STUDY ON SEISMIC IMPROVEMENTS OF EXISTING REINFORCED CONCRETE BUILDINGS

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Abstract- Inadequate attention during design and construction of some of reinforced concrete (RC) buildings has raised questions about the performance level of these existing buildings under future earthquakes. This paper aims to evaluate seismic improvements of existing RC buildings. For this, total of five existing RC buildings constructed in major seismicity zone, Mandalay city, are selected. Two possible improvement solutions are proposed; steel bracings and RC shear walls. Linear static analysis is carried out for structural stability checking of existing structures based on UBC 97 code. From these checkings, 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 5) whereas steel bracing is effective solution for less deficient buildings (Model 1, 2, 3 and 4).

Index Terms- Existing RC Buildings, RC Shear Walls, Steel Bracings, Seismic Improvements.

I. INTRODUCTION

Earthquake is unavoidable natural disaster which causes several damages, and high casualties depend 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 may happen again in the future. In Myanmar, Mandalay lies closed to the most active fault along the Sagaing Fault [5]. Earthquake resistant 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, hazardous buildings should be reliably identified and conceived improvement interventions aimed at the most critical deficiencies only.

In the present study, five existing RC buildings located in three townships of Mandalay city have been analysed by ETABS software. Structural deficiencies of existing structures have been determined under linear static analysis. For these, steel bracings and RC shear walls are added to meet structural stability. Then, nonlinear static analysis has been carried out for performance evaluation and it is found that improved structures under linear static analysis do not meet performance objectives described in FEMA 356 and structural capacities are also less than demand-DBE. So, locations for steel bracings and RC shear walls have been modified. Seismic improvements of proposed buildings have been evaluated in terms of strength, ductility, capacity values (spectral acceleration) and performance points.

II. METHOD OF SEISMIC ANALYSIS

In this study, linear static and nonlinear static (pushover) analyses are performed for evaluating performance of structures. Seismic hazard analysis is carried out for considering future earthquake hazard level in Mandalay city.

A. Linear Static Analysis

As linear static analysis is equivalent static analysis. The seismic force effect on the structure can be translated to equivalent lateral force at the base of the structure which can be distributed to different stories and thus to the vertical structural elements [8].

B. Nonlinear Static Analysis

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. On a building frame, and plastic rotation is monitored, and lateral inelastic forces versus displacement response for the complete structure is analytically computed. This type of analysis enables weakness in the structure to be identified. The decision to retrofit can be taken in such studies [8].

C. Seismic Hazard Analysis

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].

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

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 [9].

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

Where, PGA is peak ground acceleration, Mw is moment magnitude and R is source distance, km [8].

TABLE I
ESTIMATED SEISMIC HAZARD LEVEL FOR MANDALAY CITY

Earthquake Type	Return Period, T_R	Probability P	Magnitude (M_w)	PGA
SE	72	0.1390	6.5	0.2
DBE	475	0.0021	7.3	0.4
MCE	247	0.0004	7.8	0.6

III. DESCRIPTION OF EXISTING RC BUILDINGS

In this study, five existing RC buildings in Mandalay were selected for analysis. All selected existing buildings are mid-rise reinforced concrete buildings situated in three townships of Mandalay, namely Chan Mya Thar Zi, Aung Myay Tharzan and Pyi Gyi Tagon townships. Structural detailed design data and drawings of proposed buildings are available from Mandalay City Development Committee. 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 II and Table III respectively.

TABLE II
LOCATION AND CONFIGURATION OF EXISTING RC BUILDINGS

Model	No of Storey	Building Dimension (L×B×H)	Location	
			Latitude	Longitude
1	6	87'×58'×79'	21° 53.880'	96° 06.360'
2	7	51'×36'×90'	21° 55.999'	96° 05.676'
3	7	51'×36'×92'	21° 55.905'	96° 06.637'
4	7	79'×32'×89'	21° 59.369'	96° 04.189'
5	8	194'×63'×115'	21° 55.260'	96° 05.580'

TABLE III
ORIGINAL DESIGN CATEGORIES OF EXISTING RC BUILDINGS

Model	Support Condition		Earthquake Load		Wind Load	
	Foundation Types	Column Base	Source Type	R	Speed (mph)	Type
1	Isolated	Pinned	A	8.5	80	B
2	Isolated	Pinned	A	8.5	80	B
3	Mat	Fixed	A	8.5	80	B
4	Isolated	Pinned	A	8.5	80	B
5	Mat	Fixed	A	8.5	80	B

IV. STRUCTURAL STABILITY CHECKING FOR 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 IV.

TABLE IV
STRUCTURAL STABILITY CHECKING FOR EXISTING RC BUILDINGS

Model		Δ_M(in) <0.025h	Drift Ratio <0.02/R	FS_{OM} > 1.5	$FS_{Sliding}$ >1.5	Δmax/Δavg >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	1.403	0.0016	25.46	4.01	1.06
	Y	1.469	0.0017	12.39	4.38	1.50

From these checkings, 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 5).

V. SEISMIC IMPROVEMENT OPTIONS

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

A. Addition 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 [6]. In this paper, X type concentric steel bracings (W8×24) are used.

B. Addition of Shear Walls

The addition 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 [6]. In this paper, 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.

VI. SEISMIC IMPROVEMENTS UNDER LINEAR STATIC ANALYSIS

From linear static analysis results, proposed existing RC buildings are needed to correct deficiencies of structural stability. So, steel bracings and RC shear walls are considered to add in existing structures according to the required locations to meet structural stability as shown in Table V.

TABLE V
LOCATION FOR STEEL BRACINGS AND RC SHEAR WALLS

Model	Steel Bracings (W8×24)		RC Shear Wall (10"thickness)	
	Floor level	Location	Floor level	Location
1	Basement	- All sides	Basement	- All corner
	1F	- All corner		
2	Basement	- All sides	Basement	- All corner
	1F	- All corner		
3	Basement	- All sides	Basement	- All sides
	1F	- All sides		
4	Basement	-Front & back center - Left & Right corner	Basement	- Front & back center - Left & Right corner
5	Basement	- All sides	Basement	- Left & right center - Lift & stair sides
	1F	- All corner		

VII. COMPARISON OF PERFORMANCE RESULTS UNDER LINEAR STATIC ANALYSIS

From linear static analysis, performance results before and after improvements are compared in terms of structural weight, torsional irregularity, storey drift and storey shear.

A. Structural Weight

Structural weight for existing buildings before and after improvements is presented in Table VI.

TABLEVI
STRUCTURAL WEIGHTS

Model	Structural Weight (kips)			% Increase	
	Existing	Steel Bracings	Shear Walls	Steel Bracings	Shear Walls
1	3841.9	3866.2	3965.3	0.63	3.21
2	1649.9	1664.2	1757.4	0.87	18.65
3	1829.2	1843.2	2027.9	0.77	10.86
4	2712.5	2725.9	2826.5	0.49	4.21
5	12207.4	12284.7	13764.6	0.63	12.76

From Table VI, it can be seen that addition of shear walls shows significant increase in structural weight more than 3%, but steel bracings, not more than 1% increase.

B. Torsional Irregularity

Two existing buildings (Model 3 and 5) are not satisfied in torsional irregularity. For these buildings, torsional irregularity checking before and after improvements is presented in Table VII.

TABLE VII
TORSIONAL IRREGULARITY CHECKING

Model		Δmax/Δavg		Limit	Remarks
3	Existing	X	1.34	1.2	Unsatisfied
		Y	1.07	1.2	Satisfied
	Steel Bracings	X	1.16	1.2	Satisfied
		Y	1.08	1.2	Satisfied
	Shear Walls	X	1.17	1.2	Satisfied
		Y	1.07	1.2	Satisfied
5	Existing	X	1.06	1.2	Satisfied
		Y	1.5	1.2	Unsatisfied
	Steel Bracings	X	1.06	1.2	Satisfied
		Y	1.2	1.2	Satisfied
	Shear Walls	X	1.05	1.2	Satisfied
		Y	1.19	1.2	Satisfied

From Table VII, it can be seen that both steel bracings and shear walls correct deficiencies of torsional irregularity in X and Y direction.

C. Storey Drift

The maximum drift ratio in X and Y directions before and after improvements are presented in Table VIII and Table IX respectively.

TABLE VIII
STOREY DRIFT IN X DIRECTION

Model	Storey Drift (in)			% Decrease	
	Existing	Steel Bracings	Steel Bracings	Steel Bracings	Shear Walls
1	0.0028	0.0013	0.0023	53.57	17.86
2	0.0041	0.0017	0.0015	58.54	63.41
3	0.0018	0.0014	0.0015	22.22	16.67
4	0.0029	0.0006	0.0006	79.31	79.31
5	0.0016	0.0014	0.0009	12.5	43.75

TABLE IX
STOREY DRIFT IN Y DIRECTION

Model	Storey Drift (in)			% Decrease	
	Existing	Steel Bracings	Steel Bracings	Steel Bracings	Shear Walls
1	0.0024	0.0010	0.0017	58.33	29.17
2	0.0039	0.0013	0.0010	66.67	74.36
3	0.0014	0.0011	0.0012	21.43	14.29
4	0.0029	0.0004	0.0006	86.21	79.31
5	0.0017	0.0015	0.0008	11.76	52.94

From Tables VIII and IX, it can be seen that both steel bracings and shear walls show a significant decrease in storey drifts in both X and Y direction which satisfy deficiencies of P-Δ effect and storey drifts.

D. Storey Shear

The maximum storey shears in X and Y directions before and after improvements are presented in Table X and Table XI respectively.

TABLE X
STOREY SHEAR IN X DIRECTION

Model	Storey Shear (kips)			% Increase	
	Existing	Steel Bracings	Shear Walls	Steel Bracings	Shear Walls
1	279.94	281.07	284.57	0.41	1.65
2	107.41	132.67	123.46	23.52	14.9
3	149.01	149.77	157.24	0.51	5.52
4	186.41	186.88	190.41	0.25	2.15
5	987.83	991.19	1109.35	0.34	12.3

TABLE XI
STOREY SHEAR IN Y DIRECTION

Model	Storey Shear (kips)			% Increase	
	Existing	Steel Bracings	Shear Walls	Steel Bracings	Shear Walls
1	279.94	281.92	284.57	0.41	1.65
2	107.41	132.67	123.46	23.52	14.9
3	156.89	157.70	165.56	0.52	5.53
4	186.41	186.88	190.41	0.25	2.15
5	905.42	908.05	1016.79	0.29	12.3

From Tables X and XI, it can be seen that in both X and Y direction, addition of steel bracings shows a slight increase in storey shear not more than 1% but for Model 2, nearly 25% increase. Addition of shear walls shows increase in storey shear not more than 15%.

VIII. 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 buildings are less than demand-DBE. This means that these building's ability is not good under DBE earthquake level. So, steel bracings and RC shear walls are needed to add in existing structures until these structures meet performance objectives. New modified locations for steel bracings and RC shear walls are presented in Table XII.

TABLE XII
NEW MODIFIED LOCATIONS FOR STEEL BRACINGS AND RC SHEAR WALLS

Model	Steel Bracings (W8×24)		RC Shear Wall (10"thickness)	
	Floor level	Location	Floor level	Location
1	Basement	- All sides	Basement to 2F	- All corner
	1F to 3F	- All corner		
2	Basement	- All sides	Basement	- All corner
	1F to 4F	- All corner	1F to 2F	- Left & Right corner

IX. COMPARISON OF PERFORMANCE RESULTS UNDER NONLINEAR STATIC ANALYSIS

From nonlinear static analysis, performance results before and after improvements are compared in terms of capacity curve, ductility, structural capacity (spectral acceleration) and performance points.

C. 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].

Comparisons of capacity curves of proposed existing buildings before and after improvements are shown from Fig.1 to Fig.4.

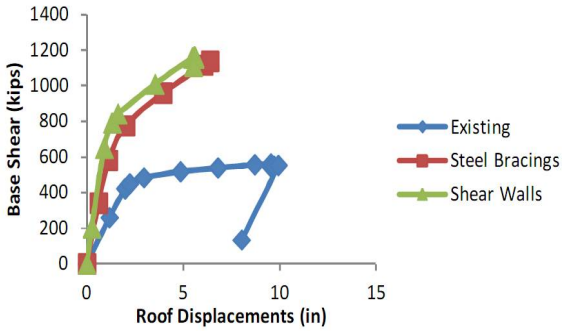


Fig.1. Comparison of capacity curves for building model 1

For Model 1, it can be seen that both addition of steel bracings and shear walls show a significant increase in strength as compared to existing structure.

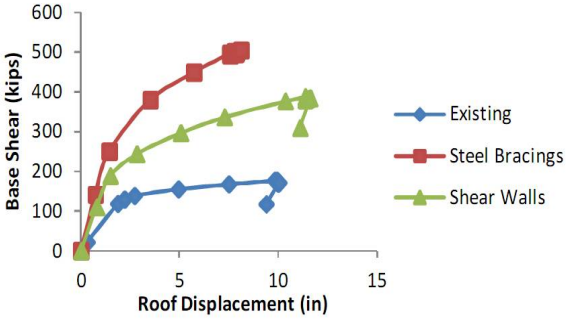


Fig.2. Comparison of capacity curves for building model 2

For Model 2, it can be seen that addition of steel bracings shows a significant increase in strength as compared to shear walls.

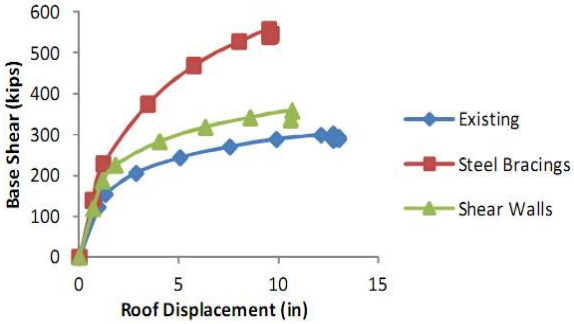


Fig.3. Comparison of capacity curves for building model 3

For Model 3, it can be seen that addition of steel bracings shows a significant increase in strength as compared to shear walls.

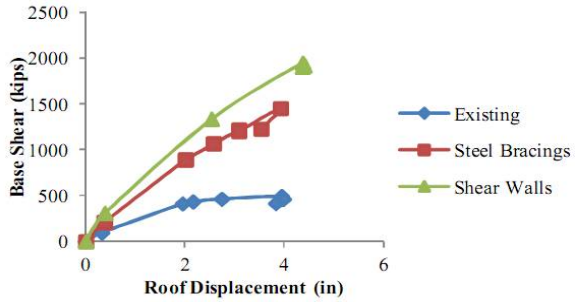


Fig.4. Comparison of capacity curves for building model 4

For Model 4, addition of shear walls shows a significant increase in strength as compared to steel bracings.

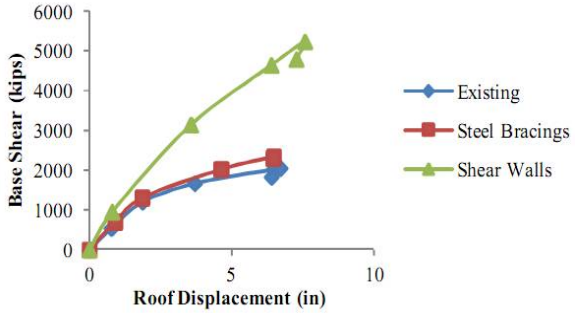


Fig.5. Comparison of capacity curves for building model 5

For Model 5, it can be seen that addition of shear walls shows a significant increase in strength as compared to steel bracings.

E. 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.

$$\mu = \frac{\Delta_{max}}{\Delta_y} \quad (3$$

Where, μ is structural ductility, Δmax is maximum displacement and Δy is yield displacement [4]. Ductility of proposed existing building before and after improvements is shown in Table XIII.

TABLE XIII
DUCTILITY OF EXISTING RC BUILDINGS BEFORE AND AFTER IMPROVEMENTS

Model	Existing			Steel Bracings			Shear Walls		
	Δ_y	Δ_{max}	μ	Δ_y	Δ_{max}	μ	Δ_y	Δ_{max}	μ
1	1.9	9.9	5.0	1.1	6.4	5.6	1.0	5.6	5.6
2	1.8	10.0	5.4	1.4	8.1	5.6	1.5	11.6	7.8
3	1.3	13.0	9.8	1.2	9.6	7.9	1.2	10.7	9
4	0.7	3.8	5.6	0.4	3.9	10.4	0.4	4.4	11.4
5	1.9	6.7	3.6	1.8	6.5	3.5	0.8	7.3	9.1

From Table XIII, it is observed that both steel bracings and shear walls increase the ductility of proposed existing buildings but for Model 3, ductility is slightly decreased.

F. 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.6.

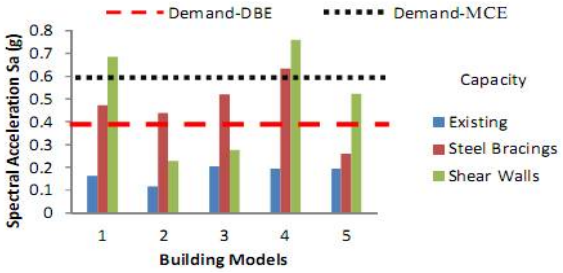


Fig.6. Comparison of capacity and demand

From Fig.6, it can be seen that addition of steel bracings shows increase in capacity more than demand-DBE for building Model 1, 2, 3 and 4. Addition of shear walls shows a significant increase in capacity more than demand–DBE for building Model 1, 4 and 5. For Model 1 and 4, capacity value exceeds demand-MCE.

G. 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. Performance level is the permissible amount of damage, given that design earthquake hazards are experienced.

Performance level and basis safety objectives (BSO) defined from FEMA356 are 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

Performance objectives are life safety building performance under DBE hazard level and collapse prevention performance under MCE hazard level [4]. The performance points of proposed existing buildings under DBE and MCE earthquake level are shown in Table XIV.

TABLE XIV
PERFORMANCE POINTS OF EXISTING RC BUILDINGS BEFORE AND AFTER IMPROVEMENTS

Model		Performance Point		Performance Level	EQ Level
		Sa	Sd		
1	Existing	0.149	3.713	CP	DBE
		0.162	7.090	CP	MCE
	Steel Bracings	0.338	2.326	LS	DBE
		0.418	3.755	CP	MCE
	Shear Walls	0.468	1.670	LS	DBE
		0.591	2.698	CP	MCE

2	Existing	0.106	5.210	CP	DBE
		N/A	N/A	N/A	MCE
	Steel Bracings	0.286	3.047	LS	DBE
		0.365	4.828	CP	MCE
	Shear Walls	0.165	3.779	LS	DBE
		0.205	6.669	CP	MCE
3	Existing	0.171	3.497	CP	DBE
		0.199	6.304	CP	MCE
	Steel Bracings	0.330	2.600	LS	DBE
		0.425	4.169	CP	MCE
	Shear Walls	0.215	2.917	LS	DBE
		0.252	5.123	CP	MCE
4	Existing	0.190	4.103	CP	DBE
		N/A	N/A	N/A	MCE
	Steel Bracings	0.535	2.175	LS	DBE
		0.763	3.341	CP	MCE
	Shear Walls	0.514	2.268	LS	DBE
		0.693	3.448	CP	MCE
5	Existing	N/A	N/A	N/A	DBE
		N/A	N/A	N/A	MCE
	Steel Bracings	0.228	3.360	CP	DBE
		N/A	N/A	N/A	MCE
	Shear Walls	0.368	2.953	LS	DBE
		0.495	4.502	CP	MCE

From Table XVI, it is observed that both addition of steel bracings and RC shear walls are satisfied for four existing buildings (Model 1, 2, 3 and 4) to meet performance objectives. But, only addition of RC shear walls is satisfied for existing building (Model 5).

CONCLUSION

In this study, five existing RC buildings are evaluated for seismic improvements by using linear static and nonlinear static (pushover) analysis. Steel bracings and RC shear walls are used as improvement options.
Under linear static condition, structural improvements are evaluated based on structural stability as defined in UBC code. Both improved methods correct deficiencies of torsional irregularity and P-Δ effect. Addition of shear walls shows more increase in structural weight as compared to steel bracings. Storey shears are also increased but storey drifts are reduced after improvements with steel bracings and shear walls.
Under nonlinear static condition, structural performance improvements are evaluated based on structural capacity and expected performance of the building to meet performance objective requirements. Addition of steel bracings shows a significant increase in strength for three building Model 1, 2, 3 whereas addition of shear walls shows a significant increase in strength for three building Model 1, 4 and 5. Both improved methods show increase in ductility but slightly decrease for building Model 3. Addition of steel bracings and 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 5, only addition of 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 and 4) as it is not only economical method but also easy to install. For Model 5, only RC shear walls are satisfied for required seismic performance.

ACKNOWLEDGMENT

Firstly, the authors would like to express our profound gratitude to Dr. Myo Nyunt, Rector of Mandalay Technological University, for his kindness, permission and suggestion for completion of this paper. The authors would like to express gratitude to Dr. Nilar Aye, Professor and Head of Department of Civil Engineering, Mandalay Technological University for her valuable suggestion and excellent comments to conduct this paper. Finally, the authors would like to thank our parents and all of friends, for their supports and encouragement throughout this research.

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] Peeranan Towashiraporn, Earthquake risk assessment of Mandalay city, Asian Disaster Preparedness Center(2012).
[6] 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 2015.
[7] Kadid and A. Boumrkik, Pushover analysis of reinforced concrete framed structures, Asian journal of civil engineering (Building and Housing) Vol.9, No.1(2008).
[8] Cornell, C.A., Banon, H., Shakal, A.F., Seismic Motion and Response Prediction Alternatives, Earthquake Engineering and Structural Dynamics, 1979.
[9] Myo Thant, Nwai Le Ngal, 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.

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