Global Retrofitting Strategies for an Existing Three-storied RC School Building in Mandalay, Myanmar

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ABSTRACT Low to severe earthquakes occur around the world every year, damaging and causing structural failure in buildings. Consequently, seismic improvements are required for existing buildings that are vulnerable to damage by seismic forces. The objective of this study was to investigate retrofitting strategies in terms of their sustainability. Mandalay, Myanmar, was selected as the study area as it is located near the Sagaing fault, which itself is in a strong earthquake zone (seismic zone 4). A three-storied RC building with a non-seismic design was selected as a case study building. An investigation was carried out into the performance and vulnerability of the building under three earthquake hazard levels. The vulnerability index value was calculated using the Priority Index method. Meanwhile, non-linear static pushover analysis was performed to investigate the performance of the existing building using SAP2000 V14 software. Four different types of retrofitting strategies were considered, namely reinforced concrete shear walls with openings, reinforced concrete shear walls without openings, steel plate shear walls, and finally steel bracing. Among these, it was found that the use of steel plate shear walls was the best retrofitting technique, owing to it having the best performance along with the lowest displacement. Its performance level reached up to the Immediate Occupancy (IO) level even under the conditions of a Maximum Consider Earthquake (MCE).

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1. INTRODUCTION

Earthquakes are one of the serious natural disasters on Earth. Unlike other disasters, there is no sign or warning to enable preparations against damage or the collapse of buildings caused by an earthquake. The only way to prevent this damage is to consider the seismic load in new and existing buildings. Non-seismically designed buildings have deficient lateral load resistance and can rapidly lose their performance during an earthquake, leading to collapse. Therefore, both gravity loads and lateral loads should be considered in the analysis of new and existing buildings.

According to the surveying data from the Mandalay City Development Committee, most of the existing buildings in Mandalay, Myanmar, have been designed only for gravity loads, not for the seismic load. Mandalay is situated in seismic zone 4 near the Sagaing fault (Thant et al. 2012), and hence the main consideration must be seismic load. The proposed school building was mostly focused on the effects of gravity loads and they did not contribute to providing seismic loads as stated in as-built drawings. While seismic load was considered by adding to the original design, the performance of the building was poor and thus, retrofitting strategies had to be examined.

In this study, there were two main parts. The vulnerability and performance level of the existing building was the first part of the study. The second part was to improve the performance level of the existing school building by

retrofitting. The existing building was retrofitted by considering externally strengthening the structure, with the insertion of bracing or shear walls at some locations. The purpose of the study was to upgrade the seismic safety of the existing building to the desired level with the best and most appropriate techniques in a short time, with minimum cost (Thwe and Thwin 2020).

2. MATERIALS AND METHODS

2.1 Study area

The proposed building was No-14 Basic Education High School, a three-storied, non-seismic reinforced concrete (RC) building, located on 80th street between 32nd and 33rd street, Chan Aye Thar Zan Township, Mandalay, Myanmar. Mandalay is very close to the Sagaing fault, which is a major fault in Myanmar. Therefore, the proposed school building was selected to investigate the existing structural performance level and to identify which type of retrofitting techniques would be suitable for it.

2.2 Method

The vulnerability assessment of the existing RC building was checked using the Priority Index (PI) method. The PI method was studied by Hassan and Sozen using data from the Turkey earthquake (Nyein 2018). It was tested by O'Brien et al. in Haiti (Nyein 2018), following which it was

found that a smaller priority index corresponds to higher seismic vulnerability. The PI method does not require time-consuming and impractical dynamic analysis. Furthermore, this method is developed for low-rise buildings, masonry infill walls, non-engineered buildings, and poor reinforcement detailing (Hassan and Sozen 1997).

Hassan and Sozen (1997) have defined vulnerability indices related to base shear strength as follows (Equations 1, 2, and 3).

$$\text{Column Index} = \frac{1}{2} \frac{A_{\text{col}}}{A_{\text{floor}}} \quad (1)$$

$$\text{Wall Index} = \frac{A_{\text{RC wall}} + \frac{1}{10} A_{\text{mw}}}{\sum A_{\text{floor}}} \quad (2)$$

$$\text{Priority Index} = \frac{0.5 A_{\text{col}} + \sum A_{\text{RC wall}} + \frac{1}{10} \sum A_{\text{mw}}}{A_{\text{floor}}} \quad (3)$$

where A_{col} is the cross-sectional area of columns at ground level, $A_{\text{RC wall}}$ is the cross-sectional area of RC walls in one horizontal direction, A_{mw} is the cross-sectional area of infill masonry walls in one horizontal direction, and A_{floor} is the summation of floor areas above the base level.

This method requires only the dimensions of the structure as the input and is based on defining the position of a building on a two-dimensional plot using the wall and column indices. The wall index, WI, is the ratio of the effective wall area at the base of the building to the total floor area above the base. In the computation of the effective area, 100% of reinforced concrete walls, 10% of non-reinforced infill walls, and 50% of column area are considered effective. Hassan and Sozen (1997) observed the vulnerability of reinforced concrete structure to decrease with increasing combinations of column and wall indexes. It follows that vulnerability decreases as the sum of column and wall indices increase. An additional index was defined by Hassan and Sozen (1997) as the sum of the column and wall indices. It was termed the "Priority Index." According to Turkey earthquake damage data, a building is vulnerable to earthquakes if its PI value is less than 0.4, and non-vulnerable to earthquakes if its PI value is greater than or equal to 0.4 (Dönmez and Pujol 2005). Furthermore, the PI value can be classified into five categories. When PI values range from 0 to 0.099, the building is defined as collapsible, 0.1-0.199 as severe, 0.2-0.299 as in a moderate state, 0.3-0.399 as light, and ≥ 0.4 as non-vulnerable (Zhou et al. 2013).

2.3 Tools and materials

An investigation was conducted on whether the actual strength, arrangement, and sizes of reinforcing bars and concretes constructed are complying with a design drawing. The investigation materials used were a concrete rebound hammer, rebar detectors, Vernier calliper, and measuring tape. Non-linear static pushover analysis was carried out in SAP2000 software to investigate the perfor-

mance of the building before and after retrofitting based on the three earthquake hazard levels.

2.4 Evaluation of the existing building

In this study, the vulnerability and performance of existing school RC building in seismic zone 4 of Mandalay was evaluated. The school was a three-story RC building, which was designed only for gravity load and constructed nearly 20 years ago, so it was necessary to evaluate the structural performance with the additional seismic load. The elevation and plan view of the building is shown in Figure 1.

2.4.1 Assessment of seismic vulnerability

The vulnerability assessment of the existing RC building was checked using the Priority Index (PI) method. The PI method was used to determine the vulnerable conditions of the existing building. The required data for this method were the building plan dimensions, column and wall cross-sections, and number of stories. Priority indices were calculated using Equations 1, 2, and 3. The existing building had two column sizes of $12 \times 12''$ and $15 \times 20''$ and the thickness of both interior and exterior masonry infill walls was 4.5". There was no RC wall. The ground floor plan of the existing building is shown in Figure 1.

After calculating the Priority Index (PI) value (Table 1), the existing building was found to be vulnerable, with PI values of 0.19% and 0.21% in the NS and EW directions, respectively, below the allowable limit of 0.4%.

2.4.2 Performance evaluation under pushover analysis

Performance points and performance levels of these buildings were determined with the FEMA 356 and Capacity-

FIGURE 1. Elevation and plan view of the school building.

TABLE 1. Priority Index value for existing building in N-S and E-W directions.

No	Floor area (ft ²)	Column area (ft ²)	M. wall area N-S (ft ²)	M. wall area E-W (ft ²)	PI value		Allowable	Remark
					N-S	E-W		
1	8460	22.5	45	66	0.19%	0.21%	0.4%	1

TABLE 2. Checking performance levels for existing building.

Direction	Seismic ground motion	Base shear (kip)	Displacement (in)	Performance level		Remark
				Provided level	Allowable level	
Push X	SE	221.1	4.406	C	O, IO	Not OK
	DBE	NA	NA	NA	LS	Not OK
	MCE	NA	NA	NA	CP	Not OK
Push Y	SE	NA	NA	NA	O, IO	Not OK
	DBE	NA	NA	NA	LS	Not OK
	MCE	NA	NA	NA	CP	Not OK

Spectrum Method of ATC 40. In this study, the performance objectives were basic safety performance objectives: operational (O) level and immediate occupancy (IO) level under SE, life safety (LS) performance level under DBE, and collapse prevention (CP) level under MCE earthquake (Applied Technology Council 1996). Table 2 shows the performance levels for the existing building.

After nonlinear static pushover analysis, the performance of the existing building was found to fall in the collapse (C) damage level in Serviceability Earthquake (SE). The existing performance level was not satisfactorily within the allowable limit of Immediate Occupancy (IO) level in SE, and therefore the existing building was deemed to be in need of retrofitting.

2.5 Retrofit strategies

A retrofit strategy is a technical option for improving the strength and other attributes of resistance of a building or a member to seismic forces. Retrofit strategies can be classified under global and local strategies. A global retrofit strategy targets the performance of the entire building under lateral loads. A local retrofit strategy targets the seismic resistance of a member, without significantly affecting the overall resistance of the building (Chakrabarti et al. 2008). The local strategy tends to be the most economical retrofitting approach when only a few of the building's components are inadequate (Federal Emergency Management Agency 2000). In this study, there was a 45% deficiency in beams and 22% deficiency in columns. Therefore, the global retrofit strategy was suitable for the building in

cases of structural consideration, economical point of view, workability, and time consumption according to FEMA 356. In this study, a 10-inch thick reinforced concrete shear wall, 2-inch thick steel plate shear wall, and C15x50 steel bracing were selected as global retrofit strategies.

3. RESULTS AND DISCUSSION

3.1 Retrofit with RC shear wall

Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and non-structural elements. Properly designed and detailed buildings with shear walls have been shown to have good performance in past earthquakes (Sahin 2014). It is an extremely effective method of increasing both building strength and stiffness. A shear wall system is often economical and tends to be readily compatible with most existing concrete structures (Applied Technology Council 1996). Figures 2a, 2b, and 2c show cases 1, 2, and 3 of the retrofit with the RC shear wall.

Tables 3 and 4 show the performance points and performance levels of cases 1, 2, and 3 for retrofitting with RC shear wall in an X and Y earthquake direction. In both earthquakes, the lowest displacements were found in case 1. However, the performance levels of case 1 in DBE and MCE were not satisfactorily within the allowable limits.

3.1.1 Method statement for installation of RC shear wall

Shear walls were connected to the model structure by dowels placed into the holes drilled in the faces of the beams

FIGURE 2. a) Case 1 of RC shear wall; b) case 2 of RC shear wall; c) case 3 of RC shear wall.

TABLE 3. Retrofit with RC shear wall (Push X).

Case	SGM*	Performance point		Performance level
		Force (kip)	Displacement (in)	
1	SE	642.362	1.023	O
	DBE	974.758	1.650	IO
	MCE	1364.400	2.498	C
2	SE	1075.770	1.619	IO
	DBE	1567.567	2.703	C
	MCE	2220.131	4.300	C
3	SE	650.483	1.164	O
	DBE	991.661	1.932	IO
	MCE	1383.900	3.176	C

*Seismic ground motion.

TABLE 4. Retrofit with RC shear wall (Push Y).

Case	SGM*	Performance point		Performance level
		Force (kip)	Displacement (in)	
1	SE	632.005	1.131	O
	DBE	961.101	1.812	C
	MCE	1352.787	2.733	C
2	SE	1057.986	1.426	O
	DBE	1571.406	2.276	C
	MCE	2271.848	3.507	C
3	SE	464.058	1.426	O
	DBE	624.798	2.247	O
	MCE	842.917	3.474	IO

*Seismic ground motion.

and columns. Dowels were fixed into the old concrete by epoxy resin. Dowels were equidistantly installed onto the column and beam surfaces in contact with the exterior shear walls. Longitudinal reinforcements of the SWs were anchored to the same continuous footing as the columns (Kaplan et al. 2011).

3.2 Retrofit with RC shear wall with openings

Figures 3a, 3b, and 3c show cases 1, 2, and 3 of retrofitting with RC shear walls with openings. These were in the same locations and of the same thickness as the RC shear walls without openings.

Tables 5 and 6 show the performance points and performance levels of cases 1, 2, and 3 of retrofitting with RC shear walls with openings in X and Y earthquake directions.

TABLE 5. Retrofit with RC shear wall with opening (Push X).

Case	SGM*	Performance point		Performance level
		Force (kip)	Displacement (in)	
1	SE	601.784	1.209	O
	DBE	901.639	1.972	IO
	MCE	1263.556	3.050	C
2	SE	908.070	1.503	C
	DBE	1324.584	2.400	C
	MCE	NA	NA	-
3	SE	684.981	1.491	O
	DBE	986.847	2.491	IO
	MCE	NA	NA	-

*Seismic ground motion.

TABLE 6. Retrofit with RC shear wall with opening (Push Y).

Case	SGM*	Performance point		Performance level
		Force (kip)	Displacement (in)	
1	SE	569.302	1.062	O
	DBE	822.834	1.697	O
	MCE	1150.619	2.689	C
2	SE	887.640	1.850	C
	DBE	1282.289	3.087	C
	MCE	NA	NA	-
3	SE	466.016	1.546	O
	DBE	625.775	2.434	O
	MCE	847.046	3.826	IO

*Seismic ground motion.

In both earthquake scenarios, the lowest displacements are found in case 1. But the performance levels of case 1 in MCE were not satisfactory within the allowable limits.

3.3 Retrofit with steel plate shear wall

Steel plate shear walls allow for less structural wall thickness than concrete shear walls and result in a lesser building weight compared with buildings that use concrete shear walls, which results in a reduction of foundation loads due to gravity and overall building seismic loads (Sahin 2014). The use of a steel plate shear wall system also reduces construction time (Sahin 2014). The locations of the steel plate shear walls were the same as that of the RC shear walls. Figures 4a, 4b, and 4c show cases 1, 2 and 3 of retrofitting with steel plate shear walls.

(a)

(b)

(c)

FIGURE 3. a) Case 1 of RC shear wall with opening; b) case 2 of RC shear wall with opening; c) case 3 of RC shear wall with opening.

TABLE 7. Retrofit with steel plate shear wall (Push X).

Case	SGM*	Performance point		Performance level
		Force (kip)	Displacement (in)	
1	SE	556.478	0.792	O
	DBE	901.514	1.264	O
	MCE	1235.334	2.143	IO
2	SE	966.694	1.269	IO
	DBE	1360.755	2.336	D
	MCE	1759.540	3.985	D
3	SE	641.894	0.950	O
	DBE	941.497	1.686	IO
	MCE	1258.009	2.935	C

*Seismic ground motion.

Tables 7 and 8 show the performance points and performance levels of cases 1, 2, and 3 in terms of retrofitting with steel plate shear walls in X and Y directions of an earthquake. In both earthquake scenarios, the lowest displacements were found in case 1. The performance levels of all cases in three earthquake hazard levels were satisfactorily within the allowable limits.

3.3.1 Method statement for installation of steel plate shear walls

Firstly, the holes are drilled in existing columns and cleaned with a compressed air gun or blow out pump. After moistening these holes with a pump, the injectable adhesive anchors are filled into these holes. Spring washers are placed to prevent fastening or loosening due to vibrations (i.e. seismic loads). Then, steel plates are carried to the place and

TABLE 8. Retrofit with steel plate shear wall (Push Y).

Case	SGM*	Performance point		Performance level
		Force (kip)	Displacement (in)	
1	SE	598.884	0.786	O
	DBE	956.007	1.257	O
	MCE	1358.789	1.890	O
2	SE	991.320	0.963	O
	DBE	1532.057	1.569	IO
	MCE	2189.141	2.434	IO
3	SE	467.972	1.313	O
	DBE	658.000	2.164	IO
	MCE	894.671	3.423	IO

*Seismic ground motion.

installed onto the columns and beams using high-tension bolts (Fathalizadeh 2017).

3.4 Retrofit with steel bracing

Braced steel frames are another common method of enhancing an existing building's stiffness and strength (Applied Technology Council 1996). Typically, braced frames provide lower levels of stiffness and strength than shear walls, but they add far less mass to the structure compared with shear walls, can be constructed with less loss of light, and have a smaller effect on traffic patterns within the building (Applied Technology Council 1996). In this study, a V-inverted steel bracing was selected to retrofit the existing structure. Figures 5a, 5b, 5c, and 5d show cases 1, 2, 3, and 4 of retrofitting with steel bracing.

Tables 9 and 10 show the performance points and performance levels of cases 1, 2, 3, and 4 for retrofitting with

FIGURE 4. a) Case 1 of steel plate shear wall; b) case 2 of steel plate shear wall; c) case 3 of steel plate shear wall.

FIGURE 5. a) Case 1 of steel bracing; b) case 2 of steel bracing; c) case 3 of steel bracing; d) case 4 of steel bracing.

TABLE 9. Retrofit with steel bracing (Push X).

Case	SGM*	Performance point		Performance level
		Force (kip)	Displacement (in)	
1	SE	432.295	1.777	E
	DBE	NA	NA	-
	MCE	NA	NA	-
2	SE	587.989	1.085	O
	DBE	NA	NA	-
	MCE	NA	NA	-
3	SE	576.854	0.998	O
	DBE	NA	NA	-
	MCE	NA	NA	-
4	SE	338.738	1.183	C
	DBE	NA	NA	-
	MCE	NA	NA	-

*Seismic ground motion.

TABLE 10. Retrofit with steel bracing (Push Y).

Case	SGM*	Performance point		Performance level
		Force (kip)	Displacement (in)	
1	SE	544.155	1.150	C
	DBE	NA	NA	-
	MCE	NA	NA	-
2	SE	340.243	2.072	C
	DBE	NA	NA	-
	MCE	NA	NA	-
3	SE	526.485	0.951	C
	DBE	669.672	1.731	C
	MCE	NA	NA	-
4	SE	360.506	0.850	C
	DBE	NA	NA	-
	MCE	NA	NA	-

*Seismic ground motion.

steel bracing in X and Y earthquake directions. Retrofitting with steel bracing required more space compared with shear walls. In addition, the performance levels of all cases with steel bracing were not satisfactorily within the allowable limits.

4. CONCLUSIONS

An existing building in Mandalay, Myanmar, was retrofitted using RC shear walls (with and without openings), steel plate shear walls, and steel bracing. Retrofitting with steel bracing needed more space than that with RC shear walls and steel plate shear walls. Meanwhile, steel plate shear walls had the lowest displacement and the best performance compared with the other techniques. Therefore, retrofitting with steel plate shear walls was selected as a suitable retrofitting strategy for this case study.

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AUTHORS' CONTRIBUTIONS

TT designed the study and analyzed the data. NSLMT supervised the study. NMH co-supervised the study. TT wrote the manuscript. All authors read and approved the final version of the manuscript.

COMPETING INTERESTS

The authors have no competing interests to declare.

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