- Technical Paper -

Study of Prioritization Strategy Setting for Retrofitting of Reinforced Concrete Buildings

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ABSTRACT

Several developing countries started considering retrofitting seismically vulnerable buildings as essential for safety as well from an economic point of view. However, a large stock of vulnerable buildings exists and it’s quite impossible as well as a limited budget. This study investigated several scenarios of retrofit considering the direct economic loss for the case of RC buildings in Bangladesh. Two strategies: based on the importance of building and based of vulnerability severeness were investigated based on a sample of existing buildings and economic costs and benefits were discussed.

Keywords: Damage, Repair Cost, Retrofitting Cost, Direct Economic Loss, Cost Benefit Ratio

1. INTRODUCTION

Recent several earthquakes in several developing countries such as Haiti 2010 earthquake and Nepal 2015 earthquake had severe damage to buildings and as well as in economies. Therefore, several developing countries such as Bangladesh started investigating methods for evaluating the vulnerability of buildings as well as retrofitting strategies. In Bangladesh, several projects have started the investigation of evaluating and retrofitting buildings with the help and collaboration of international agencies such as efforts by the Japan International Cooperation Agency (JICA) in several research projects such as SATREPS [1] and CNCRP [2]. Bangladesh has a large stock of vulnerable buildings as shown in previous studies by Alwashali *et. al.* [3] and Islam *et. al.* [4]. The best scenario in saving human lives and economic losses will be achieved by retrofitting all vulnerable buildings. On the other hand, the budget is limited for the case of developing countries such as Bangladesh, and retrofitting all the vulnerable buildings in a short period is also difficult. Therefore, there is a necessity to set the retrofitting prioritization criteria and effective usage of the budget to get the most beneficial outcome to save economic losses and human lives, as illustrated in Fig. 1.

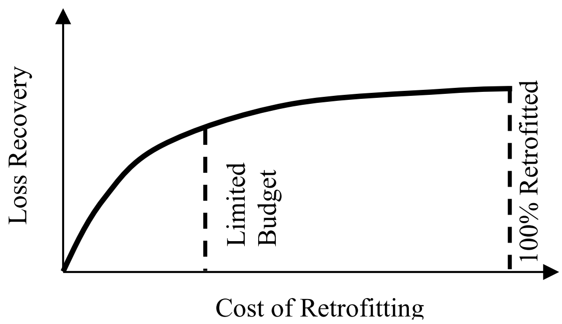

Fig. 1 Conceptual model of loss recovery vs cost of retrofitting

The objective of the study is to investigate several strategies of retrofit prioritization scenario and compare retrofit scenarios through direct economic loss recovery for reinforced concrete buildings. The direct economic loss considered in this study is assumed to be the repair cost required for building damages due to a future earthquake in Bangladesh. As a case study, the method has been investigated by applying it on 22 numbers of surveyed reinforced concrete with masonry infill buildings located in Dhaka city, Bangladesh. [5]

2. RESEARCH APPROACH

Fig.2 shows the flow diagram of the research approach. Details of each step are described in the following sections.

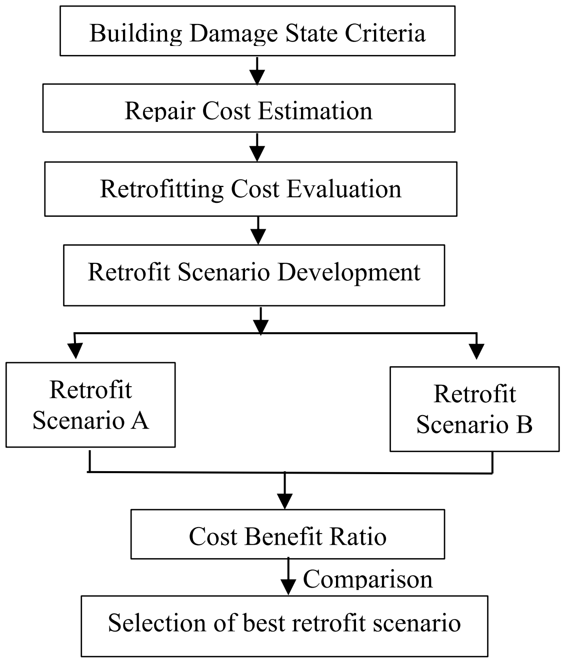

Fig. 2 Methodology adopted in the study

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2.1. Building damage estimation

It is essential to evaluate the damage state of an existing building to understand the retrofitting and repair cost. In this study, the building damage is assumed to be of five categories from slight to collapse level of damage which is also used in several past studies such as [6, 7]. There is a clear relation between expected damage and seismic capacity evaluated using the Japanese seismic evaluation standard and the seismic capacity I_s index based on previous studies in Japan [6, 7]. In a previous study by the authors [5] simplified judgment criteria of expected damage were proposed based on the seismic capacity to seismic demand ratio for the case in Bangladesh, these criteria are adopted in this study and shown in Table 1. This study evaluates the seismic capacity based on the second-level evaluation procedure as proposed in the Japanese seismic evaluation manual[11] and Bangladesh PWD-CNCRP seismic evaluation manual [2]. The expected damage is from past study [5]. The damage state is assumed in this study by assumed damage state in Table 1. When the expected damage is 'No damage' it is assumed to be 'slight damage' because the seismic capacity does not assure that there will be no damage.

Table 1 Judgment of damage criteria based on a capacity-demand ratio [5].

Capacity/ Demand	Expected Damage [5]	Assumed Damage
>1.5	No Damage	Slight Damage
1-1.5	Light Damage	Light Damage
0.75-1.0	Less Probability of collapse	Moderate Damage.
0.5-0.75	Moderate Probability of collapse	Severe damage
<0.5	High probability of collapse	Collapse

2.2. Direct repair cost of existing buildings for future earthquake

The losses due to earthquakes can be divided into direct, indirect economic losses, and human losses. The direct economic loss due to the earthquake consists of many components, such as building damages, road network damage, rail network damages, etc. are all-direct economic losses. In this study, only the direct loss due to repair of building damages are investigated.

Table 2 Damage states and repair cost (% of rebuilding cost) [8,9]

Damage state	Repair cost (% of rebuilding cost)
Slight	2%.
Light	10%
Moderate	20%.
Severe	50%.
Collapse	100%.

The direct economic loss due to building damage was considered based on assumptions taken by studies [8,9]. The repair cost is assumed for estimating the losses in correlation with rebuilding cost as a simplified procedure as shown in Table 2. For each damage state, the repair cost is assumed to be related to the rebuilding cost of the building.

Table 3 shows that the rebuilding cost for the different occupancy for Bangladesh buildings based on rough estimation in [10]. The repair cost is then calculated for the different occupancy types for certain damage states.

Table 3 Rebuilding cost for different Occupancy [10]

Occupancy	Unit Rate (US$/sqm)
Hospital	437.5
School	375
Office	337.5
Residential	312.5

This study focuses on the concept of investigating several retrofit scenarios and their prioritization method using approximate estimations rather than a detailed actual repair cost. Thus, in further studies, the actual repair cost of the building could be recalculated by adding more details for the cost estimation.

2.3. Retrofitting cost evaluation

Retrofitting can be executed by several techniques and the cost might be greatly varies depending on the retrofitting techniques. Therefore, it is very difficult to generalize the retrofitting cost with the building capacity. In this study, for simplicity, the retrofitting cost is evaluated assuming the same retrofitting techniques for all buildings. The retrofitting cost is assumed based on improving the seismic capacity by insertion of RC wing wall insertion. The size, reinforcement details are taken approximately the same for all the buildings.

The retrofitting cost is calculated on the deficiency of the building capacity to the seismic demand for a specific region. The target retrofitting is considered to be the buildings that will reach a slight damage level after retrofitting due to future earthquakes. Thus, in this study the target seismic capacity index is considered 1.5 times of the seismic demand index.

According to the Japanese seismic evaluation standard [11], the seismic index is given by Eq.1 and Eq.2

$$I_S = E_0 \text{ x } S_D \text{ x } T \quad (1)$$

$$E_0 = C \text{ x } F \quad (2)$$

Where I_S = Seismic index
E_0 = Basic Seismic Index
C = Strength Index = Q/W
Q = Minimum (Shear strength, flexural strength)
W = Weight of the building
F = Ductility index
S_D = Irregularity index
T = Time index

In this study, for simplicity, the irregularity index and time index are assumed to be unity. Rearranging Eq.1 and Eq.2, then the additional strength requirement is given by Eq. 3.

$$\Delta Q = \Delta I_s \text{ x } W / F_{exp} \quad (3)$$

Where ΔQ = Required additional strength
ΔI_S = Required additional seismic index
= I_S (target) – I_S (existing)
I_S (target) = Target seismic index = 1.5 x I_{S0}
I_{S0} = Seismic demand index
I_S (existing) = Existing building's seismic index
W = Weight of building at evaluated story
F_{exp} = Expected ductility index after retrofitting.

In this study, the retrofitting criteria are to improve the seismic capacity that slight damage would be expected during an earthquake. Thus, the criteria will be that capacity to demand ratio is equal to 1.5 (as shown previously in Table 1),. The retrofitting method is assumed to be an insertion of RC wing walls (attaching wing walls to existing RC columns). The average shear strength of RC wing walls is taken as 1.5 MPa based on [2] and the thickness of RC wing walls is considered 150 mm. The cost of retrofitting using RC wing wall insertion is considered roughly as 270 US$/sqm which is based on reviewing costs of several recent seismic retrofitting projects in Bangladesh building [2]. The cost of renovation work and transportation cost of materials have not been considered in this study for simplicity and could be added in further detailed cost analysis.

2.4. Development of retrofit prioritization strategy

The target for retrofit prioritization is to get the maximum benefit for money to be invested. Retrofit prioritization can have different strategies considering the amount of fund, the risk, and the loss prediction due to damages and collapse. The following sections investigate two different retrofit prioritization strategies studied. Fig. 3 shows that the retrofit scenarios that are taken into consideration for setting retrofit priority.

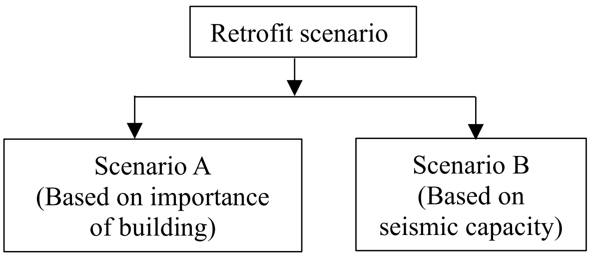

Fig. 3 Retrofit strategy for prioritization

In Fig.3, the retrofit scenario A for retrofit prioritization is considered to be by putting priority the most important buildings first. The building is given priority in descending order of importance of the building. The reason for choosing the different occupancy is that some of the building occupancies are given higher priority to retrofit as the functions of the buildings are essential such as hospitals, fire services, school buildings. The roles of these buildings are very much essential to keep all the emergency time support. The next is given that the relatively lower important buildings like some offices, garments industry, factory, etc. These all have a very much large impact to run the economy of the country smoothly. The next is retrofitting residential, and low-important office buildings. Among one category of buildings, the buildings are sorted in accordance with low to high seismic capacity. Then the less important in descending order. Fig.4 shows the explanation of retrofit scenario A.

Occupancy	Phase-1	Phase-2	Phase-3
Hospital/ School/Fire service	Low I_{S2} ↓ High I_{S2}		
Office, garments factory		Low I_{S2} ↓ High I_{S2}	
Residential, low important office			Low I_{S2} ↓ High I_{S2}

Fig. 4 Explanation of Retrofit Scenario A

The retrofit scenario B is based on the seismic capacity, where the most vulnerable buildings are to be retrofitted first. Then with increasing seismic capacity, the priority is given lower regardless of the occupancy. The building's seismic capacity is the prioritizing criteria in order to retrofit the planning strategy. The buildings are first categorized with the damage states. Then within a specific damage state, the buildings are sorted with low to high seismic capacity. Fig. 5 shows the illustration of scenario B.

Damage Level	Phase -1	Phase -2	Phase -3	Phas e -4	Phase -5
Collapse	↓				
Severe		↓			
Moderate			↓		
Minor				↓	
Slight					↓
Seismic Index, I_{S2}	Lowest → Highest				

Fig. 5 Explanation of Retrofit Scenario B

There could be several other scenarios of retrofit such as random selection of buildings based on location-wise and incremental retrofit. However, those scenarios are not considered in this study, and two scenarios the retrofit scenario A and retrofit scenario B have been considered to show the comparison as it is convenient and easily applicable to existing buildings in Bangladesh.

2.5 Judgement of retrofitting prioritization

The retrofitting prioritization is considered to be selected based on the benefit or loss recovery (Δ_{Rec}) per retrofitting cost (Ret_{cost}), as shown in Fig.6. After retrofitting buildings on priority basis before earthquake will result in reducing repair cost of the retrofitted buildings. Although the cost of retrofitting is increased with retrofitted buildings number. Benefit due to retrofitting (Δ_{Rec}) is obtained from the maximum cost minus the total cost, that decrease with the increase of % of building retrofitted. The total cost is the summation of the retrofitting cost (before earthquake) and the repair cost (if an earthquake occurs). The maximum benefit can be approached when the repair cost becomes zero; however, the retrofitting cost is high. Therefore, the ratio between Δ_{Rec} and Ret_{cost} is considered as the cost-benefit ratio (CBR), calculated by Eq.4.

$$CBR = \frac{\Delta_{Rec}}{Ret_{cost}} \tag{4}$$

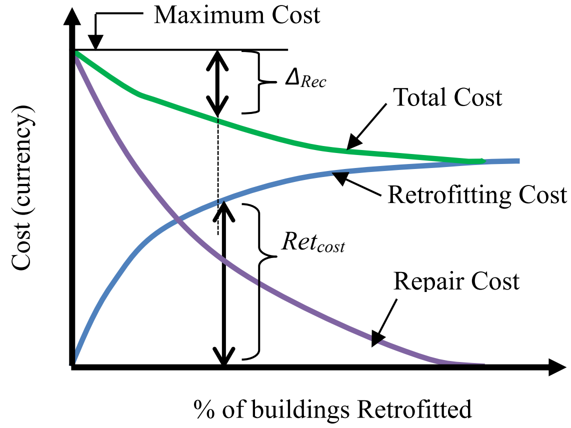

Fig. 6 Conceptual model of cost benefit ratio

Fig.6 shows that the total cost will be same as retrofitting cost when repair cost is theoretically zero. But in reality the repair cost after all the buildings being retrofitted does not become zero, that is because even after the retrofitting all the buildings, the damage slight damage would occur is considered.

The higher the cost-benefit ratio is the better effectiveness of the money utilization. Therefore, for proper utilization of the money, the cost-benefit ratio is could be as one important parameter for judgment of suitable retrofit prioritization strategy based on a limited funds.

3. APPLICATION AND RESULTS

3.1 Overview and damage state evaluation of buildings

As a simple case study, 22 buildings numbers were surveyed buildings under a research SATREPS project located in Dhaka, Bangladesh and details of those buildings are summarized in [5]. The buildings are public buildings constructed and maintained by Public Works Department (PWD), Bangladesh. The construction year varies from 1968 to 2009 [5].

Table 4 shows the general information and seismic index, I_{S2} in the minimum direction, and the related damage states. The buildings are located in Dhaka which is a moderate seismic zone (Zone factor, Z = 0.2) according to [12] and the foundation type is SC type. According to the CNCRP seismic evaluation manual [2], the seismic demand index is considered as I_{so} = 0.3. As the target damage level is slight damage, the target seismic index after retrofitting is considered 0.45. Due to the absence of a past earthquake database, in this study, damage state is defined based on the ratio between the seismic capacity index and the seismic demand index ratio as explained previously. It should be noted that the damage state of these buildings is estimated considering the minimum seismic capacity index (I_s) between transverse and longitudinal direction as shown in Table 4. The buildings' list with different predicted damage states is shown in Table 4.

Table 4 Information of the surveyed buildings [5]

Bldg . ID	Occupancy	No of story	Floor area (sqm)	Seismic index, I_{S2} (Min)	Damage states
1	School	2	176.9	0.630	Slight
2	Office	5	402.6	0.152	Severe
3	Residential	6	174.2	0.310	Light
5	Residential	6	122.6	0.440	Light
6	Office	4	513.0	0.340	Light
7	Office	3	261.7	0.468	Slight
8	Office	5	157.3	0.390	Light
9	Office	3	704.4	0.530	Slight
10	Office	8	466.8	0.410	Light
11	Hospital	10	265	0.224	Severe
12	Office	6	442	0.152	Severe
13	School	2	208.4	0.480	Slight
14	Residential	6	179.7	0.360	Light
15	Residential	5	136.9	0.350	Light
16	Office	3	324.5	0.234	Moderate
17A	Office	4	355.8	0.380	Light
17B	Office	4	434.8	0.37	Light
18A	Residential	10	105.6	0.600	Slight
18B	Residential	10	647.3	0.35	Light
19	Office	6	375.0	0.154	Severe
20	Office	7	608.5	0.198	Severe
21	Office	12	1780	0.297	Moderate

It is evident from Table 4, most of the surveyed buildings are office and residential type buildings. The rest are hospital and school buildings. The floor area distribution show that the most of the office building's floor area is higher than the residential buildings.
Fig.7 shows the occupancy-wise damaged buildings for the surveyed buildings.

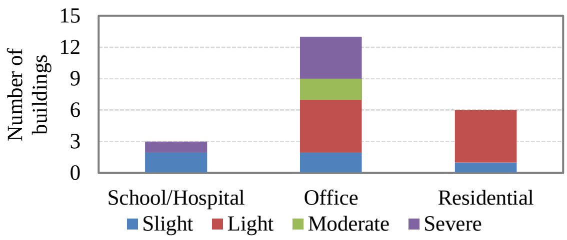

Fig.7 Damage of surveyed buildings

3.2 Retrofitting cost estimation for buildings

The retrofit cost is evaluated based on section 2.3. The simple method has been considered for retrofitting cost estimation. The RC wing wall is considered for all buildings for simplicity. The retrofitting cost for each building is estimated for all the stories. The buildings are located in Dhaka.

3.3 Results of different retrofit scenarios

The retrofit scenarios A and B are applied to the existing surveyed buildings as mentioned in section 2.4. The repair cost after each damage level is calculated by considering the building is being retrofitted according to the scenarios A and B. The total cost is estimated by the sum of repair cost and retrofitting cost. Fig. 8 and Fig. 9 show cost vs retrofit (%) for scenario A and Scenario B respectively.

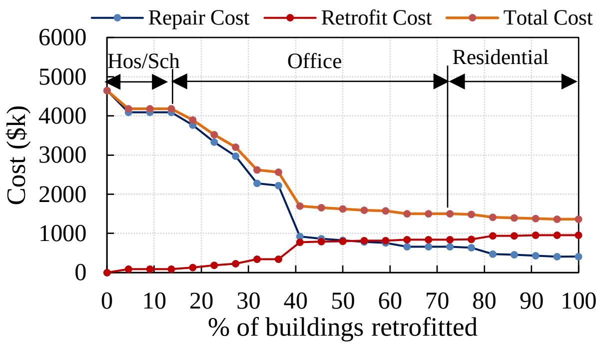

Fig. 8 Cost vs % of retrofitted buildings for scenario A

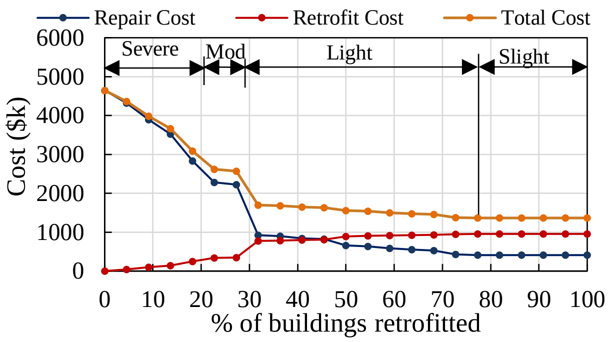

Fig. 9 Cost vs % of retrofitted buildings for scenario B

3.4 Comparison of retrofit scenarios

The cost and retrofit (%) of buildings are compared for scenario A and scenario B as shown in Fig.10. The comparison shows that the total cost recovery due to retrofitting is higher for scenario B compared to scenario A.

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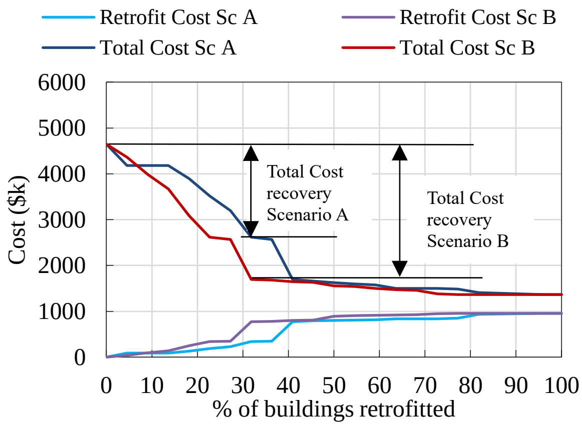

Fig. 10 Comparison between Scenario A and B

The cost-benefit ratio is estimated for each building by Eq.4 mentioned in section 2.3. The cost-benefit ratio for different occupancy-wise is given in Fig.11. Fig.11 shows the cost-benefit ratio for hospital building in terms of total cost recovery is higher. This is due to a similar amount of retrofitting that will save much more valuable property. Fig.12 shows that the severely damaged building retrofitting has much impact on cost-benefit ratio. The cost-benefit ratio if the probable to the severely damaged building is retrofitted the cost-benefit ratio is approximately 1.5 times higher than moderately damaged buildings. As the target damage level is slight damage. The building with slight damage is considered to be not retrofitted

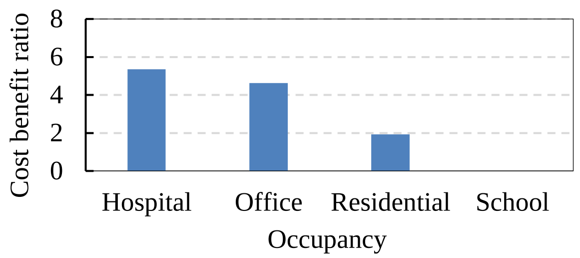

Fig. 11 Cost benefit ratio in terms of occupancy

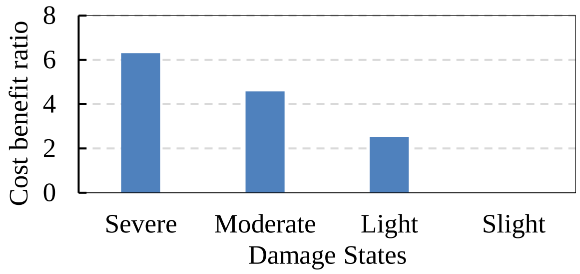

Fig. 12 Cost benefit ratio in terms of damage states

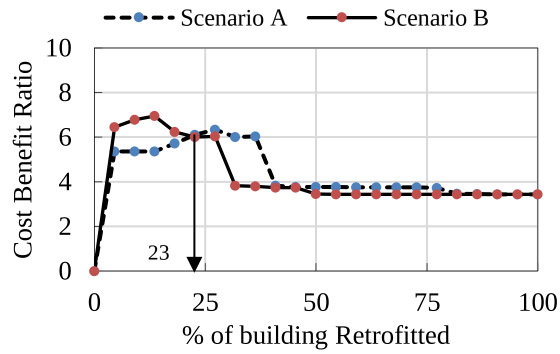

Fig. 13 Comparison of Retrofit Scenarios in terms of cost-benefit ratio

Scenario A and scenario B comparison with respect to cost-benefit ratio is shown in Fig.13. Fig.13 shows that scenario B has a higher cost-benefit ratio compared to scenario A until 23% of buildings are retrofitted. It means that until 23% of buildings are retrofitted by the same amount of retrofitting cost will give a higher total cost recovery in case scenario B compared to scenario A. The total cost recovery is achieved earlier for scenario B by retrofitting less amount of building compared to scenario A.

4. CONCLUSION

In this study, the retrofitting prioritization method was investigated based on two scenarios for surveyed buildings considering direct economic loss which is represented by repair cost due to earthquakes.

The main findings are as follows:

- It has been observed that retrofit scenario B (priority based on vulnerability showed relatively better effectiveness than retrofit scenario A (priority based on the importance of building) since the recovery due to retrofitting is achieved by retrofitting a fewer number of buildings.
- The cost-benefit ratio based on occupancy-wise due to retrofitting show that higher cost benefit ratio for the important building as the same retrofitting will save valuable property.
- The cost-benefit ratio proposed in this method could be used as one of the judging criteria for retrofit prioritization in case of limited funds.

The followings points need further future investigation:

- The number of buildings is only 22 buildings. The scenario may give bigger overall image of Dhaka city in Bangladesh if it can be applied to a larger number of buildings.
- Further details could be added for estimating damage repair cost and retrofitting cost to get more accurate results the damage repair cost and retrofitting cost should be more precise. The scenario may give better results if it can be applied on a larger number of buildings.
- The indirect loss and human loss are not considered for retrofitting scenarios and need to consider to have a full picture of the effectiveness of retrofitting scenarios and complete judgment for prioritization.
- Developing the retrofit prioritization strategy setting has been discussed in this study. The study is implemented on relatively a small building sample in an area of Bangladesh. The methodology presented in this study could be applied to larger scaler area. However, it should be noted that values presented in this study for Bangladesh case could differ from area to another based on the building's seismic capacity, occupancy and floor area, type of buildings.

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