

Evaluation of Structural Stability Improvement Systems for Existing RC Buildings

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Abstract- Inadequate attention during design and construction of some of reinforced concrete (RC) buildings has been raised questions about the performance levels of these existing buildings under future earthquakes. This study aims to improve seismic design of existing RC buildings under various deficiencies. Total of twelve existing RC buildings in major seismicity zone, Mandalay city, are targeted as case study buildings. Two possible improvement solutions such as steel bracings and RC shear walls are defined as proposed systems in this study. Linear static analysis is carried out for structural stability checking of existing structures based on UBC 97 code. According to the checking results, deficiencies of P- Δ effect are found in three existing pinned based buildings and deficiencies of torsional irregularity are also found in two existing buildings. Firstly, structural improvements under linear static analysis are performed to correct these deficiencies. Then, nonlinear static (pushover) analysis is carried out for performance evaluation of existing structures. Seismic performance enhancement of the proposed existing buildings is evaluated to achieve basis safety objective performance level described in FEMA 356. Results show that RC shear wall is more appropriate not as economic solution for more deficient buildings (Model 8, 10, 11 and 12) whereas steel bracing is effective solution for less deficient buildings (Model 1, 2, 3, 4, 5, 6, 7 and 9).

Index Terms- Existing RC Buildings, Linear Static and Nonlinear Static Analysis, Structural Stability Improvement Systems, Steel Bracings, RC Shear Walls

I. INTRODUCTION

Earthquake is unavoidable natural disaster which causes severely damages, and high casualties depends on the intensity of earthquake, distance from the earthquake source and site condition. Destructive earthquakes have happened in Myanmar and tectonic evidences show that they will happen again in the future.

In Myanmar, Mandalay lies closed to the most active fault along the Sagaing Fault as shown in Fig.1 [5]. Earthquake resistant existing buildings must be ensured during and after an earthquake. Nowadays, it is necessary to enforce a more rational approach for the seismic improvements of existing structures. Thus, deficient buildings should be reliably identified and conceived improvement interventions aimed at the most critical deficiencies only [6].

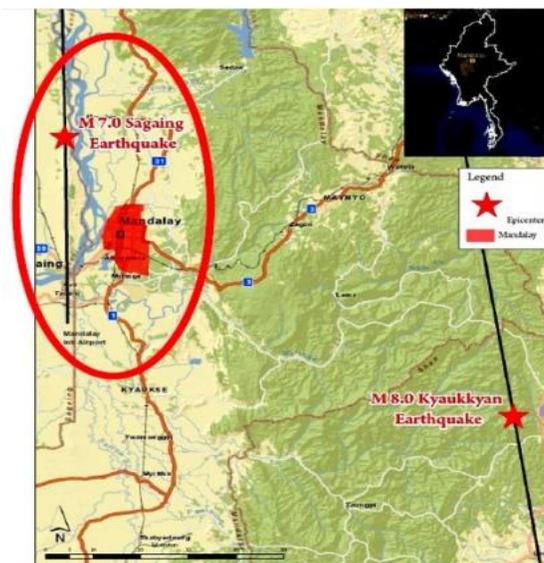


Figure 1: Location of Sagaing Fault from Mandalay City

II. METHODOLOGY

In the present study, twelve case studies of existing RC buildings located in four townships of Mandalay city, namely Chan Mya Thar Zi, Aung Myay Tharzan, Mahar Aung Myay and Pyi Gyi Tagon townships, have been used. First, design conditions of existing structures are checked to meet actual existing condition based on complete set design requirements. Next, existing structures are analyzed under linear static condition by using ETABS software. Structural deficiencies of existing structures have been determined from stability checking results based on UBC 97 code. For these buildings, improvement solutions such as steel bracings or RC shear walls are used to correct these deficiencies. Then, nonlinear static analysis is carried out to meet performance objective requirement described in FEMA 356. Seismic improvements of existing structures have been evaluated in terms of strength, ductility, capacity values (spectral acceleration) and performance points. Flowchart diagram for seismic design improvement of existing buildings is shown in Fig.2.

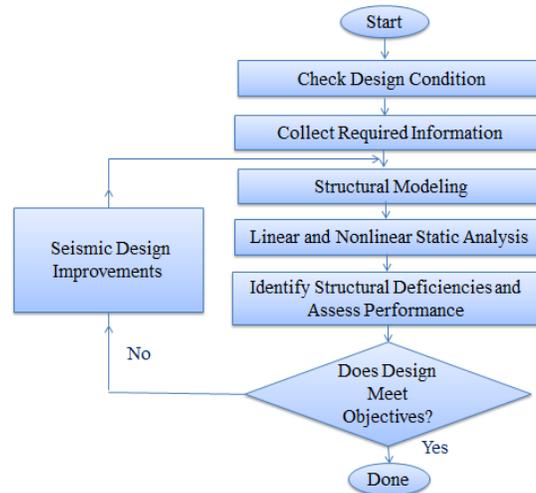


Figure 2: Implementation Procedures for Seismic Design Improvements of Existing Buildings

A. Determination of Performance Level

Performance level is the permissible amount of damage, given that design earthquake hazards are experienced, defined from FEMA 356 as follows:

- Operational (O) - Backup utility services maintain function; very little damage
- Intermediate Occupancy (IO) - The buildings remain safe to occupy; any repairs are minor
- Life Safety (LS) - Structures remain stable and has significant reserve capacity; hazardous nonstructural damage is controlled
- Collapse Prevention (CP) - The buildings remain standing but only barely; any other damage or loss is acceptable

B. Determination of Seismic Hazard Level

In considering earthquake hazard environment of Mandalay City, the probability of exceedance in 50 years is 50% for the operational earthquake level (SE), 10% for the design basic earthquake level (DBE) and 2% for the maximum considered earthquake level (MCE) [3].

$$P = 1 - \left[1 - \frac{I}{T_R} \right] \quad (1)$$

Where, P is probability of exceedance in 50 years and T_R is return period [4]. The moment magnitude is expected from the Sagaing Fault and peak ground acceleration is calculated with the source distance, 25km [10].

$$\ln(PGA) = -0.152 + 0.859M_w - 1.803 \ln(R + 25) \quad (2)$$

Where, PGA is peak ground acceleration, M_w is moment magnitude and R is source distance, km [10].

Table 1: Estimated seismic hazard level for Mandalay City

Earthquake Type	Return Period (T_R)	Probability (P)	Magnitude (M_w)	Peak Ground Acceleration PGA (g)
SE	72	0.0139	6.5	0.2
DBE	475	0.0021	7.3	0.4
MCE	2457	0.0004	7.8	0.6

C. Determination of Performance Objectives

According to FEMA 356, there are three types of performance objectives; basic safety objective, enhanced objective and limited objective as shown in Table 2. In the present study, performance objectives are basic safety performance objective; life safety building performance under DBE hazard level and collapse prevention performance under MCE hazard level [4].

Table 2: Performance objectives

		Target Building Performance Levels			
		Operational	Intermediate Occupancy	Life Safety	Collapse Prevention
Earthquake Hazard Level	50%/50 year	a	b	c	d
	20%/50 year	e	f	g	h
	DBE (10%/50 year)	i	j	k	l
	MCE (2%/50 year)	m	n	o	p

Notes: 1. Each cell in the above table represents discrete rehabilitation objectives.
 2. Three specific rehabilitation objectives are defined in FEMA-356.

- Basic Safety Objectives = cell k + p,
- Enhanced Objectives = cell k + p + any of a, e, i, b, f, j or n,
- Limited Objectives = cell c, g, d, h, l.

III. SEISMIC IMPROVEMENT TECHNIQUES

The purpose of seismic improvement is to provide existing structure more resistance to ensure safety of the structures. There are several improvement techniques used in existing structures as shown in Fig 3. Conventional improvement options such as shear walls, bracings, infill walls, wall thickening and mass reduction are mostly used in existing structures. Among them, improvement solutions such as steel bracings or shear walls are considered in this study.

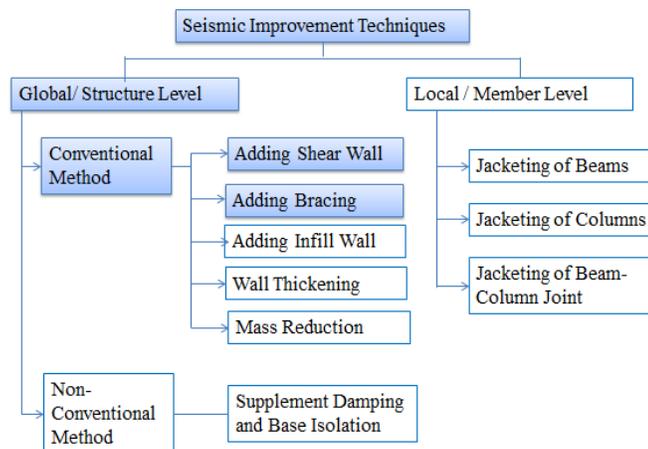


Figure 3: Classification of Seismic Improvement Techniques [4]

A. Application of Steel Bracings

The steel bracing is highly efficient and economic method to increase the resistance of existing structure against lateral forces. Steel Bracings improves the performance of frame structure by increasing its lateral stiffness, ductility and capacity. Through braces load can be transferred out of frame to braces bypassing the weak columns while increasing strength. Steel bracings are easy to apply and they can be applied externally without disturbance to the building’s occupants [7]. In this study, X-type concentric steel bracings (W8×24) are used.

B. Application of RC Shear Walls

The application of new reinforced concrete shear wall is most common practice to enhance the seismic resistance of existing building. This method has been proved more effective in controlling global drifts and structural damages in frame structures. The added elements can be either cast in place or pre cast elements. The optimal location of new elements should be considered while placing, which may align to the full height of building to minimize torsion [7].

In this study, 10"thickness, uniform reinforcing pier section type RC shear walls are used. Shear walls are provided with the same grade of materials as that of frame elements and reinforcing steel as per design requirements.

IV. DESCRIPTION OF EXISTING RC BUILDINGS

In this study, twelve existing RC buildings in Mandalay were selected for analysis. All selected existing buildings are mid-rise reinforced concrete buildings situated in four townships of Mandalay, namely Chan Mya Thar Zi, Aung Myay Tharzan, Mahar Aung Myay and Pyi Gyi Tagon townships. Structural detailed design data and drawings of proposed buildings are available from Mandalay City Development Committee (MCDC). Mandalay is located in major seismicity zone with a peak ground acceleration of 0.4g. The proposed existing buildings are composed of special moment resisting frames and are designed as per American Concrete Institute Committee [1] and Uniform Building Code [2] for loading. Case studies and origin design categories of proposed existing buildings are shown in Table 3 and Table 4 respectively.

Table 3: Locations and configurations of existing RC buildings

Model	No of Storey	Shape	Building Dimension (L×B×H)	Townships	Location	
					Latitude	Longitude
1	6	Regular	87'×58'×79'	Pyi Gyi Tagon	21 53.880'	96 06.360'
2	7	Regular	51'×36'×90'	Chan Mya TharZi	21 55.999'	96 05.676'
3	7	Regular	51'×36'×92'	Chan Mya TharZi	21 55.905'	96 06.637'
4	7	Regular	79'×32'×89'	Aung Myay Thar Zan	21 59.369'	96 04.189'
5	7	Regular	47'×30'×100'	Aung Myay Thar Zan	22 00.306'	96 05.058'
6	8	Regular	73'×32'×92'	Aung Myay Thar Zan	21 59.283'	96 04.792'
7	8	Regular	128'×57'×103'	Chan Mya Thar Zi	21 57.153'	96 05.122'
8	8	Regular	100'×65'×102.5'	Aung Myay Thar Zan	21 59.166'	96 07.200'
9	8	Regular	42'×31'×104'	Mahar Aung Myay	21 54.321'	96 06.723'
10	8	Irregular	133'×76'×116'	Chan Mya TharZi	21 56.955'	96 04.538'
11	8	Irregular	148'×120'×118'	Mahar Aung Myay	21 58.012'	96 05.462'
12	8	Irregular	194'×63'×115'	Pyi Gyi Tagon	21 55.260'	96 05.580'

Table4: Original design categories of existing RC buildings

Model	Support Condition		Earthquake Load		Wind Load	
	Foundation Type	Column Base	Source Type	R	Speed (mph)	Type
1	Isolated	Pinned	A	8.5	N/A	N/A
2	Isolated	Pinned	A	8.5	80	B
3	Mat	Fixed	A	8.5	N/A	N/A
4	Isolated	Pinned	A	8.5	N/A	N/A
5	Mat	Fixed	B	8.5	N/A	N/A
6	Mat	Fixed	A	8.5	N/A	N/A
7	Mat	Pinned	A	6.5	N/A	N/A
8	Mat	Pinned	A	8.5	N/A	N/A
9	Mat	Fixed	B	8.5	N/A	N/A
10	Mat	Fixed	A	8.5	N/A	N/A
11	Mat	Fixed	A	8.5	N/A	N/A
12	Mat	Fixed	A	8.5	N/A	N/A

From Table 3, original design categories of proposed existing RC buildings should be modified to meet the actual condition of existing structures based on structural design provisions as shown in the following cases:

- Seismic source type should be used Type A instead of Type B for building Model 5 and 9 because Mandalay is near the Sagaing Fault that is capable of producing large magnitude and that have a rate of seismic activity [2].
- It should be permitted to consider the structure to be fixed at the base instead of pinned base for building Model 6 and 7 because column supported by a continuous footing foundation mat should be assumed fixed at their lower ends [3].

V. STRUCTURAL STABILITY CHECKING OF EXISTING RC BUILDINGS

Existing RC buildings were analysed under linear static condition and have been checked for structural stability such as storey drift, P-Δ effect, overturning moment, sliding and torsional irregularity according to UBC-97 code [2] as shown in Table 5.

Table 5: Structural stability checking of existing RC buildings

Model		Storey Drift	P-Δ Effect	Overturning Moment	Sliding	Torsional Irregularity
		$\Delta_M(\text{in}) < 0.025h$	Drift Ratio $< 0.02/R$	$FS_{OM} > 1.5$	$FS_{Sliding} > 1.5$	$\Delta_{max}/\Delta_{avg} > 1.5$
1	X	2.364	0.0028	6.68	3.09	1.19
	Y	2.043	0.0024	10.94	3.09	1.09
2	X	2.912	0.0041	5.64	4.05	1.03
	Y	2.795	0.0039	11.88	4.05	1.07
3	X	1.537	0.0018	2.93	2.76	1.34
	Y	1.206	0.0014	4.93	2.62	1.07
4	X	2.463	0.0029	6.76	3.27	1.00
	Y	2.465	0.0029	17.08	3.27	1.00
5	X	0.855	0.0011	4.13	2.44	1.00
	Y	1.100	0.0014	5.14	2.44	1.02
6	X	0.959	0.0019	4.06	2.36	1.08
	Y	0.664	0.0014	5.49	2.36	1.06
7	X	1.195	0.0019	14.33	3.22	1.10
	Y	1.329	0.0021	4.99	2.96	0.84
8	X	1.199	0.0017	3.96	4.48	1.16
	Y	1.103	0.0012	4.12	3.55	1.02
9	X	1.679	0.0019	12.58	3.01	1.15
	Y	1.158	0.0014	9.84	3.01	1.19
10	X	1.199	0.0017	3.96	4.48	1.16
	Y	1.103	0.0012	4.12	3.55	1.02
11	X	1.953	0.0020	13.35	5.99	1.03
	Y	2.145	0.0022	19.14	5.61	1.18
12	X	0.783	0.0022	7.89	3.06	1.20
	Y	0.749	0.0021	7.89	3.06	1.02

From these checking, deficiencies of structural stability are found in five existing buildings (Model 1, 2, 3, 4 and 12). Deficiencies of P-Δ effect are found in three existing pinned-base buildings (Model 1, 2 and 4) and Model 2 is also unsatisfied in storey drift. Deficiencies of torsional irregularities are also found in two existing buildings (Model 3 and 12).

VI. SEISMIC IMPROVEMENT UNER LINEAR STATIC ANALYSIS

Based on linear static analysis results, five existing RC buildings (Model 1, 2, 3, 4 and 12) are needed to correct deficiencies of structural stability. So, improvement solutions such as steel bracings are considered to apply in existing structures according to appropriate locations to meet structural stability as shown in Table 6.

Table6: Location of steel bracings for existing RC buildings

Model	Steel Bracings (W8×24)	
	Floor level	Location
1	Basement	- All sides
	1F	- All corner
2	Basement	- All sides
	1F	- All corner
3	Basement	- All sides
	1F	- All sides (Diagonal)
4	Basement	- Front & back center
		- Left & Right corner
12	Basement	- All sides

A. Structural Weight

Structural weights for five existing building models before and after improvements are presented in Table 7.

Table 7: Structural weight of existing RC buildings before and after improvements

Model	Structural Weight (kips)		% Increase
	Existing	Steel Bracings	
1	3841.9	3866.2	0.63
2	1649.9	1664.2	0.87
3	1829.2	1843.2	0.77
4	2712.5	2725.9	0.49
12	12207.4	12284.7	0.63

From Table 7, it can be seen that existing buildings after improvement show a slight increase in structural weight (not more than 1% increase).

B. Torsional Irregularity

Existing building models 3 and 12 are not satisfied in torsional irregularity. For these buildings, torsional irregularity checking before and after improvements is presented in Table 8.

Table 8: Torsion irregularity checking before and after improvements

Model	Direction	Point		$\Delta_{max}/\Delta_{avg}$	Limit	Remarks
		A	B			
Existing	X	0.001050	0.001794	1.34	1.2	Unsatisfied
	Y	0.001212	0.001401	1.07	1.2	Satisfied
Steel Bracings	X	0.001033	0.001438	1.16	1.2	Satisfied
	Y	0.000962	0.001120	1.08	1.2	Satisfied
Existing	X	0.001430	0.001618	1.06	1.2	Satisfied
	Y	0.001656	0.000585	1.5	1.2	Unsatisfied
Steel Bracings	X	0.001413	0.001256	1.06	1.2	Satisfied
	Y	0.000898	0.000584	1.2	1.2	Satisfied

From Table 8, it can be seen that application of steel bracings correct deficiencies of torsional irregularity.

C. Storey Drift

The maximum drift ratio in both X and Y directions before and after improvements is presented in Table 9 and 10 respectively.

Table 9: Storey drift in X direction before and after improvements

Model	Storey Drift in X Direction (in)		% Decrease
	Existing	Steel Bracings	
1	0.0028	0.0013	53.57
2	0.0041	0.0017	58.54
3	0.0018	0.0014	22.22
4	0.0029	0.0006	79.31
12	0.0016	0.0014	13.25

Table 10: Storey drift in Y direction before and after improvements

Model	Storey Drift in Y Direction (in)		% Decrease
	Existing	Steel Bracings	
1	0.0024	0.0010	58.33
2	0.0039	0.0013	66.67
3	0.0014	0.0011	21.43
4	0.0029	0.0004	86.21
12	0.0017	0.0015	11.31

From Tables 9 and 10, it can be seen that application of steel bracings show a significant decrease in storey drifts in both directions which satisfy deficiencies of P- Δ effect and storey drifts.

D. StoreyShear

The maximum storey shear in both X and Y directions before and after improvements are presented in Table 11 and 12 respectively.

Table 11: Storey shear in X direction before and after improvements

Model	Storey Shear in X Direction (Kips)		% Increase
	Existing	Steel Bracings	
1	279.94	281.07	0.41
2	107.41	132.67	23.52
3	149.01	149.77	0.51
4	186.41	186.88	0.25
12	987.83	991.19	0.34

Table 12: Storey shear in Y direction before and after improvements

Model	Storey Shear in Y Direction (Kips)		% Increase
	Existing	Steel Bracings	
1	279.94	281.92	0.41
2	107.41	132.67	23.52
3	156.89	157.70	0.51
4	186.41	186.88	0.25
12	905.42	908.05	0.29

From Tables 11 and 12, it can be seen that in both X and Y direction, application of steel bracings shows a slight increase in storey shear not more than 1% but for Model 2, nearly 25% increase.

VII. SEISMIC IMPROVEMENTS UNDER NONLINEAR STATIC ANALYSIS

After satisfying structural stability under linear static condition, improved structures do not meet performance objectives under nonlinear static condition. It is also found that capacity values of all proposed buildings are less than demand-DBE. This means that these building's ability is not good under DBE earthquake level. So, steel bracings or RC shear walls are needed to add in existing structures until these structures meet performance objectives.

Eight existing buildings are satisfied for required performance by using steel bracings but four existing buildings are only satisfied with RC shear walls. According to the required locations, locations of steel bracings and RC shear walls under nonlinear static analysis are presented in Table 13 and Table 14 respectively.

Table 13: Location of steel bracings for existing RC buildings

Model	Steel Bracings (W8x24)	
	Floor level	Location
1	Basement	- All sides
	1F to 3F	- All corner
2	Basement	- All sides
	1F to 4F	- All corner
3	Basement	- All sides
	1F to 3F	- All sides
4	Basement to RF	- Front & back center
		- Left & right corner
5	Basement	- All sides
	1F	- Back corner (Diagonal) - Left & Right corner
6	Basement	- All sides
	1F to 4F	- All corner
7	Basement	- All sides
	1F to RF	- Front & back center - All corner
9	Basement	- All sides
	1F to 3F	- All sides (Diagonal)

Table 14: Location of shear walls for existing RC buildings

Model	Shear Walls (10" thickness)	
	Floor level	Location
8	Basement	- Front & back center two bay - Left & right sides/ Lift sides
	1F to RF	- Left & Right center / Lift sides
10	B to RF	- Stair & Lift sides
11	Basement	- All corner
	1F to RF	- Front & right corner - Lift & stair sides
12	Basement	- Left & right center - Lift & stair sides
	1F to RF	- Lift & stair sides

A. Capacity Curve

The force and deformation curves or capacity (pushover) curves for proposed existing buildings before and after rehabilitation are plotted to assess the global response of structures. The health of the structure is judged by capacity curve [4]. Capacity curves of eight existing buildings improved with steel bracings are shown from Fig.4 to Fig.7 and four existing buildings improved with RC shear walls are shown from Fig.8 to Fig.9.

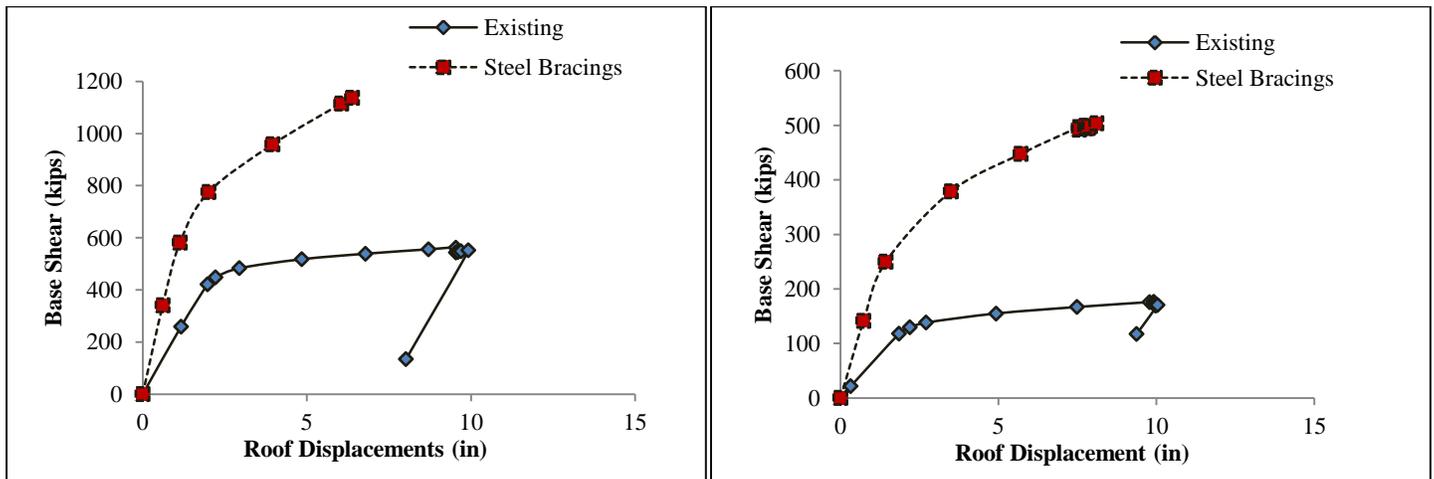


Figure 4: Capacity Curves before and after Improvements (Model 1 and Model 2)

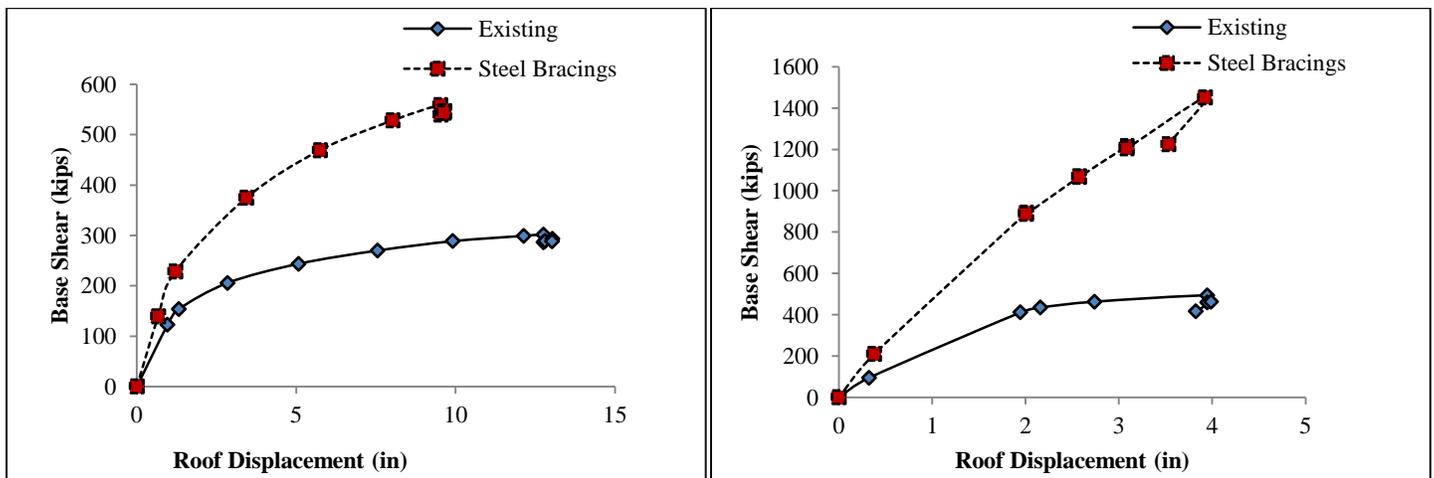


Figure 5: Capacity Curves before and after Improvements (Model 3 and Model 4)

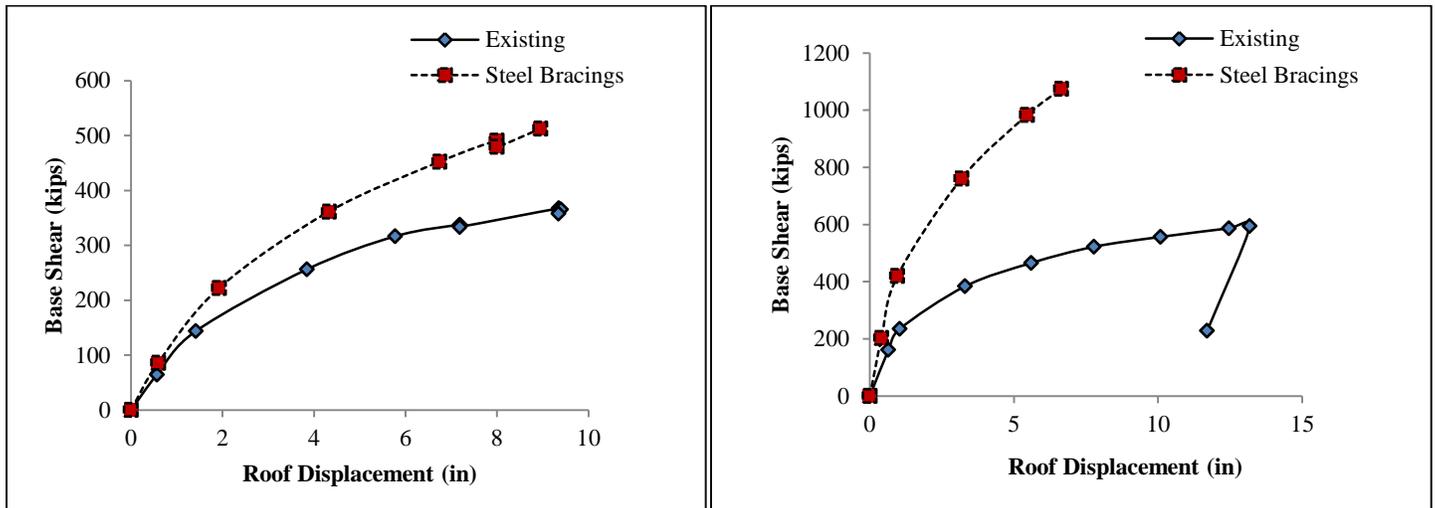


Figure 6: Capacity Curves before and after Improvements (Model 5 and Model 6)

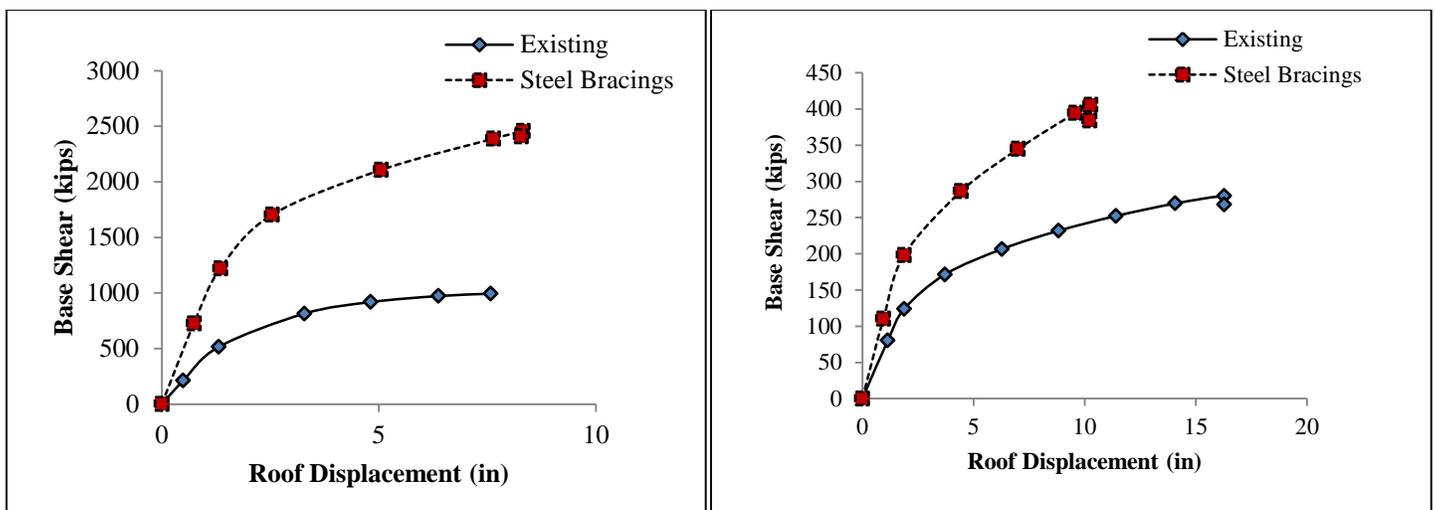


Figure 7: Capacity Curves before and after Improvements (Model 7 and Model 9)

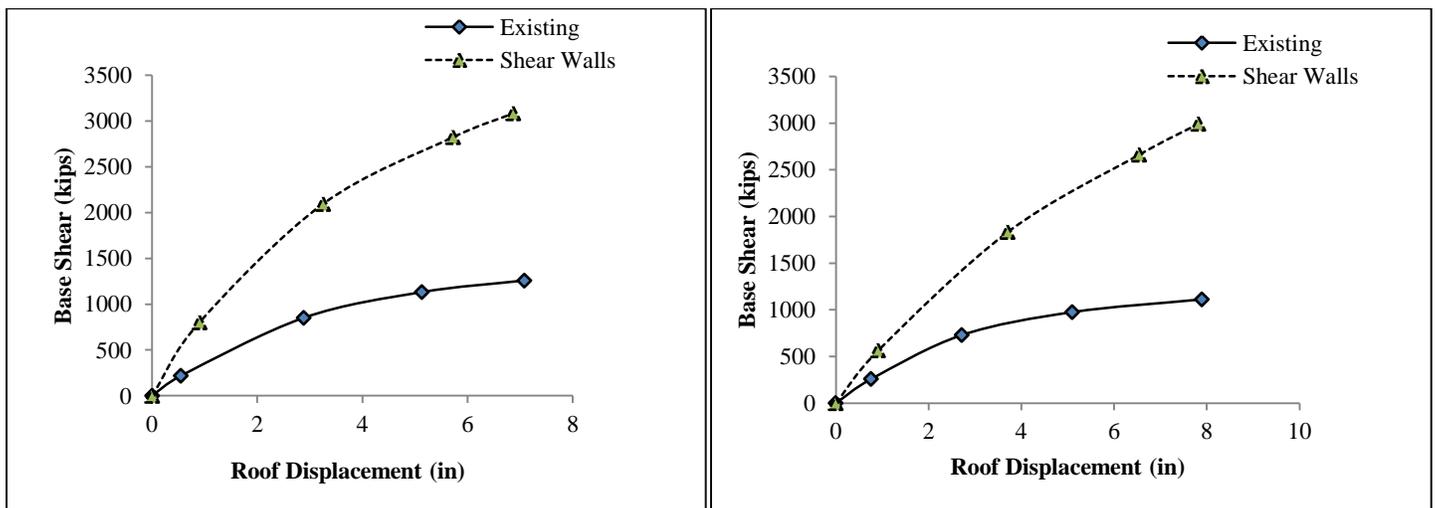


Figure 8: Capacity Curves before and after Improvements (Model 8 and Model 10)

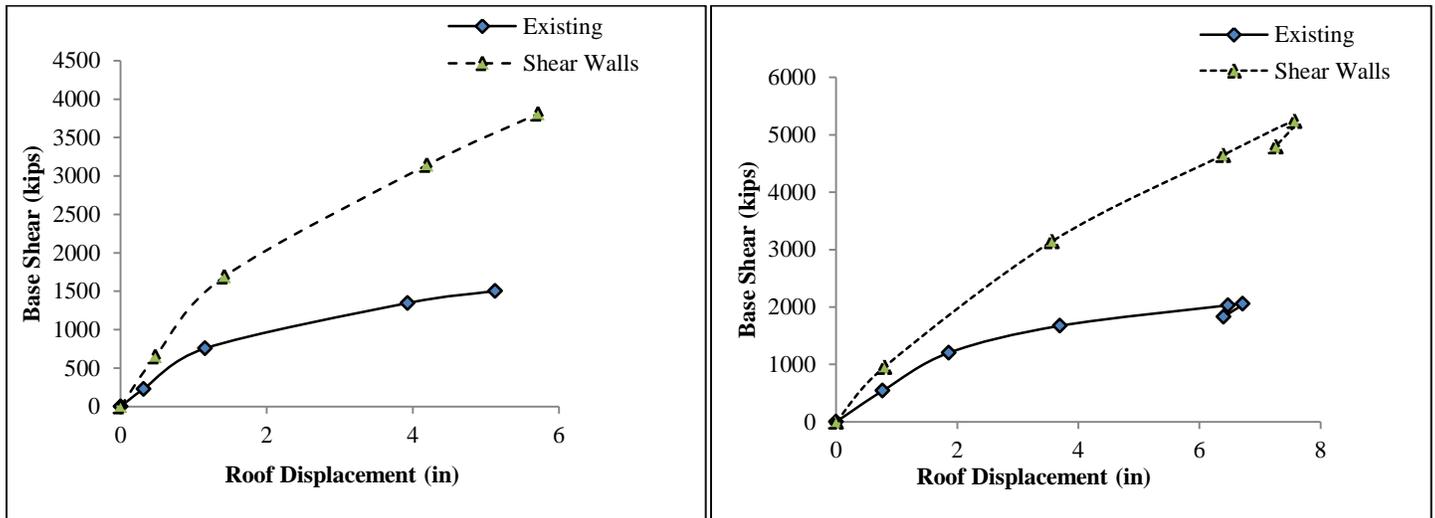


Figure 9: Capacity Curves before and after Improvements (Model 11 and Model 12)

From Fig.4 to Fig.9, it can be seen that existing buildings improved with steel bracings and shear walls show a significant increase in strength.

B. Ductility

Ductility is the structural property that will need to be relied on in most structures if satisfactory behavior under damage control and survival limit state is to be achieved.

$$\mu = \frac{\Delta_{max}}{\Delta_y} \tag{3}$$

Where, μ is structural ductility, Δ_{max} is maximum displacement and Δ_y is yield displacement. Ductility of proposed existing building before and after improvements is shown in Table 15.

Table 15: Ductility of existing RC buildings before and after improvements

Model	Existing Structure			Improved Structure		
	Δ_y	Δ_{max}	μ	Δ_y	Δ_{max}	μ
1	1.976	9.926	5.023	1.133	6.383	5.634
2	1.855	10.038	5.411	1.436	8.112	5.649
3	1.323	13.035	9.852	1.208	9.649	7.988
4	0.678	3.827	5.645	0.379	3.926	10.359
5	1.420	9.348	6.583	1.925	8.951	4.649
6	1.043	13.188	12.644	0.403	6.644	16.486
7	1.314	7.579	5.768	1.347	8.318	6.175
8	0.800	7.080	8.850	0.700	6.871	9.816
9	1.888	16.282	8.624	1.149	10.270	8.938
10	0.922	7.897	8.565	0.913	7.823	8.568
11	1.156	5.128	4.436	1.000	5.713	5.713
12	1.860	6.715	3.610	0.799	7.265	9.093

From Table 15, it can be seen that application of steel bracings increase the ductility of existing structures but for Model 3 and 5, ductility is slightly decreased. It is observed that application of shear walls shows a significant increase in ductility of existing buildings.

C. Structural Capacity

Demand is a representation of the earthquake ground motion. Capacity is a representation of the structure’s ability to resist seismic demand [4]. Comparison of capacity and demand for proposed buildings models before and after improvements is shown in Fig.10.

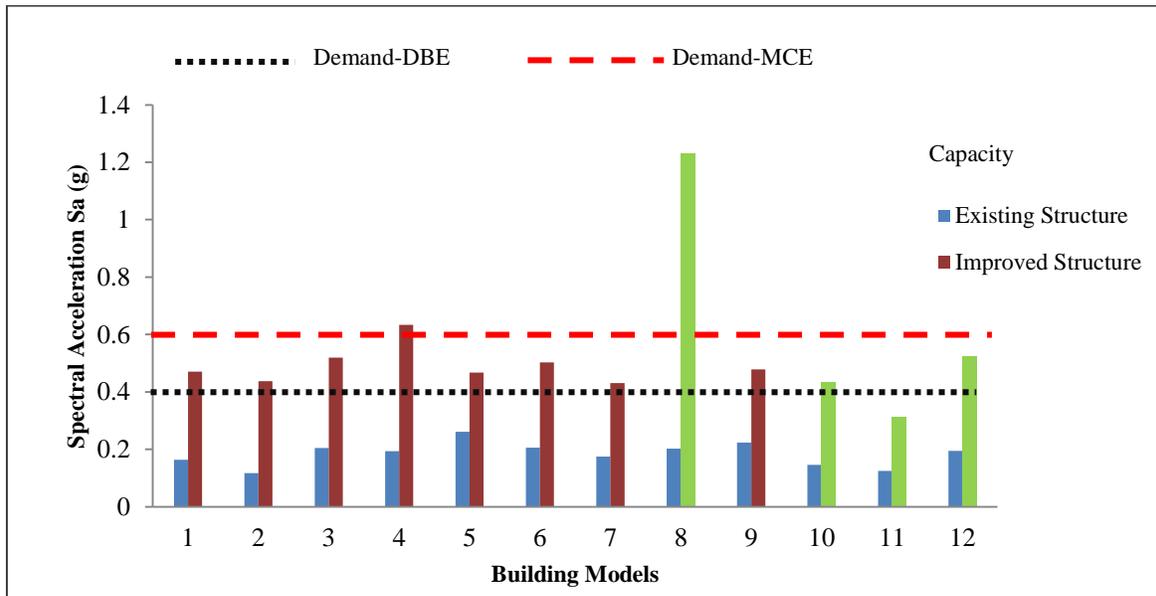


Figure 10: Capacity and Demand before and after Improvements

From Fig.10, it can be seen that application of steel bracings shows increase in capacity more than demand-DBE for eight existing buildings (Model 1, 2, 3, 4, 5, 6, 7 and 9). For Model 4, capacity value exceeds demand-MCE. Application of shear walls also shows a significant increase in capacity more than demand-DBE for three existing buildings (Model 8, 10, 11 and 12). For Model 8, capacity value exceeds demand-MCE but for Model 11, capacity value less than demand-DBE.

D. Performance Point

Performance point of the building is the intersection of capacity and demand curves. Based on the location of this performance point, performance level of the building is determined. The performance points of proposed existing buildings under DBE and MCE earthquake level are shown in Table 16.

Table 16: Performance points of existing RC buildings before and after improvements

Model		Performance Point		Performance Level	EQ Level	Performance Objectives
		Sa	Sd			
1	Existing	0.149	3.713	CP	DBE	No
		0.162	7.090	CP	MCE	
	Steel Bracings	0.338	2.326	LS	DBE	Yes
		0.418	3.755	CP	MCE	
2	Existing	0.106	5.210	CP	DBE	No
		N/A	N/A	N/A	MCE	
	Steel Bracings	0.286	3.047	LS	DBE	Yes
		0.365	4.828	CP	MCE	
3	Existing	0.171	3.497	CP	DBE	No
		0.199	6.304	CP	MCE	
	Steel Bracings	0.330	2.600	LS	DBE	Yes
		0.425	4.169	CP	MCE	
4	Existing	0.190	4.103	CP	DBE	No
		N/A	N/A	N/A	MCE	
	Steel Bracings	0.535	2.175	LS	DBE	Yes
		0.763	3.341	CP	MCE	

5	Existing	0.213	3.612	CP	DBE	No
		0.249	5.772	CP	MCE	
	Steel Bracings	0.298	3.032	LS	DBE	Yes
		0.382	4.767	CP	MCE	
6	Existing	0.187	3.425	CP	DBE	No
		0.205	5.989	CP	MCE	
	Steel Bracings	0.394	2.320	LS	DBE	Yes
		0.480	3.251	CP	MCE	
7	Existing	N/A	N/A	C	DBE	No
		N/A	N/A	C	MCE	
	Steel Bracings	0.325	2.315	LS	DBE	Yes
		0.372	3.688	CP	MCE	
8	Existing	N/A	N/A	N/A	DBE	No
		N/A	N/A	N/A	MCE	
	Shear Walls	0.685	1.928	LS	DBE	Yes
		0.943	2.883	CP	MCE	
9	Existing	0.162	4.122	CP	DBE	No
		0.196	7.023	CP	MCE	
	Steel Bracings	0.296	2.990	LS	DBE	Yes
		0.375	4.692	CP	MCE	
10	Existing	N/A	N/A	N/A	DBE	No
		N/A	N/A	N/A	MCE	
	Shear Walls	0.309	3.674	LS	DBE	Yes
		0.409	5.499	CP	MCE	
11	Existing	N/A	N/A	N/A	DBE	No
		N/A	N/A	N/A	MCE	
	Shear Walls	0.178	1.485	LS	DBE	Yes
		0.282	3.079	CP	MCE	
12	Existing	N/A	N/A	N/A	DBE	No
		N/A	N/A	N/A	MCE	
	Shear Walls	0.368	2.953	LS	DBE	Yes
		0.495	4.502	CP	MCE	

From Table 16, application of steel bracings are satisfied for eight existing buildings (Model 1, 2, 3, 4, 5, 6, 7 and 9) to meet performance objective requirements but only RC shear walls are satisfied in four existing buildings (Model 8, 10, 11 and 12).

VIII. DISCUSSION AND CONCLUSION

In this study, twelve existing RC buildings are evaluated for structural stability improvements under seismic loads by using linear static and nonlinear static (pushover) analysis. Steel bracings and RC shear walls are used as improvement systems.

Under linear static condition, structural improvements are evaluated based on structural stability as defined in UBC code. Deficiencies of structural stability are found in five existing buildings (Model 1, 2, 3, 4 and 12). For these buildings, additions of steel bracings are satisfied to overcome these deficiencies.

Under nonlinear static condition, structural performance improvements are evaluated based on structural capacity and expected performance of the building to meet performance objective requirements. All the proposed existing buildings are required to improve seismic performance. Steel bracings are used as improvement solutions for eight existing buildings (Model 1, 2, 3, 4, 5, 6, 7 and 9) and

RC shear walls are used in four existing buildings (Model 8, 10, 11 and 12) for required performance.

Application of steel bracings or shear walls shows a significant increase in strength of existing structures. Both improved systems show increase in ductility but slightly decrease for building Model 3, 5 and 6. Moreover, application of steel bracings or RC shear walls shows increase in structural capacity more than demand-DBE. It is observed that both methods improve the building performance to meet performance objectives but for Model 8, 10, 11 and 12, only application of RC shear walls is satisfied.

In this study, it can be concluded that the use of steel bracings is effective solution for seismic improvements of existing reinforced concrete structures (Model 1, 2, 3, 4, 5, 6, 7 and 9) as it is not only economical method but also easy to install. For Model 8, 10, 11 and 12, only RC shear walls are satisfied for required seismic performance.

ACKNOWLEDGMENT

Firstly, the author would like to express her profound gratitude to Dr. Sint Soe, Rector of Mandalay Technological University, for his encouragement and managements. The author would like to express gratitude to Dr. Nilar Aye, Professor and Head of Department of Civil Engineering, Mandalay Technological University for her helpful advice, management and encouragement.

The author also wishes to record the greatest and special thanks and owe in gratitude to her supervisor, Dr. San Yu Khaing, Professor, Department of Civil Engineering, Mandalay Technological University, for her careful guidance, advices and invaluable encouragement.

Finally, the author specially thanks to all her teachers and her family, especially her parents, for their supports and encouragement.

REFERENCES

- [1] Anonymous 1997. "Building Code Requirements for Structural Concrete" (ACI 318-99) and Commentary (ACI 318-99) USA: American Concrete Institute 1999.
- [2] International Conference of Building Officials. 1997. "Structural Engineering Design Provision" Volume 2. Uniform Building Code UBC (1997).
- [3] ATC 1996. Seismic Evaluation and Retrofit of Concrete Buildings. Volume 1, ATC-40 Report, Applied Technology Council, Redwood City, California
- [4] FEMA. 2000. Prestandard and Commentary for the Seismic Rehabilitation of Buildings. FEMA 356, Federal Emergency Management Agency, Washington, D.C.
- [5] Peeranant Towashiraporn, Earthquake risk assessment of Mandalay city, Asian Disaster Preparedness Center(2012).
- [6] Tutor Prof. Gaetano Manfredi, Conditional assessment of seismic rehabilitation techniques on the full scale spear structure(2012).
- [7] Yaseer Alashkar, Sohaib Nazar, Mohammad Ahmed, Comparative study of seismic strengthening of RC building by steel bracings and shear walls, International journal of civil and structural research Vol. 2, Issue 2, pp: (24-34), Month: October 2014 - March 201512
- [8] Kadid and A. Boumrkik, Pushover analysis of reinforced concrete framed structures, Asian journal of civil engineering (Building and Housing) Vol.9, No.1(2008).
- [9] Cornell, C.A., Banon, H., Shakal, A.F., Seismic Motion and Response Prediction Alternatives, Earthquake Engineering and Structural Dynamics, 1979.
- [10] Myo Thant, Nwai Le Ngai, Soe Thura Tun, Maung Thein, Win Swe and Than Myint, Seismic Hazard Assessment for Myanmar, Myanmar Earthquake Committee (MEC), Myanmar Geosciences Society (MGS), March 5, 2012.
- [11] ETABS User's Manual, "Integrated Building Design Software", Computer and Structures Inc. Berkeley, USA.

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