STUDY ON PERFORMANCE BASED SEISMIC EVALUATION AND STRENGTHENING FOR VULNERABLE BUILDINGS IN MANDALAY REGION

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Abstract- This paper discusses study on performance based seismic evaluation and strengthening technique for existing brick-nogging buildings in Mandalay region. The main objective of this paper is to investigate their seismic performances, damage probabilities and to determine suitable strengthening technique of existing brick-nogging buildings under strong earthquake shaking. Myanmar is located in Alpide earthquake belt and quite earthquake prone region. There had been a lot of major earthquake (M7.0 – M7.9) and a strong earthquake (M8.0) in the past and some of which were quite destructive. Based on the observation of Thabeikkyin earthquake at 2012, the existing brick-nogging buildings reached the most vulnerable condition. Moreover, they were mostly constructed by local occupant. So, in this research, twelve case study buildings are selected to evaluate their seismic performances and damage probabilities for determining that they may or may not need further strengthening. As for the development of Performance based concept, nonlinear Static (Push-over) Analysis is used: to check performance levels of structure under minimum operational earthquake (MOE), design basic earthquake (DBE) and maximum considered earthquake (MCE) ground motions. Fragility curves were derived by using analytical approach with capacity spectrum method. The method of displacement control analysis was used. The 2% of total structure heights was used for displacement control value. Based on analysis results, it was needed to strengthen for resisting up to maximum considered earthquake shaking. Therefore, bracing was selected for upgrading them. After strengthening, the proposed buildings would be sustained MCE damage condition at almost the same probabilities of failure in existing condition. The study shows that the buildings were most vulnerable to slight damage and least vulnerable to complete damage. In this paper, design requirements were referenced from ATC-40, FEMA 356/273 and HAZUS MH and it was designed out by using Structural Analysis Program (SAP 2000) software.

Index Terms— Performance based seismic evaluation, Vulnerable buildings, Fragility curves, Push over analysis, Brick-nogging buildings, Strengthening technique.

I. INTRODUCTION

Destructive earthquakes have happened in Myanmar and tectonic evidences show that they may happen in the future. Therefore, the consequence of major earthquake in urban areas now could be devastating. The primary objective of earthquake resistance design is to prevent buildings collapse during earthquake. A structure should be safe against collapse and consequences of failure. Thus, it is necessary to investigate how can improve seismic performance of non-engineered and vulnerable buildings under strong earthquake shaking.

It is not possible to rebuild thousands of existing buildings to make them earthquake resistant. Thus, it is become inevitable to formulate techniques to improve the seismic performances of such type of existing buildings.

Therefore, this study is conducted to investigate their seismic performances, damage probabilities and to determine suitable strengthening technique of existing brick-nogging buildings under strong earthquake shaking.

II. DESCRIPTION OF THE STUDY AREA

Mandalay city, the second largest city of Myanmar, lies very closed to the dextral Sagaing fault and the city have experienced several destructive earthquakes. Also most of local occupants built their houses by using traditional building styles and methods. Most of houses are not systemically constructed and even these structures can collapse in terms of medium and small earthquake shaking.

According to study, if strong earthquake occurs, low-rise buildings can seriously destroy more than high-rise buildings. Because high-rise buildings designed from the structural point of view including consideration of earthquake effect but it is mostly neglected in low-rise buildings. Experience from the recent earthquake, it has been observed that brick-nogging buildings showed poor performance during earthquake shaking. Therefore, it is needed to investigate the seismic effect on low-rise (brick-nogging) buildings.

Building statistic for Mandalay City is illustrated in Fig.1.

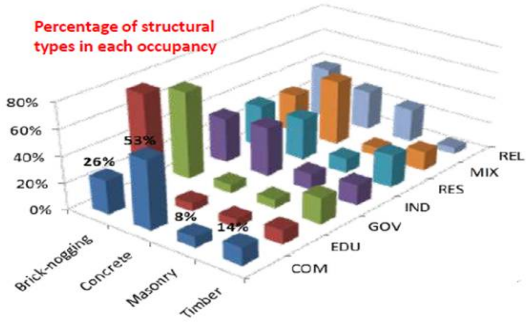

Fig. 1 Building statistic for Mandalay City

Based on the Fig.1, brick-nogging buildings were mostly constructed by local occupant for almost all types of occupancy. Moreover, 80% of educational buildings have been constructed by using this type of construction. For this reason, these types of buildings are targeted to evaluate.

III. METHODOLOGY

A. General Framework

The methodology consists of two frameworks: the first is to evaluate seismic performances that involve the development of analytical fragility curves and damage probability matrix of existing brick-nogging buildings and the second is to determine suitable strengthening technique based on their subjected vulnerable conditions. It utilizes nonlinear analysis techniques, and explicitly considers uncertainties in ground motion, construction style and different usage of material and their properties.

B. Description of Process

The steps comprising the methodology are shown in the Fig.2.

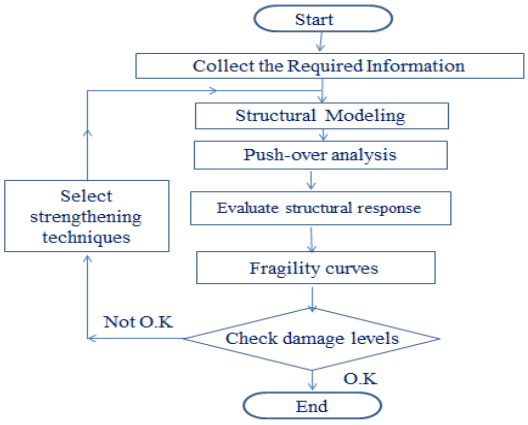

Fig. 2 Flow charts for general frame work

C. Analyse Models

To identify seismic performance of existing buildings, performance based seismic evaluation concept can be used. For the development of this concept, nonlinear static (Push-over) analysis becomes an interesting choice in planning and evaluating building. However, the existing output cannot determine the possibility of damage. Therefore, the development of pushover analysis is much needed in order to know the damage probability on earthquake mitigation effort [4].

So, collapse assessment is performed using nonlinear static (push-over) analysis procedures to help validate the behaviour of nonlinear models.

D. Driving Analytical Fragility Curves

Fragility curves can be defined as its damageability while the structure's vulnerability is a consequence of this damageability. Fragility curves are derived by using analytical approach using push-over analysis with capacity spectrum method. Concept of CSM is the reduction of elastic spectrum intersecting capacity curve at the spectrum coordinate to obtain performance point. Therefore, analysis is based on physical models and damage data is obtained by numerical analysis [2]. Structural systems or components can analyse with different ground motion recorded at different levels of intensity. In this case, the spectral displacement is targeted to compare for determining buildings capacity sustain.

E. Evaluate Buildings' Vulnerabilities

Damage is described by one of four discrete damage states: Slight, Moderate, Extensive and Complete structural damage. The permissible amount of damages is based on different seismic hazard levels. Ranges of damage are used to describe building damage, since it is not practical to have a continuous scale, and damage states provide with an understanding of the building's physical condition [5].

It utilizes results from nonlinear static analyses to determine an appropriate value of the performance of the structures and to evaluate the acceptability of a trial value of the spectral displacement and spectral acceleration.

F. Strengthening Technique

In practice, it is not possible to rebuilt thousands of existing buildings to make them earthquake resistant. So, it is necessary to sustain their seismic performances. Building must be strengthened when the evaluation of the building indicates that the strength available before the damage was insufficient and restoration alone will not be adequate in future earthquake.

Strengthening process is more economical as compare to demolition and reconstruction under structural damage [1].

Strengthening is the process of adding capacity to a member of structure to improve over its original strength. There are four basic types of seismic strengthening. They are – (1) Public safety, (2) Structure survivability, (3) Primary structure undamaged and (4) Structure unaffected.

The classification of building strengthening technologies considering - their goal, materials and the criteria used to verify their effectiveness, easy to use, cost-effective and it would better if include aesthetically. In this study, two different types of bracings are selected for upgrading buildings structural response based on the condition of locally available material and easily installation.

IV. CASE STUDY

In this paper, twelve buildings were considered to construct physical models which are commonly constructed by local people. They are shown in Table I.

TABLE I
CASE STUDY OF PROPOSED BUILDINGS

Case Study	Occupational Purpose	Shape of Building	Dimension of building(ft)
I	Residential building	Square	24 x 24 x 10
II			24 x 24 x 20
III	School building	Rectangular	48 x 24 x 10
IV			48 x 24 x 20
V	School building	E-shape	80 x 48 x 10
VI			80 x 48 x 20
VII	Office building	C-shape	80 x 48 x 10
VIII			80 x 48 x 20
IX	School building	L-shape	16 x 24 x 10
X			16 x 24 x 20
XI	Office building	T-shape	32 x 24 x 10
XII			32 x 24 x 20

In this study, the selected buildings were checked to resist earthquake effect by using Push-over analysis with Structural Analysis Program (SAP) 2000 software. Brick-nogging buildings are constructed with combination of wooden frame and brick walling. Therefore, in this analysis, frames of building were used wooden frame type and their sizes are used as existing ones.

It is considered that high seismic hazard near Sagaing fault is situated in the seismic zone 4. Dead loads and live loads are used according to ACI code. Soil profile type is S_D and seismic source type is C. Material properties are shown in Table II.

TABLE II
MATERIAL PROPERTIES OF PROPOSED BUILDINGS

Types of wood	Pyinkado
Bending at extreme fibre	2500 psi
Axial compression combined with bending	1900 psi
Unit weight	50 psf
Modulus of Elasticity	2000 ksi
Moisture content	10.3%

IV. ANALYTICAL RESULTS

A. Push-over Analysis

In this study, nonlinear Static (Push-over) Analysis method was used to check performance levels of structure. To perform push-over analysis, there need to define at least two types of static nonlinear case and the first case must be for gravity load and the other for lateral load [6].

For gravity load, appropriate option for control was load. It is zero initial condition and therefore the structure has zero displacement and velocity. Assigned loadings are dead load and some portion (mostly 25%) of live load. The method of displacement control analysis is used.

The 2% of total structure heights is used for displacement control value. Built-in default hinges were used and only moment hinges were considered. Hinges location are 5% from the column faces [6]. To reach life safety performance level, the particular displacement that obtained from Push-over analysis for each type of buildings is shown in Table III.

TABLE III
SPECTRAL DISPLACEMENTS AND ACCELERATION

Case	ΔS (in)	Case	ΔS(in)
I	0.63	VII	1.653
II	1.834	VIII	2.854
III	0.39	IX	1.123
IV	1.88	X	2.596
V	1.56	XI	1.655
VI	2.683	XII	4.211

B. Capacity Spectrum Curves

In capacity spectrum method, push-over curve with certain modification was changed to capacity spectrum. Graphs of capacity spectrum were then compared with the response spectrum, ADRS format. From the capacity spectrum or performance curves, we can obtained spectral displacement (S_d), spectral acceleration (S_a) and time period (T). ADRS was plotted into response curve which then intersects capacity curve to obtain performance point and hence the value s_d at the building considered [3]. The values of spectral displacement and acceleration for case study buildings were shown in Table IV.

TABLE IV
SPECTRAL DISPLACEMENTS AND ACCELERATION

Case	S_a (in)	S_d (in)	Case	S_a (in)	S_d (in)
I	0.934	3.586	VII	0.851	1.63
II	0.656	5.044	VIII	0.717	3.621
III	0.742	3.625	IX	0.838	1.128
IV	0.887	3.858	X	0.793	3.212
V	0.868	1.508	XI	0.897	1.674
VI	0.733	3.466	XII	0.695	3.6

Capacity spectrum curves can be drawn by using the values of spectral displacement and spectral acceleration. Using these curves, the existing performance levels of each proposed brick-nogging buildings can be classified [3]. Capacity spectrum curve for case study building I is shown in Fig.3.

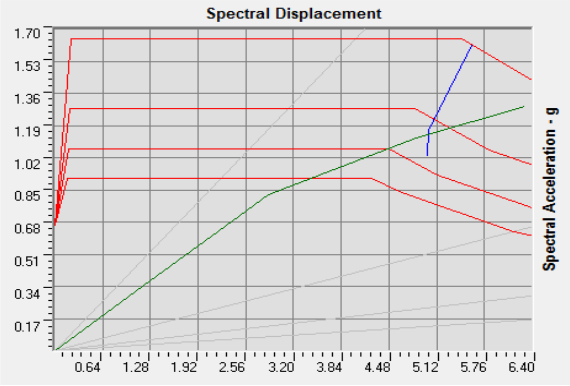

Fig. 3 ATC-40 capacity spectrum curve for case study building I

C. Fragility Curves

Building fragility curves are associated with capacity curve properties, damage states and ground shaking. These curves defines boundaries of different damage state which includes fragility curves for slight, moderate, extensive and complete structural damages. The probability of damage at a given level of spectral displacement is obtained from the calculation of Push-over analysis[5]. By analyzing, the performance point at target spectral displacement S_d for each proposed buildings are obtained. The values of cumulative damage probability are derived from the following equation:

$$P[ds|S_d] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right]$$

P[ds/Sd] = damage probability value, ds
Sd = inelastic spectral displacement (in)
Sd,ds = the median value of spectral displacement at which the building reaches the threshold of damage state: ds
βds = the standard deviation of the natural logarithm of spectral displacement for damage state: ds
Ø = distribution function of cumulative normal standard

By using these equation, the probability of exeeedance for each buildings were derived. Based on the value of cumulative probability, fragility curves can be sketched. The fragility curves distribute damage among Slight, Moderate, Extensive and Complete damage states [5].

In this curves, the structure is subjected to ground acceleration of 0.4g, the performance of the structure is reached at each spectral displacement. Fragility curves for case study building I is shown in Fig.4.

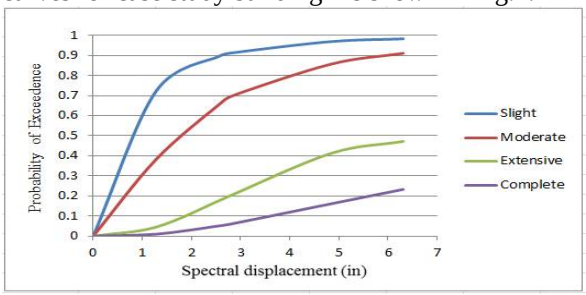

Fig. 4 Fragility curves for case study building I

D. Damage Probabilities

The result of fragility curves can be used to achieve the value of each damage probability for proposed buildings at different damage levels. For any given value of spectral response, discrete damage-state probabilities are calculated as the difference of the cumulative probabilities which results are shown in Table V.

TABLE V
CUMULATIVE DAMAGE PROBABILITY FOR CASE STUDY BUILDINGS

Case	S_a (in)	S_d (in)	Case	S_a (in)	S_d (in)
I	0.934	3.586	VII	0.851	1.63
II	0.656	5.044	VIII	0.717	3.621
III	0.742	3.625	IX	0.838	1.128
IV	0.887	3.858	X	0.793	3.212
V	0.868	1.508	XI	0.897	1.674
VI	0.733	3.466	XII	0.695	3.6

The bar chats of compare damage probabilities at each different four damage state for proposed buildings are presented in Fig.5.

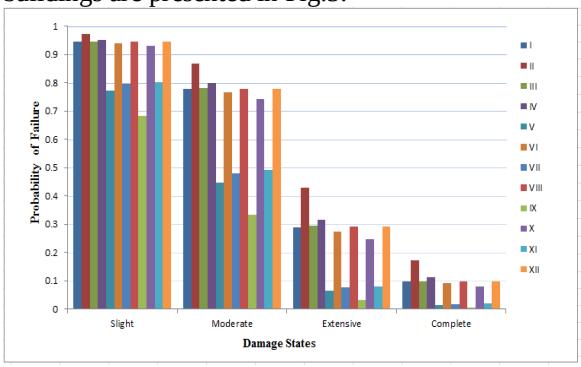

Fig. 5 Cumulative damage probability for case study buildings

E. Strengthening of Existing Buildings

After analysing, almost all case study buildings are in very weak condition at the ground shaking of 0.4g because their performances are reached in life safety damage state even very few amount of lateral displacement. So, they need to be strengthened to resist up to maximum considered future earthquake. In this study, two different types of bracing members (Steel brace W4X13 and Timber brace 5in X 2in) are selected for upgrading buildings structural response based on the condition of locally available material and easily installation. After strengthening cases, the proposed buildings would be sustained up to MCE damage condition at almost the same probabilities of failure in existing condition. Compare damage probabilities are shown in Table V.

TABLE V
DAMAGE PROBABILITY FOR CASE STUDY BUILDINGS

Case	Cumulative probability (%)			
	Slight	Moderate	Extensive	Complete
I	94.35%	77.69%	28.77%	9.68%
II	97.17%	86.86%	42.86%	17.2%
III	94.52%	78.12%	29.46%	9.35%
IV	95.18%	79.95%	31.7%	11.2%
V	77.34%	44.83%	6.43%	1.5%
VI	93.94%	76.73%	27.43%	9.18%
VII	79.67%	48.01%	7.64%	1.83%
VIII	94.3%	74.94%	28.2%	8.69%
IX	68.21%	33.36%	3.29%	0.66%
X	93.06%	74.22%	24.83%	7.93%
XI	80.23%	49.21%	8.08%	1.92%
XII	94.41%	77.94%	29.12%	9.68%

TABLE V
DAMAGE PROBABILITY FOR CASE STUDY BUILDINGS

Case		Damage Probabilities			
		Slight	Moderate	Extensive	Complete
I	Original	94.35%	77.69%	28.77%	9.68%
	W4X13	95%	79.67%	31.42%	10.83%
	T5"x2"	97.2%	86.78%	42.86%	17.03%
II	Original	97.17%	86.86%	42.86%	17.2%
	W4X13	97.78%	88.88%	47.41%	19.77%
	T5"x2"	98.61%	92.22%	56.12%	21.78%
III	Original	94.52%	78.12%	29.46%	9.35%
	W4X13	93.57%	75.49%	26.54%	8.53%
	T5"x2"	96.64%	84.85%	39.36%	14.92%
IV	Original	95.18%	79.95%	31.7%	11.2%
	W4X13	95.35%	80.78%	32.83%	11.51%
	T5"x2"	96.95%	85.77%	41.29%	14.87%
V	Original	77.34%	44.83%	6.43%	1.5%
	W4X13	78.64%	46.72%	7.08%	1.66%
	T5"x2"	72.52%	38.21%	4.46%	0.96%
VI	Original	93.94%	76.73%	27.43%	9.18%
	W4X13	92.65%	73.24%	23.89%	7.48%
	T5"x2"	90.99%	69.15%	20.05%	6%
VII	Original	79.67%	48.01%	7.64%	1.83%
	W4X13	80.02%	48.8%	7.93%	1.9%
	T5"x2"	74.68%	41.29%	5.26%	1.19%
VIII	Original	94.41%	77.94%	29.12%	9.68%
	W4X13	95.91%	82.51%	35.48%	12.92%
	T5"x2"	94.84%	79.1%	30.5%	10.56%
IX	Original	68.21%	33.36%	3.29%	0.66%
	W4X13	74.99%	41.68%	5.37%	1.22%
	T5"x2"	75.17%	41.88%	5.48%	1.25%
X	Original	93.06%	74.22%	24.83%	7.93%
	W4X13	89.62%	65.71%	17.62%	5.05%
	T5"x2"	87.08%	61.03%	14.01%	3.84%
XI	Original	80.23%	49.21%	8.08%	1.92%
	W4X13	84.85%	56.75%	11.51%	3.01%
	T5"x2"	82.12%	51.99%	9.18%	2.28%
XII	Original	94.41%	77.94%	29.12%	9.68%
	W4X13	93.82%	76.23%	27.09%	8.92%
	T5"x2"	90.99%	69.15%	20.05%	5.94%

F. Comparative Study on the Damage Probabilities of Before and After Strengthening Cases with Fragility Curves

The compare damage probabilities between original condition and after strengthening case are also drawn by mean of vertical lines on the fragility curves with different seismic hazard levels. The colours of lines represent their hazard level such as the green colour is the original (existing) condition at DBE level, the blue colour is for strengthening case at DBE level and the red colour is for strengthening case at MCE level respectively. The results are clearly shown in Fig.6 to Fig 17.

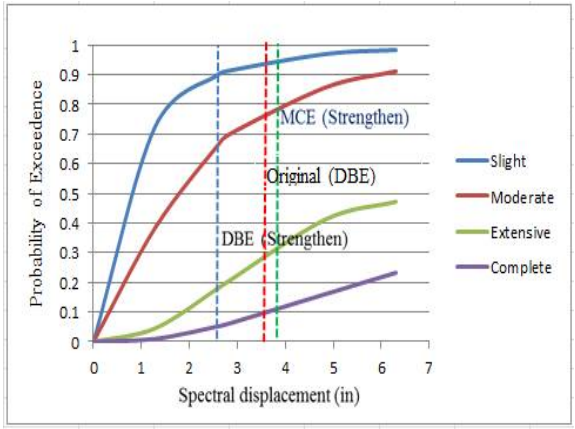

Fig. 6 Compare results for case study building I

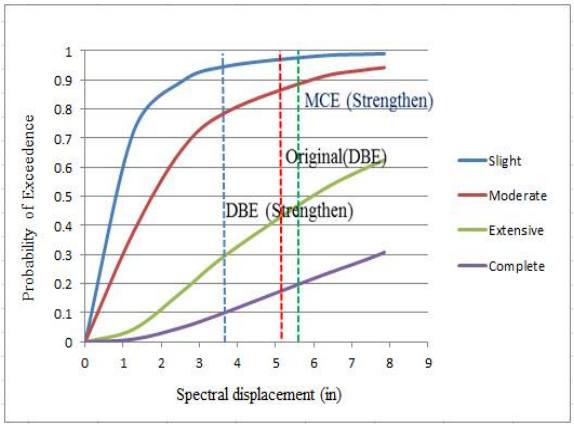

Fig. 7 Compare results for case study building II

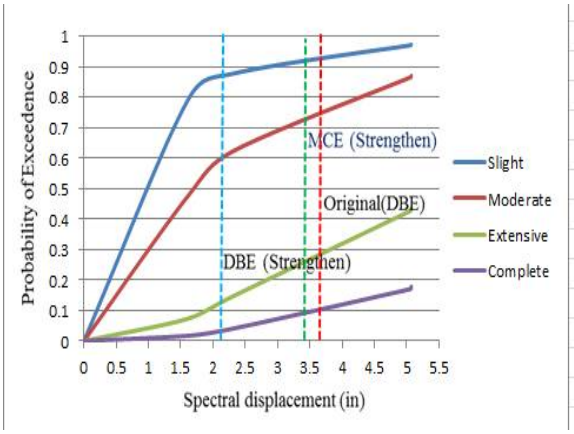

Fig. 8 Compare results for case study building III

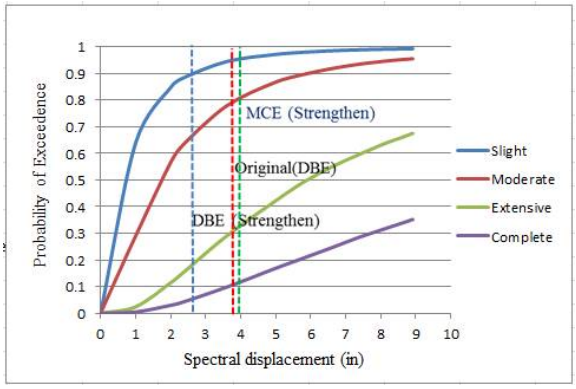

Fig. 9 Compare results for case study building IV

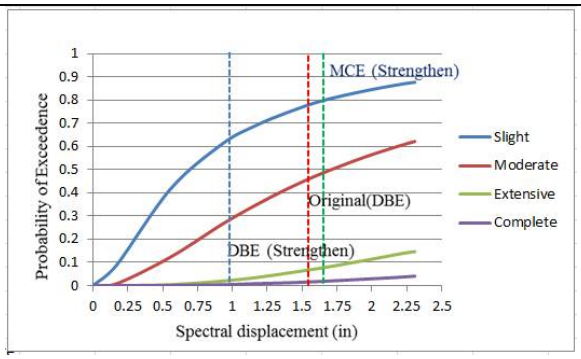

Fig. 10 Compare results for case study building V

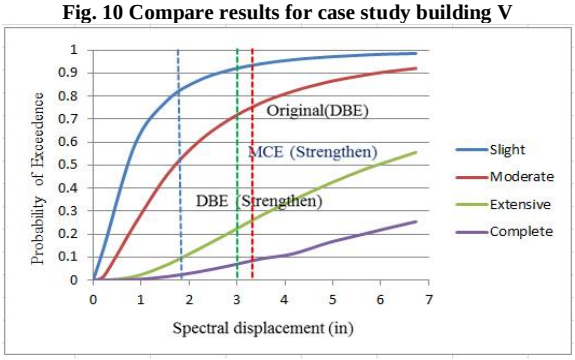

Fig. 11 Compare results for case study building VI

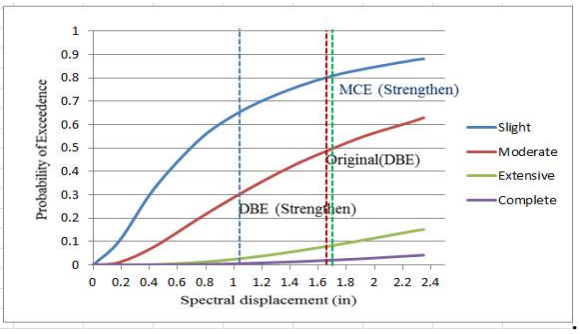

Fig. 12 Compare results for case study building VII

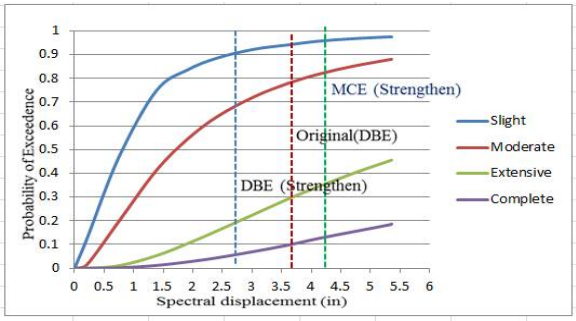

Fig. 13 Compare results for case study building VIII

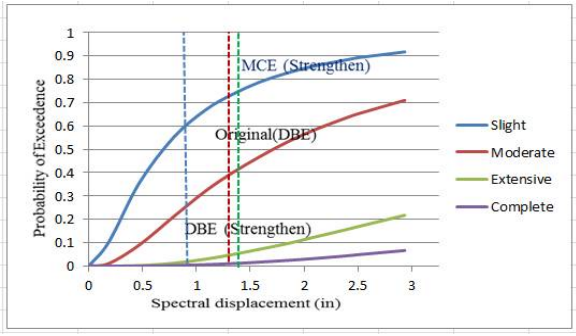

Fig. 14 Compare results for case study building IX

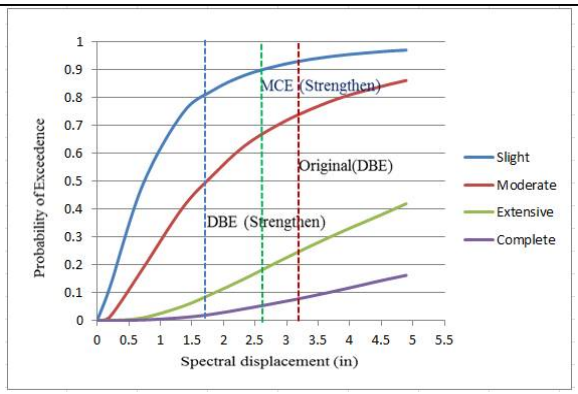

Fig. 15 Compare results for case study building X

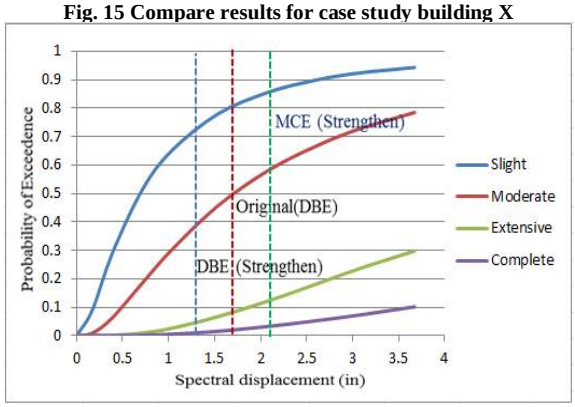

Fig. 16 Compare results for case study building XI

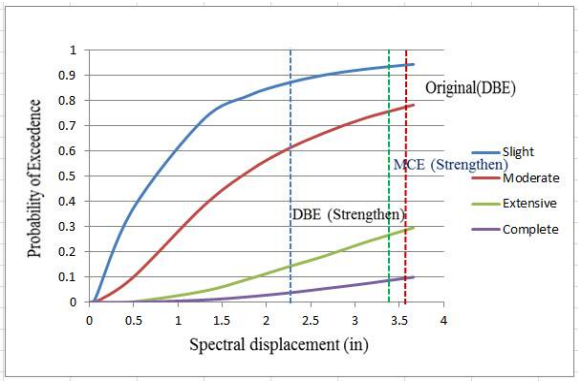

Fig. 17 Compare results for case study building XII

V. DISCUSSION AND CONCLUSION

In this study, 12 typical buildings which are based on mostly constructed by localized, are carried out. By checking their performances using push-over analysis, almost all case study buildings are in very weak condition at the ground shaking of 0.4g. The performance of monitored structures can roughly be assessed by checking the hinge formations. In capacity spectrum method, the performance points for all types of case study are performed with spectral displacement, Sd. The spectrum curves are reached at live safety performance level and it is in the plastic limit state. Even small amount of load is added to this structure, it will reach up to collapse prevention level. In fragility assessment, the spectral displacement is target to compare for determining their capacity sustain. Analysis results revealed that the structures did not have sufficient structural capacity to resist

even a moderate earthquake. Therefore it can concluded that they need further strengthening to resist future earthquake.

After the proposed buildings had been strengthened, they can sustain up to MCE damage condition at almost the same probabilities of failure in original states. The study shows that the buildings are most vulnerable to slight damage and least vulnerable to complete damage. Two different materials and sections are used for upgrading them. They are selected by means of their goals, shapes, and effectiveness and even from the point of cost comparison. Among them, rectangular shape buildings such as Case 1, Case II, Case III, Case IV and Case IX are reasonable with W4X13 bracings and the other irregular shape buildings are suitable with T5X2 bracings respectively. Based on the results, the strength of selected two types of bracing members much not differs in each other. (~ 1 to 3%) So, it is concluded that victims can use all types of proposed bracing members for upgrading their structures: based on locally available materials and sections.

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