrofit. Short term plan for very high vulnerable building and medium term plan for high vulnerable building can be taken. It can be taken to year wise retrofit plan based on priority. For short term plan, Priority-1 building can be taken emergency retrofit within first year. Priority-2 building can be retrofitted within second year and Priority-3 building within third year.

Table 6. Short Term and Medium-Term Plan for Retrofit (Source: Developed by authors, 2019)

Short term: 1-3 year (very high vulnerable building)			**Medium term: 4-6 year (high vulnerable building)**		
Year for Retrofit	Priority	Number of Building	Year for Retrofit	Priority	Number of Building
1st Year	1	2	4th Year	1	13
2nd Year	2	1	5th Year	2	5
3rd Year	3	2	6th Year	3	3

In case of medium-term plan, Priority-1 building can be taken emergency retrofitted within fourth year. Priority-2 building can be retrofit within fifth year and Priority-3 building within sixth year. This short term and medium-term plan will be applied only for very high vulnerable and high vulnerable buildings.

10 Conclusion

Earthquakes is the tremendous threat for the economy, and well-being of the cities, and communities. While thousands of buildings may collapse in the cities and serious causation occur. The vulnerability of a city is termed to losses imposed to urban elements in case of a disaster and its intensity may vary based on its nature and quality. Vulnerability of a city is an extensive factor encompasses all existing in a city, and since all components in a city is connected to each other, therefore, it increases very quickly. All involving factors in the vulnerability study may not be considered as a whole therefore AHP method has been employed at a present study for weighting major building components as well as their behavior which obey the fuzzy logic. The concept of social vulnerability helps to identify those characteristics and experiences of individuals and communities that enable them to respond to and recover from earthquake hazards. This type of study will assist the planning and development organizations become stricter to compel the citizens as well as developers to follow construction rules and regulation, whereas, at present these are not exercised properly. The indicators and model of this study will definitely contribute in the vulnerability assessment as well as initiate mitigation efforts against earthquake of Dhaka city.

References

[1] CDMP. (2014). Scenario Based Earthquake Contingency Plan of Mymensingh Municipality Area. Comprehensive Disaster Management Programme (CDMP), Ministry of Food and Disaster Management, Government of the People's Republic of Bangladesh.

[2] UN, (2020). UN World Urbanization Prospects. Retrieved from https://worldpopulationreview.com/world-cities/dhaka-population/. Accessed on 08/06/2020.

[3] Ahmed, S., Ahmed, H. (2010). Disaster risk and risk mitigation in Dhaka other cities, UNICEF, Dhaka, Bangladesh.

[4] Rahman, M.A. (2010). Dhaka in Danger. The daily star, June 10, 2010. Retrieved on 05 November, 2020 from https://www.thedailystar.net/news-detail-142043

[5] Ferdousi, S., Rahman, M.T. (2010). Earthquake in Bangladesh: How much are we prepared to face it? Bangladesh J Pathol, 25(1): 1-2.

[6] CDMP. (2009a). Earthquake Contingency Plan for Dhaka City. Dhaka: Comprehensive Disaster Management Program (CDMP), Ministry of Food and Disaster Management, Government of the People's Republic of Bangladesh, Phase 1.

[7] CDMP. (2009b). Risk Assessment of Dhaka, Chittagong and Sylhet City Corporation Area. Dhaka: Comprehensive Disaster Management Program (CDMP), Ministry of Food and Disaster Management, Government of the People's Republic of Bangladesh, Phase 1.

[8] CDMP. (2009c). Vulnerability Assessment of Dhaka, Chittagong and Sylhet City Corporation Area. Dhaka: Comprehensive Disaster Management Program (CDMP), Ministry of Food and Disaster Management, Government of the People's Republic of Bangladesh, Phase 1.

[9] ADPC (2009), 7.5 quake can kill 1.3 lakh in Dhaka: survey. Bdnews24.com, 21 September, 2009. Retrieved on 01 November, 2020 https://bdnews24.com/bangladesh/2009/09/21/7.5-quake-can-kill-1.3-lakh-in-dhaka-survey

[10] CDMP. (2010). Dhaka city at risk of massive destruction. The daily star, January 24, 2010. Retrieved on 15 October, 2019, from https://www.thedailystar.net/news-detail-123247

[11] Saaty, T.L. (1980). The Analytic Hierarchy Process: Planning, priority setting, resource allocation. New York: McGraw Hill.

[12] Harker, P.T., Vargas, L. (1987). "The Theory of Ratio Scaled Estimated: Satty's Analytical Hierarchy Process." Management Science, 33(11): 1385-403.

[13] Eastman, J.R., Jin, W., Kyem, P.K., Toledano, J. (1993) Raster Procedures for Multicriteria/ Multiobjective Decisions. Photogrammetric Engineering and Remote Sensing, 61, 539-547.

[14] Saaty, T.L. (1994). Fundamentals of Decision Making. RSW Publications. Retrieved on 21 October 2020, from https://books.google.com.bd/books?id = wct10TlbbIUC&printsec = frontcover#v = onepage&q&f = false