

# SEISMIC EVALUATION AND RETROFIT OF EXISTING REINFORCED CONCRETE BUILDINGS

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## ABSTRACT

Seismic evaluation and retrofitting of existing RC buildings are very important for earthquake disaster mitigation for Myanmar because almost all RC buildings in Myanmar have been built without national building codes and seismic designs. In this study, the Japanese seismic evaluation method is studied and applied to one Japanese building and one Myanmar building in order to introduce these evaluation methods into Myanmar in the future. To verify the seismic evaluation methods, the responses of two buildings are performed for the nonlinear frame analysis with STERA 3D program again. After analyzing data by STERA 3D program, the results are also coincided with the seismic evaluation methods. After evaluation, both target buildings are found to be weak in seismic performance. Simple retrofit methods such as wing walls, RC shear walls and structural slits are chosen to increase their seismic capacity. After retrofit, enough seismic capacity is obtained in both target buildings.

**Keywords:** Seismic Evaluation, Nonlinear Frame Analysis, Retrofit, Existing RC Building.

## 1. INTRODUCTION

Although Myanmar had many disasters in the past, disaster education has been very weak and all these disasters were totally forgotten. Then, the Taly's earthquake ( $M_w=6.8$ ) hit Myanmar on 24th March 2011 and people's awareness has risen again now. Most of buildings in Myanmar are moment resisting RC frame structures and they were built without any seismic consideration. In such a situation, their seismic performance is uncertain and it is also difficult to judge which buildings are safe or not. So, seismic performance of all existing RC buildings needs to be evaluated and checked. Seismic evaluation and retrofit for existing RC buildings are useful and effective measure for mitigation of earthquake disasters. If these buildings do not have enough seismic capacity, proper retrofit and strengthening are needed for them to prepare for the future earthquakes.

In this study, the Japanese seismic evaluation method is studied and used. First, seismic evaluation is conducted with a Japanese building damaged by the 2011 Off the Pacific Coast of Tohoku Earthquake. Then, this method is applied again to evaluate seismic performance of a Myanmar RC school building so that seismic capacity of existing RC buildings in Myanmar will be able to be checked in future by these methods. To verify the two screening methods, the responses of two buildings are performed for the nonlinear frame analysis with STERA 3D program. If the target building does not have enough seismic capacity and needs to increase strengths, it is retrofitted by simple methods such as wing walls, RC shear walls and structural slits to increase its seismic capacity.

## 2. METHODOLOGY

There are three levels of seismic evaluation methods in current Japanese standard guidelines. In the first method, material strength and contribution of cross sectional areas of vertical members are

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considered. In the second level method, ductility or deformation capacity and strength of the vertical members are considered. To know the seismic capacity of buildings, it is necessary to calculate the seismic index of the structure ( $I_s$ ) first. The seismic index ( $I_s$ ) is an index which represents the seismic performance of the structure. The larger value of  $I_s$  means higher seismic performance of the structures. The seismic index of the target structures ( $I_s$ ) is calculated with following basic Eq.(1). Basic seismic index of the structures ( $E_0$ ) can be obtained by product of strength index  $C$  and ductility index  $F$ . Strength index is expressed in term of story shear coefficient. The ductility index  $F$  is calculated from the ultimate deformation capacity normalized by the story drift of 1/250 in which most columns fail in shear.

Other reduction factors such as structural irregularity ( $S_D$ ) and time index ( $T$ ) are also used to reduce the seismic index of the target structure. But main influencing factor in seismic evaluations is the basic seismic index ( $E_0$ ) which is simply the product of  $F$  and  $C$  in all three methods.

$$I_s = E_0 \cdot S_D \cdot T \quad (1)$$

## 2.1. First Level Screening Method of Seismic Evaluation

In this level, seismic capacity is calculated based upon the cross sectional area of vertical elements, their shapes and the concrete compressive strength. The vertical elements are divided into three groups depending upon  $h_0/D$  values of different column and wall types. The basic seismic index ( $E_0$ ) of the target structure is obtained by using following two equations. They depend upon the target buildings which have extremely short column or not. The larger value would be taken from the Eq.(2) and (3).

$$E_0 = \frac{n+1}{n+i} (C_w + \alpha_1 \cdot C_c) F_w \quad (2)$$

$$E_0 = \frac{n+1}{n+i} (C_{sc} + \alpha_2 \cdot C_w + \alpha_3 \cdot C_c) F_{sc} \quad (3)$$

Then, irregularity index ( $S_D$ ) and time index ( $T$ ) are calculated with the standard guidelines. After that, the seismic index of the target structure ( $I_s$ ) is compared with seismic demand index of the target building ( $I_{s0}$ ). If  $I_s$  value is larger, the seismic performance of the building is ok. If not, we need to check it with the second screening method.

## 2.2. Second Level Screening Method of Seismic Evaluation

In the second level, the axial force and reinforcement are considered to calculate the strengths and ductility of the vertical members. The vertical elements are classified into five different categories. The ductility indexes  $F$  of all vertical members are grouped into three different groups in maximum. In the second level seismic evaluation, shear force at ultimate flexural capacity and ultimate shear capacity of columns and walls are calculated, and then their results were compared. The effective strength factor  $\alpha$  can be taken from the standard according to their different ductility  $F$ . The cumulative strength index  $C_T$  of each story can also be calculated by the sum of the strength  $C$  with multiplication of the story shear modification factor  $(n+1)/(n+i)$ . There are two basic equations in the second level screening. Eq.(4) is the ductility- dominant basic seismic index of the structure and Eq.(5) is strength-dominant basic seismic index of the structure.

$$E_0 = \frac{n+1}{n+i} \sqrt{E_1^2 + E_2^2 + E_3^2} \quad (4)$$

$$E_0 = \frac{n+1}{n+i} \left\{ C_1 + \sum_j \alpha_j C_j \right\} F_1 \quad (5)$$

The strength index  $C$  in the second screening method is the ratio of the ultimate load-carrying capacity of the vertical members in the story concerned to the weight of the building including live load for seismic calculation supported by the story concerned. For ultimate lateral load-carrying capacity of the vertical members ( $Q_u$ ), minimum value must be chosen from  $Q_{mu}$  and  $Q_{su}$ .

$$C = \frac{Q_u}{\sum W} \quad (6)$$

### 2.3. Nonlinear frame analysis by STERA 3D

After the analysis of the target building with Japanese seismic standard guidelines, the calculated results are verified again with nonlinear frame analysis program STERA 3D. First, the pushover analysis is carried out in longitudinal and transverse directions for both target buildings. Then, earthquake response analysis is conducted with the 2011 earthquake ground motion to T-City Hall and the El Centro earthquake ground motion to Myanmar School building.

## 3. CASE STUDY OF THE JAPANESE AND MYANMAR BUILDINGS

### 3.1. Detail of the Target Buildings in Japan and Myanmar

The Japanese target building is the T-City Hall in Ibaraki prefecture. It is a two-story RC building constructed in 1966 and had been damaged by the 2011 Off the Pacific Coast of Tohoku Earthquake. The first floor plan and the appearance are shown in Fig. 1 and Photo 1. This building has 3 spans in longitudinal direction and 1 span in transverse. The first story height is 3.6 m and the second story height is 2.9 m. The unit floor weight is calculated as 5.98 kN/m<sup>2</sup> for the second floor and 11.03 kN/m<sup>2</sup> for the first floor by assuming the unit weight of concrete is 21.42 kN/m<sup>3</sup>. The hoop spacing of the columns is 300 mm. The compressive strength is obtained as 25.44 N/mm<sup>2</sup>. Yield strength of steel is assumed as 294 N/mm<sup>2</sup>. Two columns with spandrel walls in the first floor were severely damaged by shear failure as shown in Photo 1. But, no damage of columns is observed in the second story. In the first story, due to a RC shear wall out of frame which caused eccentricity, some damages occurred in non-structural hollow block in-filled walls between columns in the east frame by torsional response.

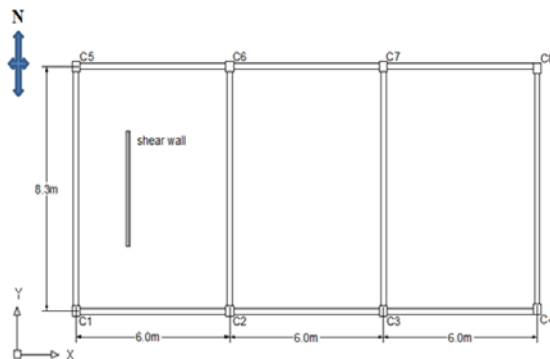


Figure 1. First floor plan of T-City Hall



Photo 1. Appearance of T-City Hall

Myanmar School Building is two-story RC building built after the 2008 Cyclone Nargis. The first floor plan and the elevation are shown in Figs. 2 and 3. This building has 7 spans in longitudinal

direction and 3 span in transverse. All columns are long without shear walls, standing walls or hanging walls. Both the first and second story heights are 3.657 m. Structural and elevation plans are regular in both the first and second story. The unit weights of the second and first floor are calculated as 5.11 kN/m<sup>2</sup> and 10.27 kN/m<sup>2</sup> respectively. The compressive strength of concrete is taken as 17.24 N/mm<sup>2</sup> (2,500 psi) and yield strength of steel is taken as 275.79 N/mm<sup>2</sup> (40,000 psi). The hoop spacing of columns is 152 mm (6 inches).

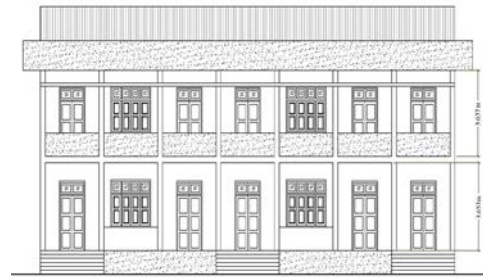
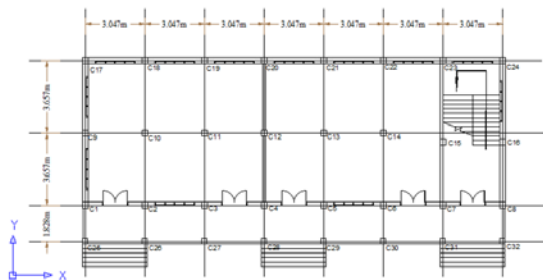


Figure 2. First floor plan of Myanmar School      Figure 3. Front elevation of Myanmar school

### 3.2. Results of Seismic Evaluation

The calculated results of seismic evaluation for T-City Hall and Myanmar school building are shown in Table 1 and 2, respectively. For T-City Hall, the seismic performance is weak in first story by the first screening. The seismic performance is weak in both first and second story by the second screening. The main reason is due to the effect of short columns with spandrel walls and insufficient lateral reinforcement in both stories.

After seismic evaluation for Myanmar School Building, seismic performance is weak in the first story in both longitudinal and transverse directions. The main reason is due to larger longitudinal reinforcement ratio ( $P_t > 1\%$ ) in some of columns and this effect reduced the ductility of these columns in the first story. Flexural failures of these columns are also observed in the dynamic analysis.

Table 1 Results of seismic evaluation for T-City Hall

Story	Screening Level	Before retrofit			After retrofit		
		$I_S$	$C_{TUS_D}$	Evaluation	$R I_S$	$C_{TUS_D}$	Evaluation
2	First screening	1.10	-	OK	1.80	-	OK
1		0.50	-	NG	1.29	-	OK
2	Second screening	0.58	0.72	NG	1.41	0.78	OK
1		0.30	0.37	NG	0.86	0.63	OK

Table 2 Results of seismic evaluation for Myanmar School Building

Story	Screening Level	Before retrofit			After retrofit (Longitudinal)			After retrofit (Transverse)		
		$I_S$	$C_{TUS_D}$	Evaluation	$R I_S$	$C_{TUS_D}$	Evaluation	$R I_S$	$C_{TUS_D}$	Evaluation
2	First Screening	1.52	-	OK	1.52	-	OK	1.52	-	OK
1		0.5	-	NG	1.49	-	OK	1.39	-	OK
2	Second screening	0.91	0.70	OK	0.91	0.70	OK	0.91	0.70	OK
1		0.36	0.36	NG	0.75	0.75	OK	0.76	0.76	OK

### 3.3. Results of structural analysis by STERA 3D

The contribution of the non- structural concrete hollow block walls is neglected in this analysis. The floor is also assumed as flexible in this analysis. The results of nonlinear response analysis for T-City Hall are shown in Figs. 4 and 5. The strong motion records of the 2011 Off the Pacific Coast of Tohoku Earthquake observed at K-NET station near T-City Hall are used for the dynamic analysis of T-City Hall. In both static and dynamic analysis, shear failure of columns are observed due to spandrel walls in T-City Hall. These results are coincided with seismic evaluation methods and also with actual damages.

The results of response nonlinear analysis for Myanmar school building are shown in Figs. 6 and 7. Flexural failures of columns are observed in both static and dynamic analysis with El Centro ground motion. These results are also the same as the seismic evaluation methods. In this building, we cannot verify the results with actual damages because this building does not have any earthquake experiences.

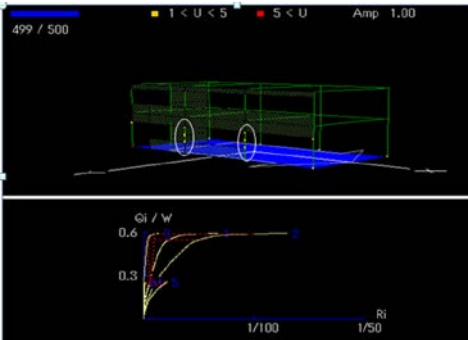


Figure 4. Static analysis in T-City Hall

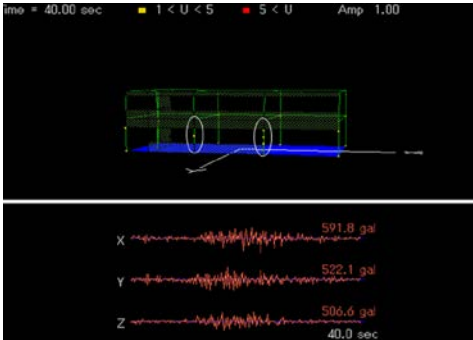


Figure 5. Dynamic analysis in T-City Hall

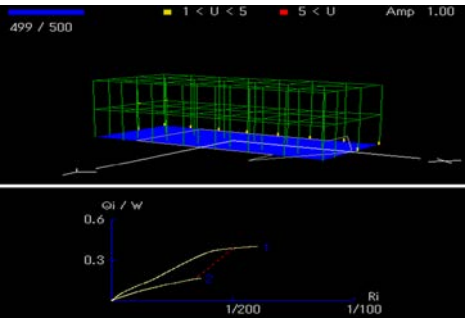


Figure 6. Static analysis in Myanmar School

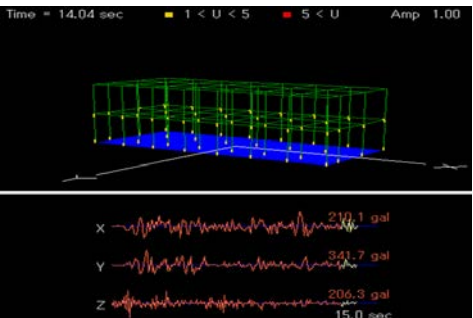


Figure 7. Dynamic analysis in Myanmar School

### 3.4. Retrofitting

It is important and necessary to consider upgrading the strength or ductility before retrofit. The  $I_S$  values of 0.6 or less are recommended for retrofit. For both buildings,  $I_S$  is less than 0.6 in the first story as shown in Tables 1 and 2. For this paper, only RC shear walls, wing walls and structural slits are used for retrofitting for both cases because these methods are easy to apply with available work force and materials in Myanmar. For T-City Hall, wing walls are used. For Myanmar School Building, RC shear walls are used. The calculated results of seismic evaluation after retrofit are shown in Tables 1 and 2.

For T-City hall, the seismic performance is increased by using wing walls and structural slits in both story. After retrofit with 8 wing walls in the first story and with 4 wing walls in the second story, enough seismic capacity is obtained. For Myanmar school building, enough seismic capacity is obtained after retrofit with two RC shear walls in longitudinal direction and with two RC shear walls in transverse direction.

## 4. CONCLUSION AND RECOMMENDATIONS

### 4.1. Conclusion

The objective of this study is to learn the current Japanese seismic evaluation methods and verify their effectiveness through actual damages and response analysis. Then, these evaluation methods would be adopted for seismic evaluation methods for Myanmar after some modification with local seismicity and geological conditions. After study and analysis of the Japanese seismic evaluation methods and responses by STERA 3D, the coincidence and correlation of the evaluation methods and analysis are well proofed.

- For T-City Hall, the seismic performance is weak in first story by the first screening. The seismic performance is weak in both first and second story by the second screening. The required seismic performance is increased by using wing walls and structural slits in both story. After retrofit with 8 wing walls in the first story and with 4 wing walls in the second story, enough seismic capacity is obtained.
- After seismic evaluation for Myanmar School Building, seismic performance is weak in the first story in both longitudinal and transverse directions. After retrofit with two RC shear walls in longitudinal direction and with two RC shear walls in transverse direction, enough seismic capacity is obtained.
- It is also observed that the results of the base shear coefficient (which is the ratio of lateral load capacity to total weight of the building) of both buildings with seismic evaluation methods are decreased by about 25 % to 35 % when compared with the results of non-linear static analysis.

### 4.2. Recommendation for Further Study

- It is recommended to consider the contribution of non-structural concrete hollow block or burnt brick masonry in-filled walls that are neglected in the standard seismic guidelines.
- In the Myanmar School Building, assumption of the seismic demand index of the structure  $I_{so}=0.6$  for the second screening may be a little large compared with low seismicity of Myanmar.
- Appropriate seismic demand index should be reinvestigated through further study in order to apply to Myanmar which has different characteristics of buildings as well as soil parameters.
- The ductility of columns becomes smaller when large longitudinal reinforcement ratio (in which  $p_t$  is greater than 1%) is observed in the Myanmar School Building. So, appropriate longitudinal reinforcement ratio is needed to use in designs.

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## REFERENCE

- G.A MacRae.,et al.( 2010) Steps in Earthquake Proofing a Country-A Case Study of Myanmar. NZSEE Conference.  
Hazard Profile of Myanmar- July 2009  
Saito. : STERA\_3D Technical Manual Ver.3.2, Building Research Institute, Japan  
The Japan Building Disaster Prevention Association (JBDPA) (1<sup>st</sup> English Version 2001).” JBDPA, NIED: Strong-motion Seismograph Networks (K-NET, KiK-net).