- *Technical Paper* -

SEISMIC DAMAGE PROBABILITY OF EXISTING RC BUILDINGS BASED ON PAST EARTHQUAKE DAMAGE DATABASE

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ABSTRACT

Past earthquake damage databases are useful information to understand the seismic vulnerability of future earthquake. This paper presents an investigation of three past earthquake damage buildings' databases. Seismic capacity is estimated based on Shiga Map concept, and a relationship between damage ratio and seismic capacity is developed. The obtained relationship is applied on an existing RC building database located at Dhaka city, in Bangladesh where past earthquake damage database is not available. The extent of vulnerable buildings is estimated which is very useful for future preparedness.
Keywords: Seismic capacity, Damage database, Seismic vulnerability, Existing RC buildings

1. INTRODUCTION

Bangladesh is located in the high seismic region and there is a huge stock of masonry infilled RC building in the capital city, Dhaka. It is necessary to understand the extent of seismically vulnerable buildings for future preparedness. Due to the lack of a past earthquake damage database, the scenario of seismic vulnerability is not clear. In this regard, past earthquake damage information or damage databases in other countries, with identical structural system, can be used to understand the seismic capacity and extent of seismic damage.

This research aims to investigate existing earthquake damage databases collected from past earthquake records from different countries. A correlation is developed between seismic capacity and damage states. The obtained correlation is applied to an existing RC building database located in Dhaka, Bangladesh and the seismic damage extent is estimated.

2. INTRODUCTION OF PAST EARTHQUAKE DAMAGE DATABASE

In this study, three post-earthquake surveyed buildings' databases, the 2015 Nepal earthquake (Mag: 7.8), the 2016 Ecuador earthquake (Mag: 7.8), the 2016 Taiwan earthquake (Mag: 6.6), have been collected from the website www.datacenterhub.org. [1,2&3]. These databases consist of building's floor plan (hand sketch) along with information such as number of stories, floor area, cross-sectional area of RC columns, location of masonry infills, year of construction as shown in Fig. 1. All buildings are low to mid rise masonry infilled RC buildings as shown in Fig. 2. These surveyed buildings are categorized into three damage classes based on visual inspection [1]. Definitions of each damage states are shown in Table 1.

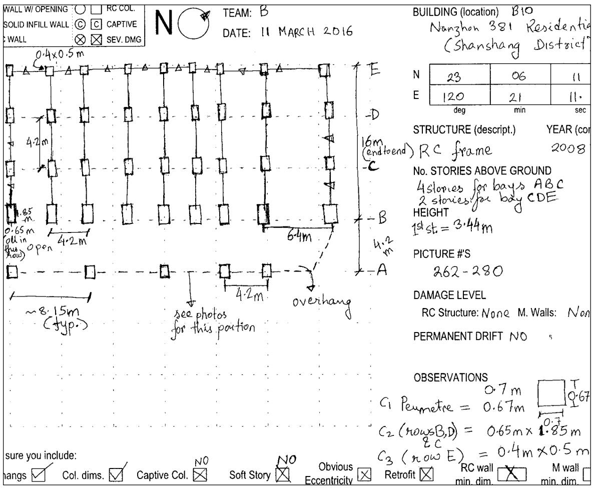

Fig.1 A typical survey datasheet [3]

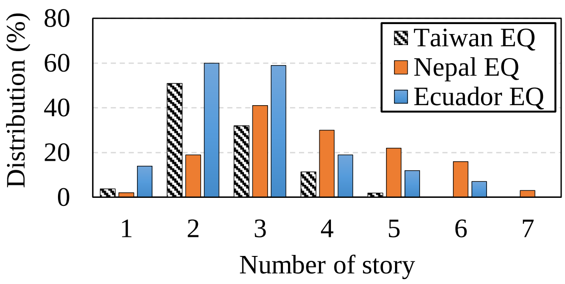

Fig.2 Distribution according to number of stories

Table 1 Damage definition [1,2,3]

Damage state	Selection criteria
Light	Hairline flexural cracks.
Moderate	Wider cracks, concrete spalling.
Severe	At least one element has failed.

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3. SEISMIC CAPACITY EVALUATION

The basic concept of seismic capacity used in this study is based on the Shiga Map concept [4]. However, the Shiga map does not consider the effects of masonry infill. In this study, the seismic capacity index has been considered as the summation of lateral strength of RC column, masonry infill, and concrete wall normalized with total building's weight [5,6] as expressed by Eq. 1.

$$\text{Seismic capacity index}=\left[\frac{\tau_c.A_c}{n.A_f.w}+\frac{\tau_{\inf}.A_{\inf}}{n.A_f.w}+\frac{\tau_{cw}.A_{cw}}{n.A_f.w}\right] \quad (1)$$

where, τ_c, τ_{inf}, and τ_{cw} are average shear strength of column, masonry infill, and concrete wall; A_c, A_{inf}, and A_{cw} are the cross-sectional areas of RC column, masonry infill, and RC wall. n, A_f and w are the number of story, floor area, and unit weight per floor area of building.

3.1 The 2015 Nepal EQ buildings database

A total of 133 low-rise RC buildings are investigated and the seismic capacity index is calculated. Fig. 3 shows the distribution of the seismic capacity index of the investigated buildings. The ranges of seismic capacity index are 0.1 to 1.1. It is seen that most of the buildings seismic capacity index ranges 0.2 to 0.4. The average value of seismic capacity index is 0.38 and the standard deviation is 0.21. Fig. 4 shows the distribution of seismic capacity index of total investigated buildings and severely damaged buildings. It is observed that the seismic capacity index of severely damaged buildings is of 0.6 or less. The average value of severely damaged buildings is about 0.28 and standard deviation 0.13. Fig. 5 shows the correlation of damage ratio and seismic capacity index. It is observed that the seismic capacity index is higher than 0.6 indicating other than severely damaged buildings which might be considered as judgment criteria for seismic capacity investigation.

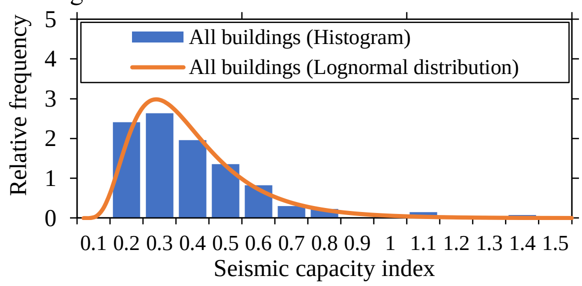


Fig. 3 Seismic capacity index of investigated buildings in the 2015 Nepal EQ

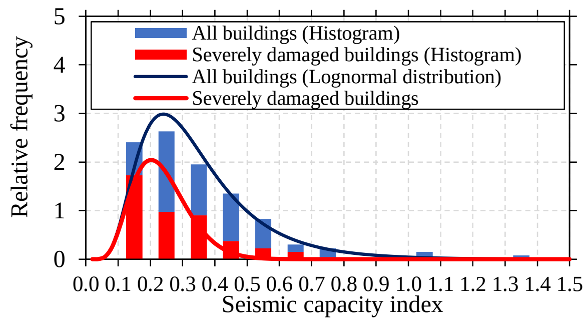


Fig. 4 Distribution of seismic capacity index for total buildings and damaged buildings in the Nepal EQ.

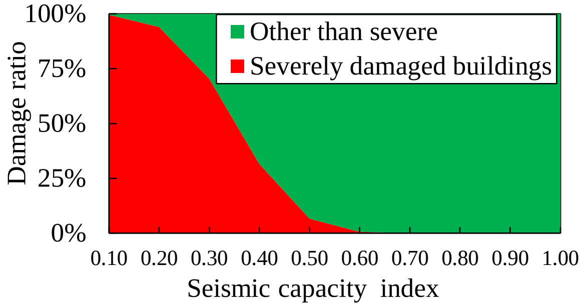


Fig.5 Correlation the seismic capacity with damage ratio based on investigated buildings

3.2 The 2016 Ecuador EQ buildings database

Seismic capacity is calculated for 171 number of RC buildings in the Ecuador EQ database. Fig. 6 shows the distribution of seismic capacity index of the investigated buildings are 0.1 to 1.2 with an average value 0.46 and standard deviation 0.22. Fig. 7 shows the distribution of seismic capacity according to severely damaged buildings and total buildings. However, observation depicts that the average value for severely damaged buildings is of 0.28 whereas other buildings provided 0.35. Fig. 8 shows the co-relationship between damage ratio and seismic capacity index for the investigated buildings. It suggests that the seismic capacity index is 0.5, 20 % of buildings are severely damaged and 80 % of buildings are other than severe.

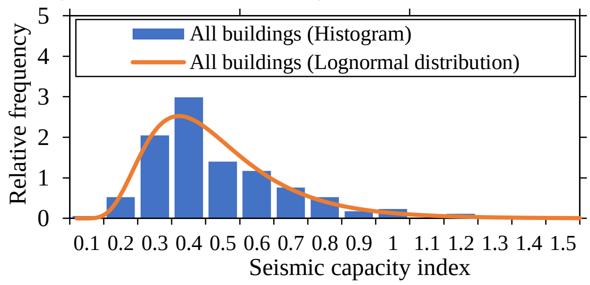


Fig. 6 Seismic capacity index of investigated buildings in the 2016 Ecuador EQ

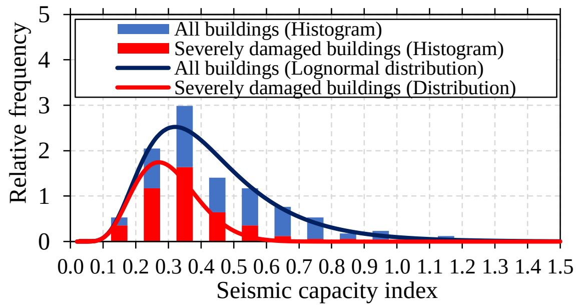


Fig. 7 Distribution of seismic capacity index for total buildings and damaged building in the Ecuador EQ

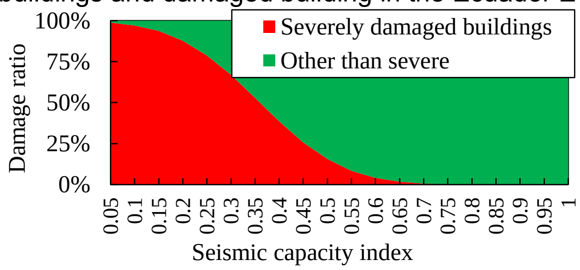


Fig. 8 Correlation the seismic capacity with damage ratio based on investigated buildings.

3.3 The 2016 Taiwan EQ buildings database

A total 65 number of RC buildings are investigated and seismic capacity index of these buildings is calculated as shown in Fig. 9. It is seen that the estimated seismic capacity index shows ranges from 0.3 to 1.1. The average values are 0.53 and the standard deviation is about 0.20. It is also observed that about 40 % of buildings contain seismic capacity ranges from 0.4 to 0.5. Study shows that about 23% of buildings were severely damaged buildings. Fig. 10 shows the distribution of seismic capacity index of severely damaged buildings with the average value of the seismic capacity index is 0.35 with a standard deviation is 0.09. A correlation between seismic capacity index and damage ratio is shown in Fig.11. It has been seen that seismic capacity index is of 0.6 or less showing the severely damaged buildings.

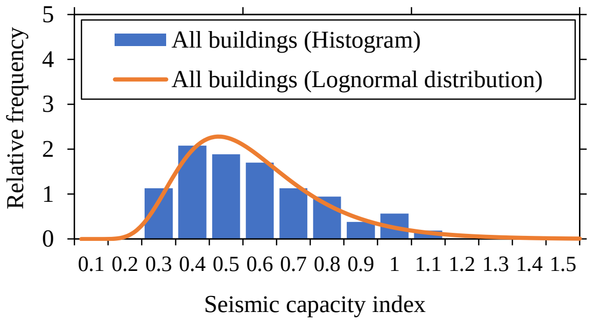


Fig.9 Seismic capacity index of investigated buildings in the Taiwan EQ

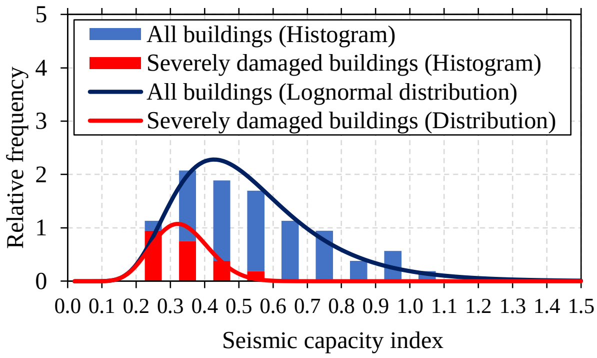


Fig.10 Distribution of seismic capacity index for total buildings and damaged buildings in Taiwan EQ

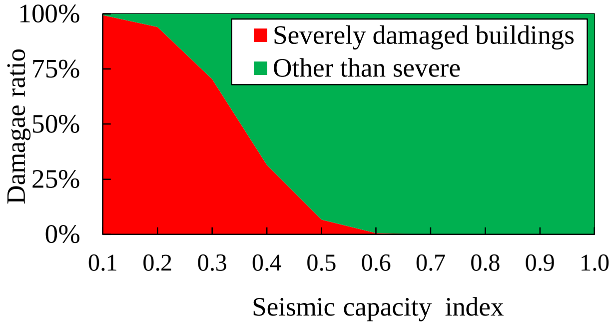


Fig.11 Correlation the seismic capacity with damage ratio based on investigated buildings

From above discussion, the obtained correlations between damage ratio and seismic capacity in the Nepal EQ, the Ecuador EQ and the Taiwan EQ buildings databases are very useful information and could be used to understand the damage status to other existing buildings in the similar region as well as another region where there is no past earthquake database by considering local seismic demand. In this study, this information is applied on an existing RC buildings database located at Dhaka city, Bangladesh as shown in the following sections.

4. APPLICATION TO EXISTING RC BUILDINGS DATABASE IN BANGLADESH

4.1 Introduction of the building database

A total number of 583 masonry infilled RC buildings database, located at Dhaka city in Bangladesh, are selected in this study [7]. The general information and characteristics are discussed in Author's another study [8]. The typical column dimension is 250 mm. The thicknesses of masonry infill are 250 mm and 150 mm for exterior and interior wall, respectively. A common survey datasheet is used to record the information as shown in Fig.12. Most of the surveyed buildings are 3 to 6 storied as shown in Fig. 13.

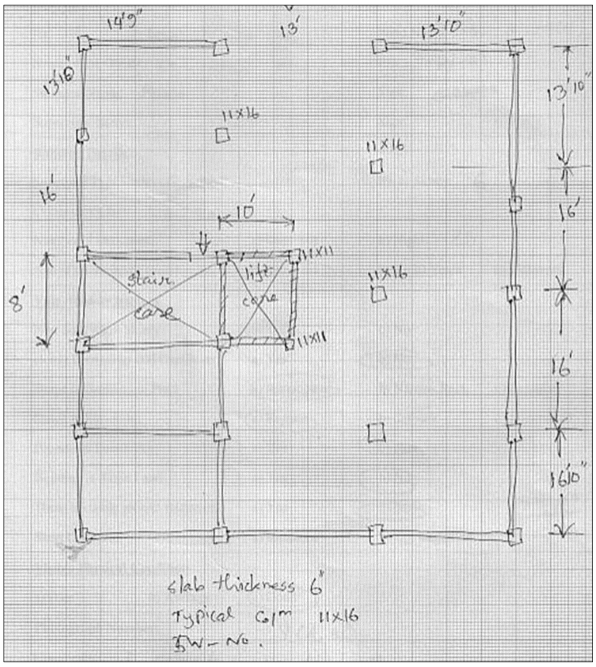


Fig.12 A typical as-built drawing for ground floor plan of building [7]

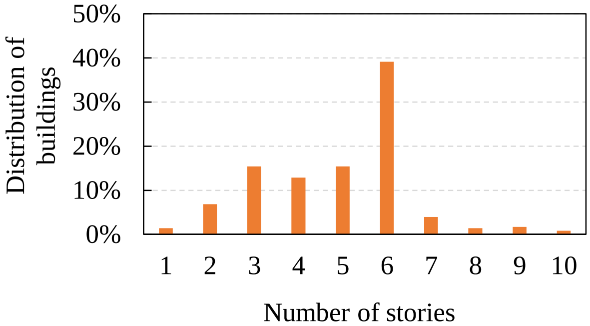


Fig.13 Distribution according to number of stories

4.2. Seismic capacity evaluation

The seismic capacity index is calculated using the information found from the database by Eq. 1 as was done for other buildings' databases in Section 3. The seismic capacity index distribution is shown in Fig.14. The seismic capacity index ranging from 0.1 to 1.3 and about half of the buildings show 0.2 to 0.3 which indicates lower seismic capacity.

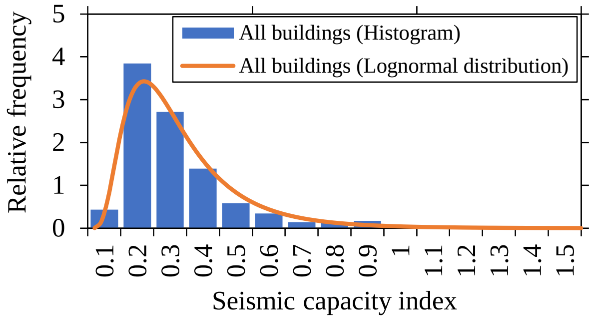


Fig. 14 Distribution of seismic capacity index of investigated buildings in Bangladesh

5. COMPARISON WITH PAST EARTHQUAKE DAMAGE DATABASE FROM DIFFERENT SEISMIC REGION

Fig. 15 shows the comparison between seismic capacity indices of all investigated buildings' database. And Table 2 shows the average and standard deviation of seismic capacity of these buildings. Comparing to all the databases, Bangladesh buildings show lower seismic capacity. The reasons behind are that lower column size and less amount of masonry infills due to open ground floor for car parking. Comparing with Nepal buildings' database, the average capacity of Nepal buildings is of 0.38 which is 1.3 times higher than Bangladesh buildings. The main reason is that column sizes and masonry infill thickness are higher comparing with Bangladesh buildings. In case of Ecuador buildings, most of the investigated buildings are low-rise which results lower building weight and higher seismic capacity. Based on Table 2, the seismic capacity of Ecuador buildings is 1.5 times higher than Bangladesh buildings. Comparing with the Taiwan buildings, it is seen that the average value of seismic capacity Taiwan buildings is 0.53 which is about twice of Bangladesh buildings database as 0.29. The reason is that the column area and the amount of masonry infill are higher in investigated Taiwan buildings comparing with Bangladesh buildings. The first seismic design code was published in 1993 in Bangladesh, 1994 in Nepal, 2001 in Ecuador, and 1974 in Taiwan, year of construction of these existing buildings may influence the seismic performance.

Table 2 Mean and standard deviation of seismic capacity index of all the investigated buildings

Database	Mean	Standard dev
Taiwan EQ	0.53	0.20
Ecuador EQ	0.46	0.22
Nepal EQ	0.38	0.21
Bangladesh buildings	0.29	0.21

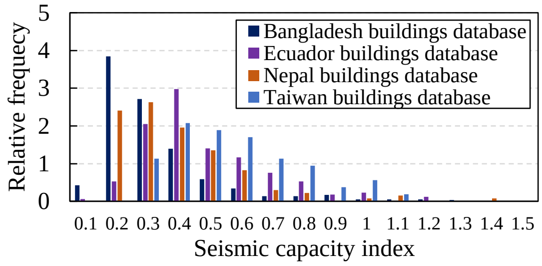


Fig. 15 Distribution of seismic capacity index of investigated buildings

6. DETERMINATION OF EXTENT OF SEISMIC DAMAGE OF EXISTING RC BUILDINGS IN BANGLADESH

In many high seismic regions, such as Japan, Taiwan, the seismic design procedure has been revised by up gradation of building code and construction procedure based on past earthquake experiences. However, in the other high seismic regions, where past earthquake data/record is not available or not archived, it is not easy to predict the extent of vulnerability due to future probable earthquakes. In this aspect, Okada and Nakano [9] conducted reliability analysis on seismic capacity of existing RC buildings in Japan. The damage ratio can be predicted by comparing with the damaged buildings of recent earthquake damages databases and the capacity of existing buildings [9]. The proposed concept is used and applied in Bangladesh buildings, as a case study. The obtained correlation between damage ratio and seismic capacity as well as seismic demand from other countries is applied on existing RC buildings database. The extent of damage considering different earthquake damage database is described in the following sections.

6.1 The 2015 Nepal EQ building database

Ground motion time histories imply that ground motion acceleration of Nepal earthquake is higher than that of the Bangladesh National Building Code (BNBC) [10] seismicity. Fig.16 shows a comparison between the response acceleration of Nepal ground motion and the BNBC [10] response acceleration. It has been seen that for Nepal, the response acceleration is about 0.60g which is 1.33 times larger than that of BNBC response acceleration (0.45g) in Bangladesh.

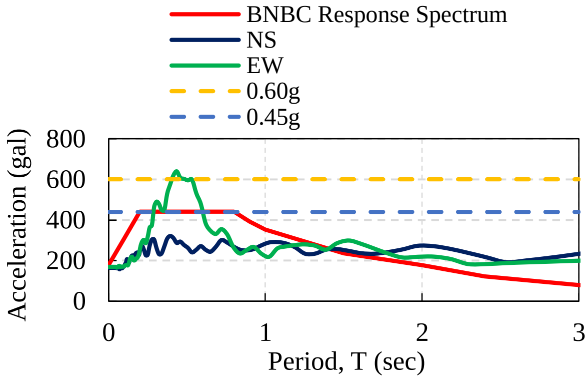


Fig. 16 Comparison of different levels of response acceleration

Fig.17 shows the distribution of severely damaged buildings of the Bangladesh buildings database using a similar damage ratio as found in the Nepal earthquake damage database. However, Bangladesh's ground motion is 0.75 times lower than that of Nepal. In this case, the distribution of severely damaged buildings has been calculated multiplying of the mean value of severely damaged buildings of Nepal database by proportion of ground motion acceleration is of 0.75. Fig. 17 shows the different distribution of severely damaged buildings considering Nepal ground motion and BNBC code seismicity.

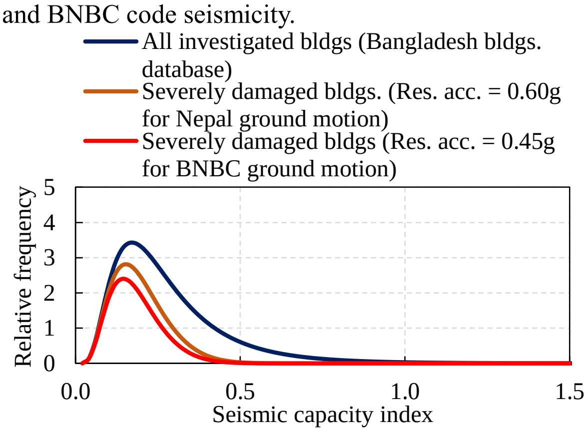
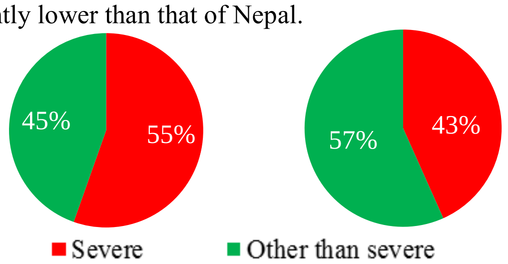


Fig.17 Distribution of seismic capacity index for severely damaged RC buildings

Fig. 18(a) and 18(b) show the extent of damage probability considering Nepal and BNBC ground motions. It has been seen that 55% of buildings will be severely damaged using a similar damage ratio for Nepal earthquake database and as per BNBC ground motion as described in the previous section the probability of severely damaged buildings is about 43% which is slightly lower than that of Nepal.



(a) Res acc. = 0.6g for Nepal ground motion (b) Res. acc.= 0.45g for BNBC ground motion

Fig. 18 Probability of seismic damage due to different levels of seismicity

6.2 The 2016 Ecuador EQ building database

Fig.19 shows the comparison of response acceleration of Ecuador ground motion and BNBC code ground motion. From recorded ground motion, it has been assumed that the average response acceleration is 0.9g which is twice of BNBC ground motion. Fig. 20 shows the distribution of severely damaged buildings corresponds to Ecuador ground motion and Bangladesh ground motion. Here, distribution of severely damaged buildings for Bangladesh ground motion is calculated by proportioning of the mean value of severely damaged buildings multiplying response acceleration proportion is of 0.50.

The probability of damage ratio is calculated using the correlation mentioned in Fig. 8. The estimated damage ratio is shown in Fig. 21. It has been observed that the probability of damage is about 69% using a similar damage ratio based on the recorded database. However, the probability of damage ratio is reducing to 36% considering BNBC seismicity. Therefore, the extent of seismic damage will be almost half in the case of Bangladesh BNBC ground motion.

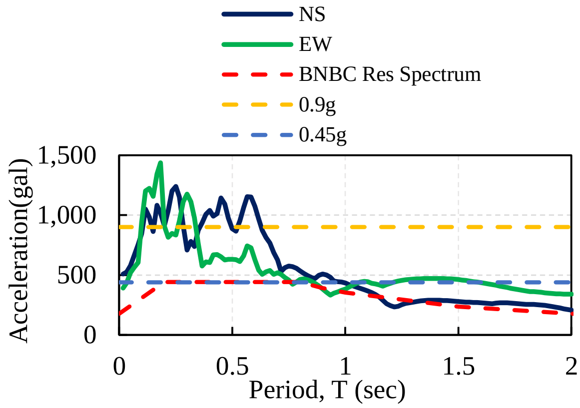


Fig. 19 Comparison of different levels of response acceleration

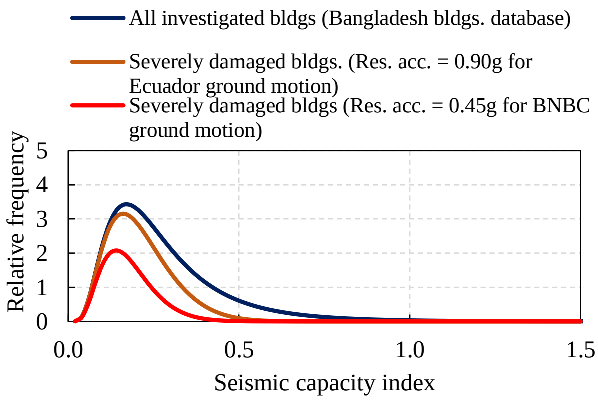
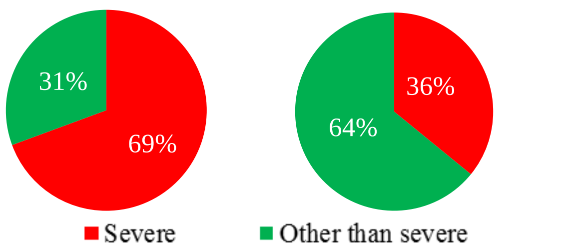


Fig. 20 Distribution of seismic capacity index for severely damaged RC building



(a) Res. acc. = 0.9g for Ecuador ground motion (b) Res. acc.= 0.45g for BNBC ground motion

Fig. 21 Probability of seismic damage due to different levels of seismicity

6.3 The 2016 Taiwan EQ building database

Fig. 22 shows a comparison between the ground motion of Taiwan EQ [3] and BNBC response acceleration. Therefore, average response acceleration is assumed 0.9g for the recorded ground motion at Station CHY 62. However, the response acceleration as per BNBC code is 0.46g which is half of the Taiwan ground motion as shown in Fig. 22.

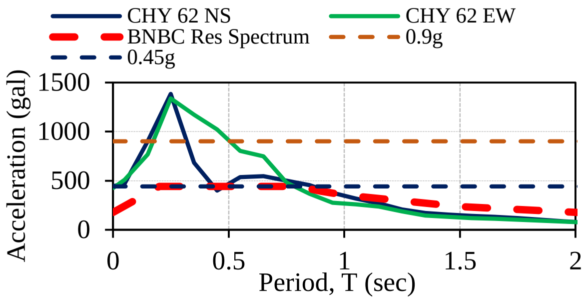


Fig. 22 Comparison of different levels of response acceleration

Distribution of severely damaged buildings is also calculated considering Taiwan EQ ground motion and BNBC ground motion as shown in Fig. 23. However, the level of seismicity in Bangladesh is half of Taiwan's EQ ground motion. Considering the proportions of seismicity level, the damage ratio has been calculated modifying the mean value of severely damaged buildings. The damage ratio considering Taiwan EQ ground motion and BNBC ground motion is of 72% and 33%, respectively as shown in Fig. 24. Taiwan is located higher seismic zone and the seismic capacity of existing buildings are much higher than Bangladesh buildings which results lower damage due to BNBC seismicity.

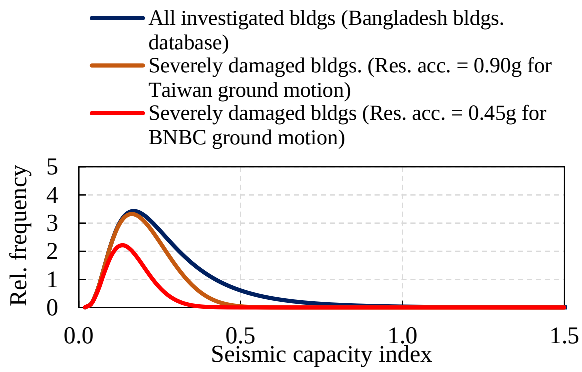
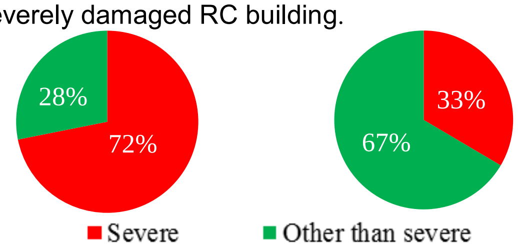


Fig. 23 Distribution of seismic capacity index for severely damaged RC building.



(a) Res acc. = 0.9g for Taiwan ground motion

(b) Res. Acc.= 0.45g for BNBC ground motion

Fig. 24 Probability of seismic damage due to different levels of seismicity

7. CONCLUSIONS

This study presents an investigation of seismic damage of existing RC building databases located at Dhaka, Bangladesh, based on past EQ damage databases in other countries. The main findings are as follows:

1. Seismic capacity of Bangladesh buildings is found lower (≈1.5 times less) than comparing with other past earthquake damage databases of the Nepal EQ, the Ecuador EQ, and the Taiwan EQ.
2. Probability of damage for Bangladesh buildings is estimated comparing with seismic capacity and ground motion intensity. The study shows that the probability of severely damaged buildings is approximated about, 43%, 36%, and 33% comparing with Nepal, Ecuador, and Taiwan earthquake damage databases, respectively.

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