SEISMIC EVALUATION & RETROFIT OF A FIVE-STORIED REINFORCED CONCRETE BUILDING IN BANGLADESH

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ABSTRACT

Bangladesh is located in a seismically active region. Many low-rise reinforced concrete (RC) buildings constructed before the implementation of the Bangladesh National Building Code 2020, which incorporates ductile detailing-based seismic design, are vulnerable to seismic hazards. Seismic evaluation of existing buildings is necessary to determine the seismic disaster risk in Bangladesh. This study aims to evaluate the seismic performance of a low-rise RC public building that was constructed before 2020 according to the detailed seismic evaluation method, situated in Sylhet, a high seismic hazard area. This method is useful for determining the seismic capacity of each story and can effectively calculate the amount of retrofitting required in each story. Based on performance deficiency using the seismic indices, three combinations of seismic retrofitting techniques involving steel-framed braces (SFB), RC shear walls, and partially grouted reinforced masonry (RMP) walls were investigated. All options were satisfactory in terms of the seismic requirements. After considering architectural and functional constraints, construction feasibility, and a comprehensive cost estimation, the insertion of RC shear walls and RMP walls emerged as the most effective retrofitting strategy for the target building in the X and Y directions, respectively. This study found that retrofitting with RMP walls is an excellent, low-cost solution for Bangladesh, as it provides substantial strength to enhance seismic resilience, safeguard lives, and decrease damage during earthquakes.

Keywords: The detailed seismic evaluation method, reinforced concrete building, seismic retrofit, cost estimation, partially grouted reinforced masonry wall.

1. INTRODUCTION

Bangladesh is highly susceptible to disasters and is known for its catastrophic cyclones, devastating floods, and significant seismic risks. This nation lies at the convergence of three tectonic plate boundaries: the Eurasian plate, the Indian plate, and the Burmese plate. The seismic activity in the region is a result of the movements of these plates, which include several active fault lines, such as the Madhupur Fault and the Dauki Fault.

Along with the high seismic risk and high population density, particularly in urban areas, the presence of soft alluvial soil layers, and limited enforcement of design code and standard construction practices significantly elevated seismic vulnerability. This situation worsens because of the widespread lack of public awareness of seismic hazards and building safety. Consequently, many residents remain unknowingly exposed to structures that may not adequately resist even moderate seismic events, significantly increasing the potential damage and casualties.

The second edition of the Bangladesh National Building Code (BNBC) was enacted in 2020. The latest edition of the code features notable changes in lateral load calculations, and for the first time, the ductile detailing of structures was included. But most of the buildings constructed before 2020 do not comply with the updated seismic provisions of the new BNBC. The high costs and technical complexities inherent in seismic retrofitting of existing structures represent a major obstacle in

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Bangladesh. Therefore, considering the volume of structures requiring intervention, the development of low-cost and readily implementable retrofitting techniques is crucial for the country.

2. DATA

The five-storied RCC target building was constructed in 1984 by the Public Works Department, Bangladesh, prior to the implementation of the first National Building Code of Bangladesh (1993). The building is located in Sylhet, which is in seismic zone 4 (as per BNBC 2020). The various essential information about the target building is shown in Table 1. The building has two types of columns with shear reinforcement spaced at 300 mm, and it also contains three types of beams. Typical beam-column layout, elevations, and column schedule are presented in Figures 1 and 2.

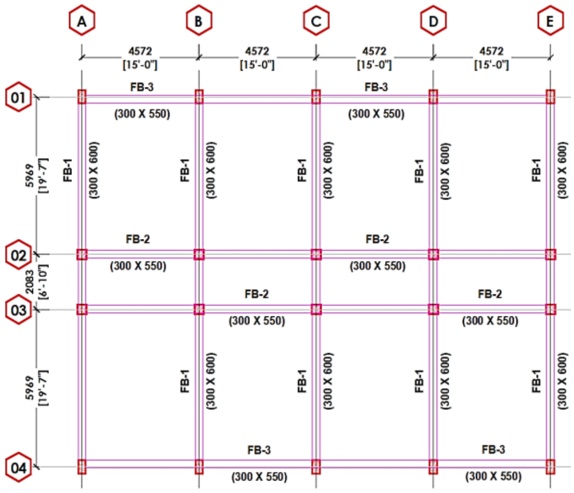

Figure 1. Beam-Column layout of typical floor.

Table 1. Basic Information: target building.

Item	Information
Name of the building	Five (5) Story Public Building
Number of stories	Five (5)
Structure type	Reinforced Concrete Office Building
Occupancy category	II
Importance factor	1.00
Seismic Zone	4 (Z=0.36, BNBC 2020)
Soil Type	SC (BNBC 2020)
Concrete strength	13.78 MPa
Steel yield strength	275 MPa
Total seismic weight	16073.8 kN
Year of construction	1984

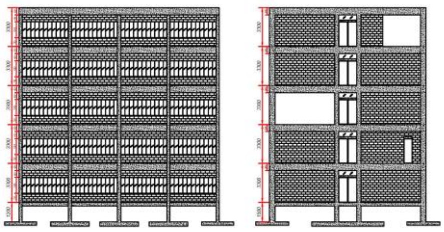
Figure 2. Elevation-1(Left) and elevation-A (Right).

Table 2. Column schedule

Column Index	Up to 2nd Floor	3rd Floor to Roof	Column Index	Up to 2nd Floor	3rd Floor to Roof
	Clear cover =40mm	Clear cover =40mm		Clear cover =40mm	Clear cover =40mm
C1	375 × 375, ● 12- d25	375 × 375, ○ 12- d20	C2	300 × 500, ● 10- d25	300 × 500, ○ 10- d20
Tie: d10@ 300 mm c/c; Legends: ● - d25 ○ -d20					

3. METHODOLOGY

3.1 Seismic evaluation using the DSE method

The detailed seismic evaluation method, Y.Nakajima et al (2020), integrates the Japanese seismic evaluation standard—the JBDPA (2001) guidelines, and the ASCE 41-13 and ATC 40 standards for modeling parameters and pushover analysis. The method is also aligned with the ISO seismic retrofit framework 16711:2021. The method adopted the ultimate point (UP) as the performance limit for the capacity of a structure (Figure 3). Then, each story's capacity, strength, and ductility indices were calculated from the story drift-shear force relationship using Equations 1 to 3 (Figure 4). For structures with structural walls, the ductility index was calculated using Equation 4 and Table 4. Then, the amount of retrofit required for each floor in both directions was calculated using Equation 5. In this study, commercial software ETABS was used for pushover analysis.

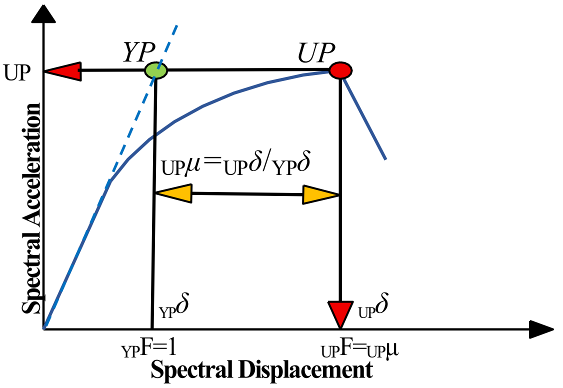

Figure 3. Evaluation of C & F index by UP (Adapted from Y. Nakajima, M.Seki, H. Suga and R. Islam, 2020).

Table 3. Legends of points of Figure 3.

Point	Yield	Ultimate Point of Member
	(green dot)	(red dot)
Notation	YP	UP
Strength	$_{YP}C$	$_{UP}C$
Deformation	$_{YP}\delta$	$_{UP}\delta$

$$I_{si} = \varphi_i \, . \, C_i \, . \, F_i \quad (1)$$

$$C_i = Q_i / W_i \quad (2)$$

$$F_i = \frac{\delta_i}{\delta_{yi}} \quad (3) \qquad R = \frac{\delta_i}{H} \quad (4)$$

Where, I_{si} = Seismic Index of i-th story, C, F are the strength and ductility indices, W= Seismic weight of building, R= Horizontal drift angle at UP., H= Story height and $\varphi_i = n+i/n+1$.

Table 4. Relationship between F-index and horizontal drift angle.

F-index	1.0	1.27	1.75	2.0	2.6	3.2
Rotational angle: R(Rad)	1/250	1/150	1/100	1/82	1/50	1/30

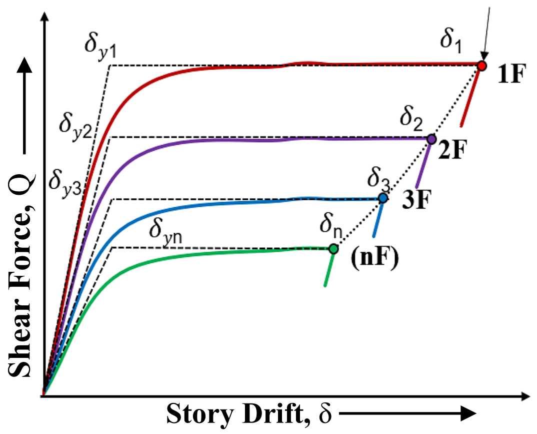

Figure 4. Story-wise shear force-story drift relationship by story restrained pushover analysis (Adapted from: BSPP Seismic Evaluation manual, 2nd Edition).

$$\Delta Q_i = {}_R\Delta\, C_i \times \sum W_i = \frac{n+i}{n+1} \times \frac{1}{{}_RF_i} \times \left(\frac{{}_RI_{si}}{S'_D \, . \, T'} - \frac{I_{si}}{S_D . \, T} \right) \times \sum W_i \quad (5)$$

Where,

ΔQ_i = Required shear strength at i-th story

${}_R\Delta C_i$ = Required strength index at i-th story $= {}_RI_{so} / {}_RF_i - Ci$

${}_RI_{so}$ = Newly defined I_{so} depending on the retrofitting system

${}_RF_i$ = Intended ductility index for retrofit for i-th story $\leq F_i$

${}_RI_{si}$ = Target seismic index at i-th story.

I_{si} = Seismic index of *i-th* story before retrofit

S_D, S'_D= Irregularity index before and after retrofit

T, T'= Time index before and after retrofit

n = number of stories

3.2 Seismic evaluation of retrofitted structure

In this study, steel-framed brace (SFB) and RC shear walls were investigated as potential retrofitting solutions. Additionally, a new and potentially low-cost solution, the RMP wall, was investigated to identify the most appropriate retrofit strategy for the building. Partially grouted reinforced masonry (RMP) walls and Fully Grouted Reinforced Masonry walls (RMF) are the two types of reinforced masonry walls by Sugano et al. (2024). RMF walls have a structure in which all masonry units are filled with grout, while RMP walls (Figure 5) have masonry units in which only those parts that are reinforced with steel bars are filled with grout. The shear strength of RMP walls was calculated using Equations 6 to 8. Equation 7 yields the shear strength of unreinforced masonry infill for diagonal cracking-sliding type failure by Seki et al. (2024), and Equation 8 yields the shear strength contribution by the steel reinforcement by AIJ (2021).

$$Q_{RMP} = Q_{sld} + Q_{su} \quad (6)$$

$$Q_{sld} = \frac{\tau_{inf}\, t_{inf}\, l_{inf}}{1-\mu \frac{h_{inf}}{l_{inf}}} \quad (7)$$

$$Q_{su} = 0.85\sqrt{\rho_w + \sigma_{wy}}\left(t_{inf}.j.r\right) \quad (8)$$

Where, Q_{RMP}, Q_{sld} and Q_{su} represent the shear strength of the the RMP wall panel, the shear strength contribution by the masonry wall, and the shear strength contribution by the steel reinforcement, respectively.

t_{inf}, l_{inf}, and h_{inf} are the thickness, length, and height of the wall panel, and τ_{inf} is the shear strength of the wall panel. ρ_w, σ_{wy} are the shear reinforcement ratio and the yield strength of the shear reinforcement, respectively.

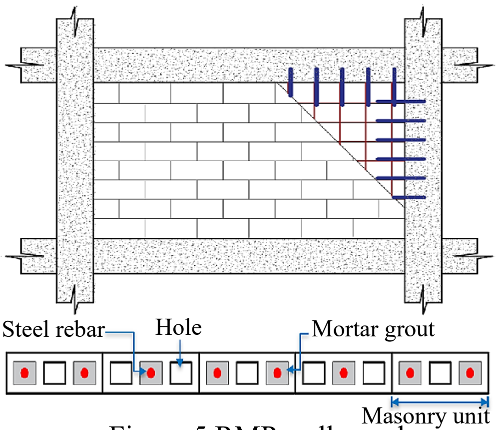

Figure 5.RMP wall panel

4. RESULTS AND DISCUSSION

The seismic demand index, as per BNBC 2020, is calculated using the Equation (9):

$$I_{so} = \frac{2}{3}\, ZIC_s \quad (9)$$

$$= \frac{2}{3} \times (0.36) \times (1.0) \times 2.78 = 0.667$$

Where, Seismic zone co-efficient, Z= 0.36
Structural importance factor, I = 1.0
Normalized acceleration response spectrum, C_s= 2.78, is a function of soil type (SC) and the fundamental period of the building, which was calculated to be 0.62 sec.

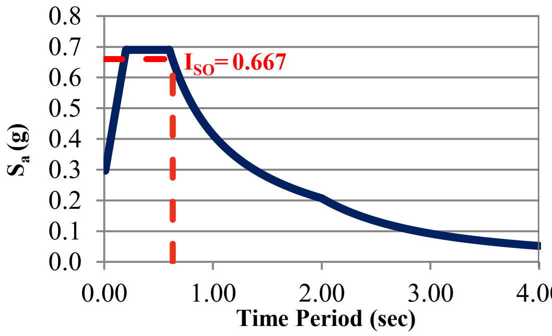

Figure 6. Seismic demand

Seismic evaluation of the building was performed using the DSE method, and C and F indices were calculated for each story in both directions using Equations 1 to 3. From the pushover analysis, the lower stories reached their limit, but upper stories remain intact; therefore, a restrained pushover analysis was required to determine the Is values of each story, and from the result, the existing building requires retrofitting in both directions up to the 4th floor. The building was investigated with three retrofitting strategies- option-1 (SFB in both directions), option-2 (RC shear walls in both directions), and option-3 (RC shear walls in X-direction and RMP walls in Y-direction). According to the 2nd level screening procedures, retrofitting arrangements for each option are tabulated in Table 5. Each of the retrofitting strategies satisfies the seismic demand of the building.

Table 5. Story-wise arrangement of different retrofitting strategies.

Floor	Option-1		Option-2		Option-3	
	X (SFB)	Y (SFB)	X (RC SW)	Y (RC SW)	X (RC SW)	Y (RMP)
5th F	-	-	-	-	-	-
4th F	2	2	2	2	2	2
3rd F	2	2	2	2	2	2
2nd F	2	4	2	4	2	4
1st F	4	4	6	4	6	8

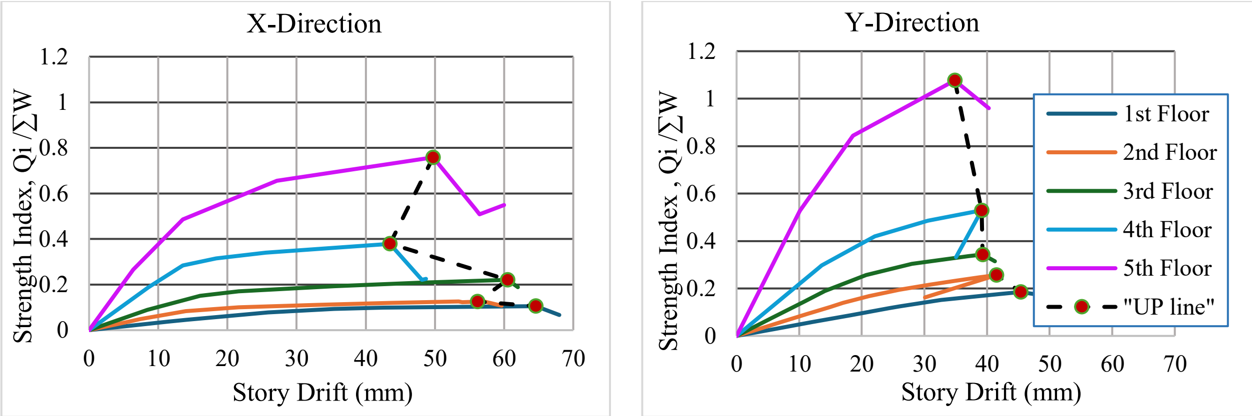

Figure 7. Story drift Vs strength index in X-direction (Left) and in Y-direction (Right) of existing structure.

A detailed cost analysis was performed according to the PWD schedule of rates for retrofit works 2022 (R), and the results are shown in Figure 8. Option-3 is the most economical retrofitting solution among the alternatives.

The most suitable retrofitting strategy was chosen according to the seismic performance evaluated by the 2nd level screening procedure, detailed cost analysis, architectural and functional constraints, construction complexity, etc. From the selection matrix (Table 6), it is evident that option-3 is the most appropriate retrofitting strategy for the building.

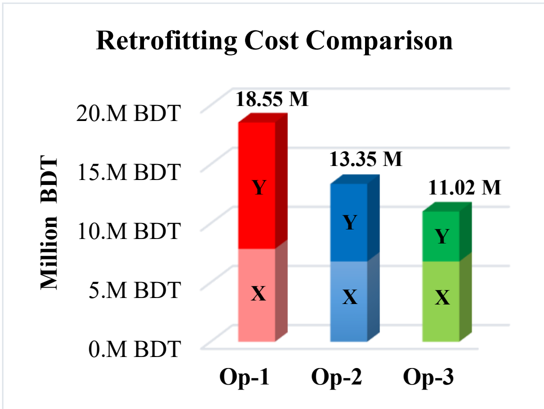

Figure 8. Cost comparison: retrofitting strategies.

Table 6. Selection matrix for the most appropriate retrofitting strategy

Sl No.	Selection Criteria	Option – 1		Option – 2		Option – 3	
		X	Y	X	Y	X	Y
1	Seismic Demand	☑	☑	☑	☑	☑	☑
2	Cost	×	×	⚠	⚠	⚠	☑
3	Architectural & Functional Constraints	⚠	⚠	⚠	☑	⚠	☑
4	Construction Complexity	×	×	⚠	⚠	⚠	☑
5	Increase in Building Weight	☑	☑	☑	☑	☑	☑

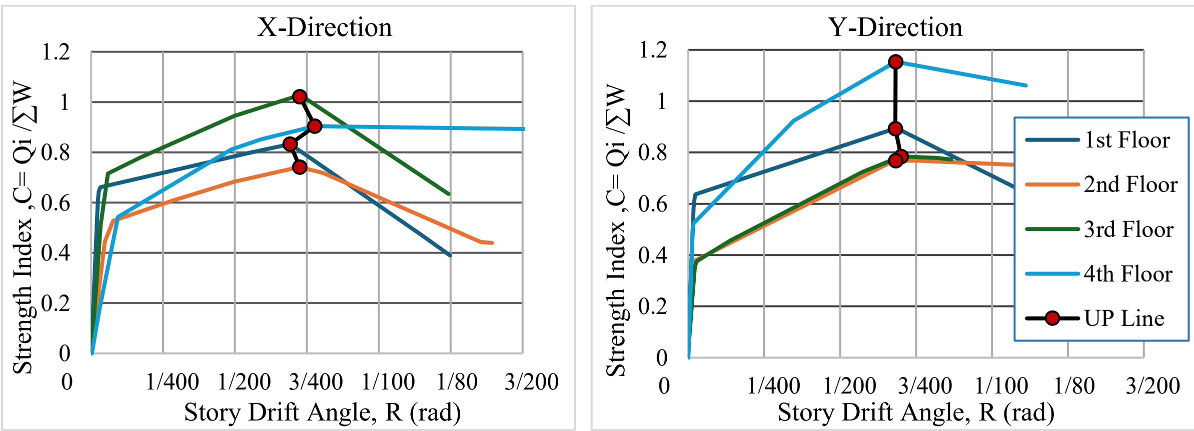

Figure 9. Story drift angle Vs strength index in X-dir (Left) and in Y-dir (Right) of retrofitting structure

The seismic performance of the building retrofitted with option-3 was evaluated again using the DSE method. As rigid members, RC shear walls or RMP walls can significantly change structural behavior by decreasing the building's fundamental period and, consequently, changing the seismic demand. Therefore, the revised seismic demand index was calculated, ${}_{R}I_{so}$= 0.69. C and F indices of the retrofitted structure were calculated using Equations 2, 4 and Table 3. From the story drift angle vs strength index graph (Figure 9), notable improvement in strength was observed and drift angle at UP ranges from 1/125 to 1/150 for both directions.

Story-wise seismic index I_s is presented in Figure 10. From the figure it is evident that retrofitting option-3 satisfied the seismic demand for each story and both directions.

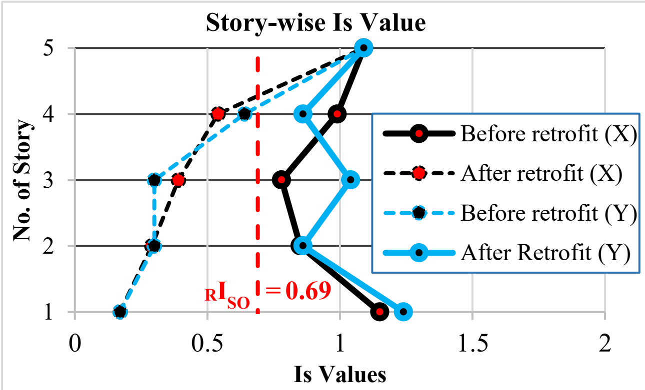

Figure 10. Comparison of I_s before and after retrofit

5. CONCLUSIONS

The seismic evaluation of the bare frame structure was performed using the DSE method. The existing structure showed very low strength in the X-direction and very low ductility in the Y-direction for an RC structure. Seismic retrofit was required up to the 4th floor in each direction. Three retrofitting strategies incorporating SFBs, RC shear walls, and RMP walls were investigated according to the 2nd level screening procedure. Considering the seismic performance of 2nd level screening, architectural feasibility, construction complexity, and cost, option 3—the strategy of using RC shear walls in the X-direction and RMP walls in the Y-direction—emerged as the most appropriate retrofitting solution. This was confirmed by the seismic evaluation of the structure retrofitted with option 3 using the DSE method. In this study, RMP walls were found to be a lightweight, cost-effective, and easy-to-implement retrofitting solution that also makes better use of locally available materials, offering a viable alternative to RC shear walls for seismic retrofitting and for new construction.

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