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ROAD NETWORK VULNERABILITY ASSESSMENT FOR SEISMIC HAZARD IN URBAN AREA

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Abstract

The conventional studies on seismic hazard focus only on infrastructural construction requirement that lacks the potential involvement of network related issues. In recent years, various studies have shown the importance of transport network reliability, which serves a great purpose for the functioning of an urban area. Not only that, in case of an emergency, a disrupted transportation network can increase the amount of damage and casualty due to the delay in performing rescue as well as evacuation operations. Worldwide experience demonstrates that a strong earthquake can cause colossal effects on both material damage and human losses. That is why having a scientific understanding of road network vulnerability will help to initiate an effective and efficient evacuation as well as rescue operation for hazardous events like the earthquake within the shortest possible time. Dhaka, being one of the world's largest megacities is seriously vulnerable to earthquake due to its geographic location and rapid unplanned urbanization. In this regard, this paper tends to illustrate an integrated model for exploring the road network vulnerability due to seismic hazard in Dhaka. To explore such scenario this study involves two interconnecting steps. Among them, the first part involves the identification of vulnerable buildings to seismic threats and considering its outcome, the identified vulnerable buildings are assessed for calculating the probability of building collapse with the use of Damage Probability Matrices. Later, the second part of the study focuses on identifying road blockage scenario of the study area that may be caused by debris generated from the probable collapsed buildings. The first part of this study utilizes Visual Rating method for identifying vulnerable buildings, whereas the second part involves a correlation between building height with debris width for illustrating road blockage scenario. Considering the combined result of these two parts, the potential application of this work includes an effective illustration of the overall road blockage scenario as well as its impacts on the accessibility of the study area.

Keywords: Road; Network; Vulnerability; Earthquake.

1. Introduction

Vulnerability automatically reveals itself in hazardous situations [1]. It is characterized to express the degree to which a system is exposed to potential hazards and threats [2]. The vulnerability of critical infrastructure during critical hazards like an earthquake can pose a serious threat to life as well as increase the number of casualties. In this regard, numerous studies have been made for exploring structural vulnerability for seismic events [3, 4, 5]. However, these conventional studies on seismic hazard focus only on infrastructural construction requirement that lacks the potential involvement of network related issues. However, there are some other studies which have illustrated the importance of transportation network reliability in terms of seismic threat [6]. Because the results from previous strong earthquakes have shown that damages in road network can considerably disrupt emergency responses like rescue and recovery operations which may eventually lead to an extended traffic disruption [7].

An earthquake with a high intensity of ground motion can cause severe effects on both human losses as well as material damages [8, 9, 10, 5]. While most of these misfortunes happen during or shortly after the earthquake, it is observed that a critical extent of human losses additionally occurs within the next hours or days. Those post breakdown losses can happen either by the limited capacity of emergency response resources or by not being able to send rescue support in the incident's location. That is why having a scientific understanding of network vulnerability assessment would help to initiate an effective and efficient evacuation as well as rescue operations for hazardous events like an earthquake within the shortest possible time.

In such regard, this paper intends to present an integrated methodology that focuses on strengthening urban road network resiliency in seismic scenarios by evaluating two main dimensions: 1) building vulnerability and 2) road blockage.

The first part considers Visual Rating (VR) method and Damage Probability Matrices (DPM) to evaluate building vulnerably due to seismic threat [11, 12]. The VR method focuses on the cross-sectional areas of columns and masonry infills in existing infilled masonry-RC buildings. On the other hand, DPM relates the

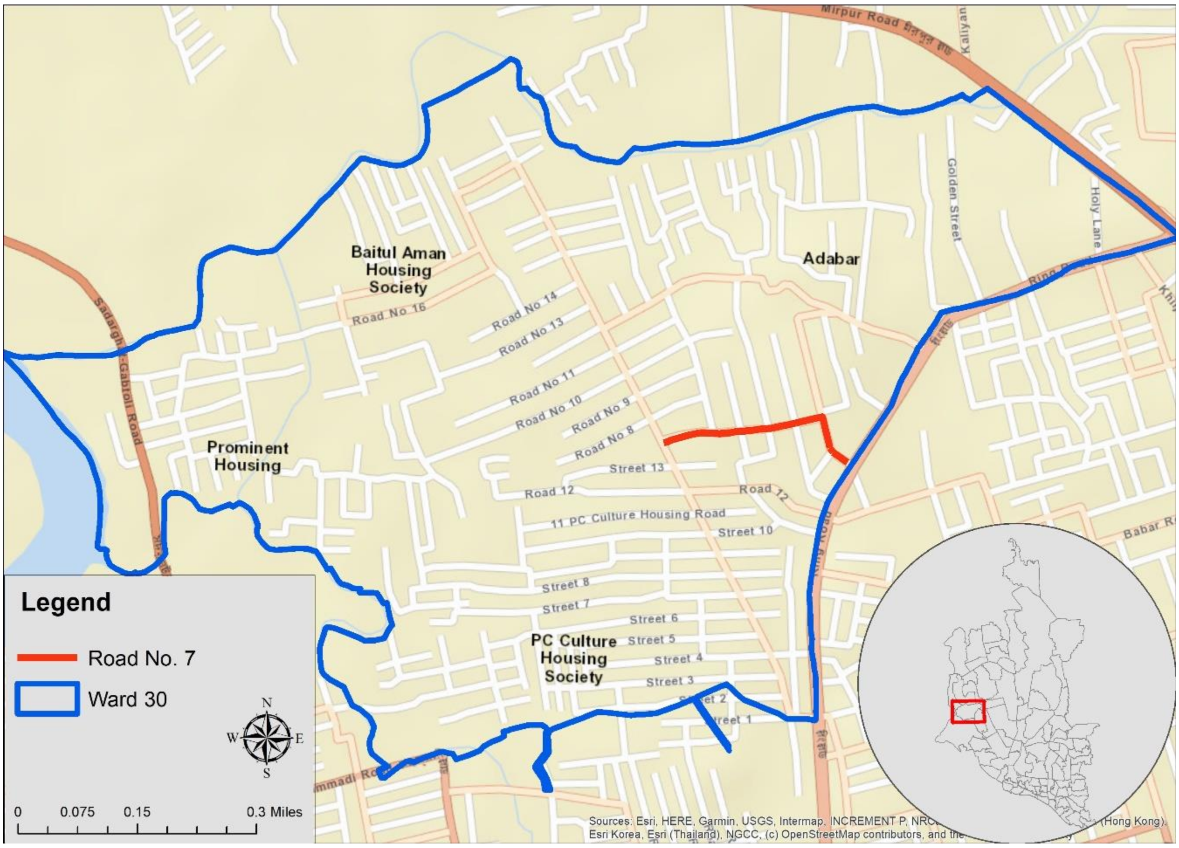

Fig 1: Study Area

outcome of VR method with respective damage states. Finally, to evaluate road blockage scenario, this research utilizes the integrated outcome of VR method and DPM to illustrate potential road blockage sites with the help of a correlation model [13].

The research has been conducted in Adabor area of Dhaka city, which is also known as Ward no 30 of Dhaka North City Corporation. Having a high density of inhabitants as well as structural entities, this area has been found very congenial to implement the developed model [14]. To ensure the effective performance of the algorithms (in terms of computational time) as well as to collect detailed information concerning the model to work, a specific road (Fig 1) has been selected within the study area. Though the road covers a small portion of the whole focusing area, yet, it works as an important connecting corridor to two major roads of Adabor area covering 42 buildings alongside it.

2. Context

The main concern of this research is to identify potential discontinuation scenarios of the transportation network in an urban area. Therefore, this study has been built based on existing knowledge on the following aspects: i) urban road network vulnerability, ii) building vulnerability assessment and iii) road blockage scenario.

2.1 Urban road network vulnerability

Urban areas are mostly congested with high-density structures along with interconnecting road network. To ensure the proper functioning of an urban area, it is very crucial to have a well-performing transportation network. But a sudden hazardous event like an earthquake can cause severe damage in terms of structural vulnerability as well as disruption in the transportation system in cities like Dhaka, where the population density stands near 50001 people per square mile [15]. Planning for cities, which has such a huge amount of inhabitants requires special attention to disaster risk management activities. And in case of an earthquake, a whole area might face a significant amount of damage if proper retrofitting actions are not considered. That is why nowadays, almost every country follows specific building construction codes, which provides certain guidelines and standards of using building materials and other construction rules. Not only that, to mitigate such threats, numerous studies have been made on different dimensions of seismic vulnerability. However, factors like transport network related issues have come into focus after the Hanshin-Awaji earthquake in 1995. Though most of the human injuries are caused by building collapse during an earthquake, the initial level of injury might lead to death if emergency support or treatment is not given to the victims in the shortest possible time. This scenario increases the demand for evaluating road network vulnerability for seismic threats within urban area. As urban road networks are already subject to traffic congestion therefore, having an additional disruption over it will result in a catastrophic situation. That is why this research tends to identify the existing road network vulnerability scenario within urban area.

2.2 Building vulnerability assessment

To assess building vulnerability, this research follows a modified visual screening method that is designed for implementing in the build-up environment of Bangladesh [11]. Considering the limitations of existing visual screening methods which do not consider the variation of the cross-sectional area of structural elements (i.e. RC wall, column, masonry infill, etc.), the Visual Rating (VR) method has been selected to conduct this study. This method considers structural factors like- column area ratio, infill wall area ratio, irregularity index, RC wall area ratio, time index, total floor area, etc. into account and finally articulates the output result into five categories [11]. Later, these categories have been linked with their respective damage state with the help of Damage Probability Matrices (DPM) to identify probable building damage scenarios [12, 16]. The Damage Probability Matrices (DPM) follows a typological model which considers that buildings of the same type react similarly.

2.3 Road blockage scenario

Building damage scenario illustrates the probability of a building getting collapsed. Later, a transformation is made of the collapsed probabilities into road network closure probabilities, which can be caused by the debris from collapsed buildings. This transformation model was developed by Argyroudis [13], where a correlation is made between the building's height or the number of stories with the width of the induced debris of collapsed buildings from previous earthquakes. This model is simple, yet realistic as it considers different building collapse shapes. In short, it assumes that the occurrence probability of debris width as well as the corresponding road closure is equal to the probability of building collapse [13]. Depending on the width of induced debris, different traffic states occur describing certain level of road closure.

3. Road Network Vulnerability Analysis in the Study Area

The prime concern of this research is to measure the potential impacts on road network performance in earthquake situations. These impacts are most detrimental to the functioning of emergency rescue services. Due to the substantial amount of delay in performing rescue services, the risk can drastically increase for the higher number of human casualties as well as material damages. In cases of post-earthquake responses, the functioning of road network disrupts because of road blockage scenario, which is mostly caused by induced debris from damaged buildings. Therefore, this research particularly focuses on vulnerable buildings that pose the potential probability of being collapsed during an earthquake event and generate a considerable amount of debris on their respective roads.

3.1 Result from building assessment

To evaluating building vulnerability for seismic threat, this research follows Visual Rating (VR) method with the integration of Damage Probability Matrices (DPM). At the initial stage, each building of the study area has

Fig 2:Building Damage Probability

been identified with their respective VR index (I_{vr}) using the formula developed by Shafiul [11]. The results from VR index ranges from I_{vr}= 0.088 to I_{vr}= 0.331. Here, the lower index value represents greater risks for building vulnerability, whereas the higher VR index represents vice versa. Later, the I_{vr} values of all the investigated buildings have been reclassified into five categories and then correlated with their respective probable damage state (i.e. no damage 0-1%, light damage 1-10%, moderate damage 10-50%, high damage 50-90%, full collapse 90-100%) that each building might face during a strong seismic event. The results from the application of this method are presented in Fig 2. The red color indicates a higher probability of building damage and following through the green color directs to a less probability. The following table has been established according to the obtained data from the field survey:

Table 1:Statistics on Building Damage Probability

Building Damage Probability	Number of Buildings (in percentage)
90-100%	7%
50-90%	31%
10-50%	40%
1-10%	2%
0-1%	19%

The findings articulate that, 7% of the buildings within the study area show the probability of getting 90-100% damage during an earthquake event. Apart from that, the majority of the buildings (40%) show probability of getting 10-50% damaged. But, the concerning fact highlights 31% of the buildings poses a threat of getting 50-90% damage probability. However, it is also observed that buildings with greater height are most vulnerable to such damage threat. The risk minimizes as the number of building stories reduces.

3.2 Blockage scenario risk computation

Adabor is a residential area, with a high building density. Most of the buildings within this area are closely in contact with each other, leaving very narrow space in between. Also, lack of open areas, as well as short

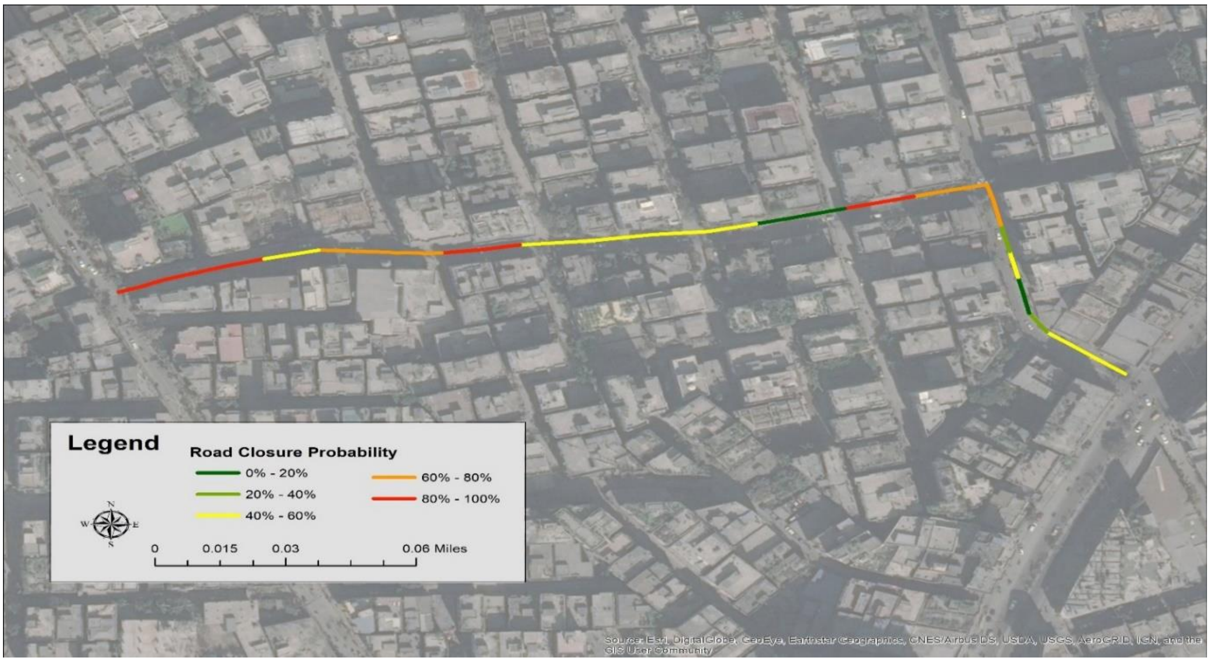

Fig 3: Road Closure Probability

distance from building's facade to streets, leads to a higher risk potential to the transportation system in case of a strong earthquake.

However, to evaluate the road blockage scenario within the study area, a simple but effective method has been applied in this research [13]. This method focuses on the damage ratio of a building, which might get revealed during a serious earthquake. Considering the results from building assessment, a correlation has been built with the height of the building to the potential width of induced debris from damaged structures. As a result, Fig 3 demonstrates the probable road blockage scenario within the study area.

The red color indicates a higher probability of road closure within that particular portion of the road as a greater amount of induced debris might concentrate within that area. Following the color sequence, the green color illustrates less concentration of probable induced debris. Though the concerning road is about 441m in length, yet it is exposed with a greater threat in terms of traffic functioning after a severe seismic event. This research has identified three major road portion where the blockage scenario might level up to 80-100%. In other words, within these three portions, the road might get completely blocked resulting in 100% inaccessibility through this road to its nearby areas.

4. Conclusion

In recent years, network vulnerability assessment for seismic hazard is an evolving topic. And in the case of Bangladesh, which lies in a seismically active zone, it is very much important to anticipate all the possible risks due to earthquakes. That is why taking precaution on only building vulnerabilities leaves out the vital factors of network related issues.

In this paper, the methodology focuses on defining the vulnerable routes of the network system for the purpose of improving the overall seismic risk management of the road network within an urban area of Bangladesh. As this type of research is quite new to this country, the result helps to identify appropriate mitigation actions for retrofitting vulnerable components as well as illustrating the importance of alternative routes in emergency situations. Though the recent researches have used different rapid screening methods to evaluate building vulnerability, this paper utilizes Visual Rating (VR) method for reaching towards more precision and detailed data on building vulnerability. Therefore, the accuracy increases for the final result of road network vulnerability which initially considers the outcome of VR method.

It is true that events like an earthquake are still unpredictable in terms of its occurrence frequency. However, knowing the vulnerable positions in a network route opens up the possibilities of achieving more effective and innovative retrofitting approaches to tackle and minimize road network related damages caused by hazardous situations like an earthquake.

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6. References

[1] Cutter, S. L. (2003). The vulnerability of science and the science of vulnerability. Annals of the Association of American Geographers, 93(1), 1-12.

[2] Mitchell, J. K., Cutter, S. L., & Wilbanks, T. J. (2003). Urban vulnerability to terrorism as hazard. The Geographical Dimensions of Terrorism, 17-25.

[3] Sharfuddin, M., Zhao, Y. G., Idota, H., & Ansary, M. A. (2010). Probabilistic evaluation of column over-design factor for frame structures considering seismic base shear distribution of BNBC. Journal of Civil Engineering (IEB), 38(2), 109-119.

[4] Sadat, M. R., Huq, M. S., & Ansary, M. A. (2010). Seismic vulnerability assessment of buildings of Dhaka City. Journal of Civil Engineering (IEB), 38(2), 159-172.

[5] El-Betar, S. A. (2016). Seismic vulnerability evaluation of existing R.C. buildings. HBRC Journal, 14. doi: 10.1016/j.hbrcj.2016.09.002

[6] Lam, W. (1999). Special issue on transport network reliability. Journal of Advanced Transportation, 121-251.

[7] Kilanitis , I., & Sextos, A. (February de 2019). Impact of earthquake-induced bridge damage and time evolving traffic demand on the road network resilience. Journal of Traffic and Transportation Engineering, 6(1), 35-48. doi:10.1016/j.jtte.2018.07.002

[8] Coburn, A. W., Pomonis, A., & Pomonis, A. (1992). Factors determining human casualty levels in earthquakes: mortality prediction in building collapse. Proceedings of the 10th world conference on earthquake engineering, 5989-5994.

[9] PETROVSKI , J. T. (2004). CRITERIA FOR SEISMIC RISK REDUCTION OF EARTHQUAKE RESISTANT BUILDINGS. 13th World Conference on Earthquake Engineering.

[10] PITILAKIS , K., ANASTASIADIS, A., KAKDERI, K., ARGYROUDIS, S., & ALEXOUDI, M. (2007). VULNERABILITY ASSESSMENT AND RISK MANAGEMENT OF LIFELINES, INFRASTRUCTURES AND CRITICAL FACILITIES. THE CASE OF THESSALONIKI' S METROPOLITAN AREA. 4th International Conference on Earthquake Geotechnical Engineering, (págs. 25-28). Thessaloniki, Greece.

[11] Islam, M. S., Alwashali, H., Sen, D., & Maeda , M. (2019). A proposal of Visual Rating method to set the priority of detailed evaluation for masonry infilled RC building. Bulletin of Earthquake Engineering, 1-22. doi: 10.1007/s10518-019-00763-5

[12] Whitman, R. V. (1973). Damage probability matrices for prototype buildings. Washington: Structures Publication.

[13] Argyroudis, S. A., Pitilakis, K. D., & Anastasiadis, A. I. (2005). Roadway Network Seismic Risk Analysis in Urban Areas: The case of Thessaloniki - Greece. Geoline. Lyon, France.

[14] (BBS), B. B. (2015). Population and Housing Census 2011 Zila Report: Dhaka. Dhaka: Bangladesh Bureau of Statistics (BBS).

[15] Ullah, G. W., & Islam, A. (2017). A Case Study on Pathao: Technology Based Solution to Dhaka's Traffic Congestion Problem. Case Studies in Business and Management, 4(2), 100. doi: 10.5296/csbm.v4i2.11906

[16] Askan , A., & Yucemen, M. S. (2010). Probabilistic methods for the estimation of potential seismic damage: Application to reinforced concrete buildings in Turkey. Structural Safety, 32(4), 262-271.

