

SEISMIC PERFORMANCE EVALUATION OF SCHOOL BUILDINGS CONSIDERING THE POST-DISASTER FUNCTION: CASE STUDY FOR FACILITIES OF PANGASINAN STATE UNIVERSITY, PHILIPPINES

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ABSTRACT

Disaster mitigation is a significant issue that must be addressed to avert the destructive impact of a disaster. Evaluation of the seismic performance of the structures is important to minimize the property damage and eliminate loss of lives against the hazardous effect of natural phenomenon such as earthquakes due to strength deterioration especially of the old buildings. The failure of structures disrupted the operation particularly on the post-disaster functions of school buildings. The Japan Building Disaster Prevention Association (JBDPA) Standard for seismic evaluation of existing reinforced concrete buildings is a detailed inspection method where the actual capacity of the structures to resist the seismic force can be determined. Moreover, proper retrofitting can be carried out to the vulnerable and essential structure to assure the safety of the building stakeholders. The JBDPA Standard focuses on the reinforced concrete structures with the concrete wall. The strength index of the masonry infill walls especially those with openings was determined from the equations of various experts. The two target structures, namely: Engineering Building 2 and four-story Administration Building are old and newly constructed buildings, respectively. The strength of the infill wall was added in the calculation of the seismic capacity of the school buildings. The backbone curve of the frame with reinforced masonry infill wall presented an informative result. The structures require retrofitting based on the first and second level screening. The result of the second level screening specified that only the first floor of the old and new buildings' longitudinal axis need to be strengthened. The behaviors of the structures before and after retrofitting were analyzed in STERA 3D. Following the concept of the JBDPA Standard was found useful in the Philippines since many existing reinforced concrete school buildings with masonry infill wall need further evaluation. Furthermore, the proposed usage index ranges from 1.25-2.00 should be considered to emphasize the importance of the school buildings in post-disaster activities.

Keywords: Post-disaster functional asset value index, JBDPA Standard, Masonry infill wall.

1. INTRODUCTION

Schools must be resilient during hazardous events such as earthquakes so that their operations would not be affected. During disasters, schools have an added value and vital function in post-disaster activities. They are often used as evacuation centers. However, when schools are damaged, the school's mission of continuously providing quality education will be disrupted. Therefore, vulnerability assessment and appropriate retrofitting must be carried out to assure that school buildings will be operational during a disaster. Prioritization of buildings must be devised to identify the structures that

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need immediate attention. The post-disaster functional asset value of the buildings is a vital indicator to refine the screening and ranking. A detailed inspection method following the concept of the Japan Building Disaster Prevention Association (JBDPA) Standard for seismic evaluation of existing reinforced concrete buildings and applying retrofiting method if necessary are effective mitigation strategies to avert the destructive impact of a disaster. Moreover, post-disaster functional asset value index is significant to define the usage index that ultimately ensures an earthquake-resistant school building.

The purpose of this study is to further evaluate the seismic performance of old and newly constructed structures, namely: Engineering Building 2 and Administration Building, respectively. The concept of the Japan Building Disaster Prevention Association (JBDPA) Standard for Seismic Evaluation of Existing RC buildings served as a guide to scrutinize the structural integrity of these buildings utilizing the first and second level of screening. According to Oreta (2011), many structures with soft first story collapsed during the 1990 Luzon earthquake in Baguio City, Philippines. The proposed usage indices for the two buildings were applied to emphasize their vulnerability and importance. The post-disaster functional asset value index (*PDV*) was associated to define the corresponding usage index, *U*, in determining the standard level of safety required for the particular location.

2. METHODOLOGY

The two target structures were evaluated by following the concept of the JBDPA Standard in determining the strength capacity of the reinforced concrete and structural steel buildings. The equivalent number of reinforcements of the steel reinforced concrete columns was considered to employ the concept of the JBDPA Standard. The strength index of masonry infill wall was integrated to the strength of columns to determine its contribution to the whole structural system.

The post-disaster functional asset value (*PDV*) was associated with the usage index to achieve the corresponding seismic demand index. The equations for the strength indices of the infill walls taken from Alwashali et al. (2017) and JBDPA Standard were compared. The strengths of vertical members such as columns and walls were combined to arrive at the current strength capacity of the structure. The vulnerable buildings were retrofitted using the reinforced concrete shear wall to increase their strength. The seismic performance of the target buildings before and after retrofiting was analyzed using STERA 3D and verified the structural integrity of the strengthened buildings using the second level screening.

3. THEORY AND METHODOLOGY

3.1 Post-disaster functional asset value (*PDV*) index



Figure 1. Satellite image of Pangasinan State University, Urdaneta City Campus showing the two target buildings.

A case study was conducted in the Pangasinan State University, Urdaneta City campus in the Philippines to guide the school administrators in determining which of the school facilities need immediate action as presented in Figure 1. The two-dimensional screening was applied to eleven (11) buildings which are built for different purposes. The facilities of the school were screened and ranked based on the post-disaster function and rapid visual screening. The quick inspection was conducted to identify the seismically hazardous buildings. The seismic hazard of the area was determined using PSHA which refers to the maximum PGA at the site and

matched to the seismic hazard index. Moreover, the structures' post-disaster functional asset values were calculated and were used to define the most important building in a post-disaster scenario.

The prioritization matrix was utilized to figure out the corresponding usage index for each building. Ilumin and Oreta (2011) divided this matrix into four quadrants that represent the Priorities I, II, III, and IV. For each quadrant, letters A, B, C, and D indicate the order of priority where A="Very High", B="High", C="Moderate", and D="Low" as shown in Figure 2. The Post-disaster functional asset value (PDV) refers to the combined values obtained from educational and emergency functions of the school. It is a numerical representation for buildings with different levels of importance to signify the uses of space which are excellent in post-disaster activities.

The vulnerable buildings were determined to employ the detailed evaluation and retrofit. In this study, the seismic performance of the two target structures, namely: Engineering Building 2 and Administration Building which also corresponds to Bldg 2 and Bldg 10, respectively were evaluated using the JBDPA Standard as shown in Figure 1. The former is an old two-story reinforced concrete building with 9.5m width and 57.5 m length which was built in the year 1985. The latter is a four-story building constructed last 2015 with the dimensions of 20m wide and 35m long. This steel structure with a soft story part in its ground floor is utilized as a parking area.

The usage index, U , of the JBDPA Standard and NSCP 2015 were modified. In this study, the usage index with the range of 1.25-2.0 was proposed. The corresponding value of U based on the school buildings' vulnerability and importance can easily be traced due to the evenly distributed indices. The PDV index and seismic index are plotted as shown in Figure 2 to determine the structure's equivalent Usage index as presented in Table 1. The outcome shown below proved that school buildings have a different level of importance in times of disaster. Moreover, it can be utilized to anticipate the degree of disruption of the school operations when these buildings are damaged.

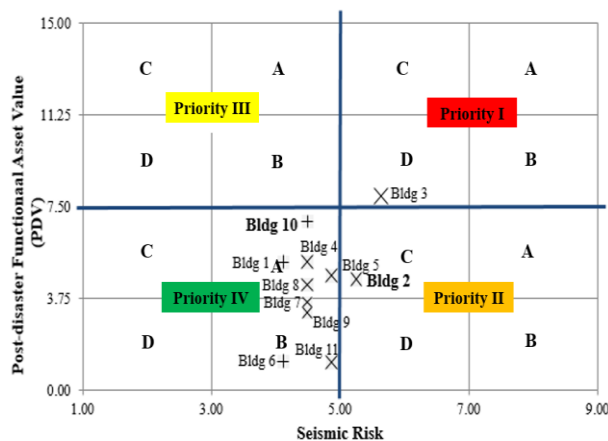


Figure 2. Seismic risk scores are plotted against the PDV values in x and y axis, respectively.

Table 1. Proposed Usage Index, U , of the school buildings in the Philippines.

Level of Priority	Highest index	Priority	Usage Index
I	2	A	2
		B	1.95
		C	1.9
		D	1.85
II	1.8	A	1.8
		B	1.75
		C	1.7
		D	1.65
III	1.6	A	1.6
		B	1.55
		C	1.5
		D	1.45
IV	1.4	A	1.4
		B	1.35
		C	1.3
		D	1.25

3.2. Following the concept of the JBDPA Standard

Seismic index of structure, I_s , connotes the actual lateral loads resisting capacity of an existing building and can be calculated using Eq. (1). The basic seismic index, E_o , of all the stories are calculated using Eqs. (2) and (3) wherein the largest value should be taken into account. Irregularity indices (S_D) equal to 1.0 and 0.90 for the old and newly constructed buildings, respectively denote the effect of structural shape and distribution of unbalanced stiffness. On the other hand, the time index, T , of values 0.8 and 1.0 defines the age and deterioration of the target buildings. The story-shear modification factor, $(n+1)/(n+i)$, changes based on the earthquake lateral force along the story height. In judging the seismic safety of a structure, this index should be equal to or greater than the seismic demand index, I_{so} , to conclude that the building is structurally sound.

The seismic demand index of structure, I_{so} , was determined using Eq. (5). The values of basic seismic demand index of structure, E_s , for both first and second level screening are 0.8 and 0.6,

respectively were based on the JBDPA Standard. Zone index, Z , equal to 1.0 is a modification factor for the target buildings since they are located at zone 4 which is the highest seismicity zone in the Philippines. Ground index, G , is a numerical representation of the soil amplification, geological conditions, and interaction between soil and building based on earthquake ground motion. The value of 1.0 was assumed for the site with a very dense type of soil. The proposed usage index, U , which indicates the use and importance of the building was applied. The usage indices equal to 1.7 and 1.4 were used for the Engineering Building 2 and Administration Building, respectively.

The strength index, C , of the vertical members such as columns and walls were computed by using Eqs. (6), (7), and (8). Moreover, aging of the concrete, β_c , for the column was determined by utilizing the $\sqrt{F_c/20}$ where F_c is equal to 20.7 MPa. In the first level screening, the ductility index of the column is equal to 1.0 while the extremely short column is 0.8. The ductility index of the wall was assumed as 1.0 to include its contribution to the whole structural system.

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

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

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

$$S_D = q_{1a} \times q_{1b} \times \dots \times q_{1j} \quad (4)$$

$$I_{so} = E_s \cdot Z \cdot G \cdot U \quad (5)$$

$$C_w = \frac{\tau_{w1} \cdot A_{w1} + \tau_{w2} \cdot A_{w2} + \tau_{w3} \cdot A_{w3}}{\Sigma W} \cdot \beta_c \quad (6)$$

$$C_c = \frac{\tau_c \cdot A_c}{\Sigma W} \cdot \beta_c \quad (7)$$

$$C_{sc} = \frac{\tau_{sc} \cdot A_c}{\Sigma W} \cdot \beta_c \quad (8)$$

$$E_o = \frac{n+1}{n+i} \sqrt{E_1^2 + E_2^2 + E_3^2} \quad (9)$$

$$E_o = \frac{n+1}{n+i} \left(C_1 + \sum_j \alpha_j C_j \right) \cdot F_1 \quad (10)$$

The strength index of reinforced masonry infill wall is determined using the two formulas which are from JBDPA Standard and Alwashali et al. (2017) as shown in Eqs. (11) and (12), respectively. The A_w denotes the area of a wall while ΣW connotes the weight of the story concerned. The value of β_c was derived by using $f'_m/20$ from the study of Naqi (2017).

Based on Alwashali et al. (2017), V_{inf} is the ultimate lateral load carrying capacity of each masonry infill wall and can be computed using Eq. (13). The f'_m , t_{inf} , l_{inf} , and λ_{op} indicate the compressive strength of masonry, thickness, length, and reduction factor due to openings such as doors and windows, respectively. Their statement pertaining to the calculation of the reduction factor using Eq. (14) from Al-Chaar et al. (2003) was adopted. The A_o and A_p are the areas of opening and masonry infill wall, respectively. Moreover, the shear stress of reinforced masonry infill wall, τ_w , was presumed as 1.0 MPa for the second level screening. Results from the two equations gave the same values. Therefore, Eq. (12) was preferred in determining the strength index, C , of the reinforced masonry infill wall.

$$C_w = \frac{\tau_w \cdot A_w}{\Sigma W} \cdot \beta_c \quad (11)$$

$$C = \frac{V_{inf}}{\Sigma W} \quad (12)$$

$$V_{inf} = 0.05 f'_m \cdot t_{inf} \cdot l_{inf} \cdot \lambda_{op} \quad (13)$$

$$\lambda_{op} = 0.6 \left(\frac{A_o}{A_p} \right)^2 - 1.6 \left(\frac{A_o}{A_p} \right) + 1 \quad (14)$$

3. RESULTS AND DISCUSSION

3.1. Seismic Evaluation

The Engineering Building 2 has forty-two (42) reinforced concrete columns. The strength index of all the columns was calculated. Majority of columns failed in shear in both directions. The strength of walls in the transverse direction was added to the columns because they have the same ductility index. However, the walls in its longitudinal direction with large openings were neglected. The Administration Building has a total of sixty-two (62) steel reinforced concrete (SRC) columns. Majority of its SRC columns failed in shear in both directions. The strengths of its walls and columns were incorporated in the computation of E_o .

The first level screening revealed a conservative result wherein the longitudinal and transverse directions of the Engineering Building 2 need retrofitting. Moreover, the first, second and third floors of the Administration Building require strengthening. The second level screening is a more detailed method of evaluation. It exposed that only the first story of these two buildings along the longitudinal direction need to be retrofitted.

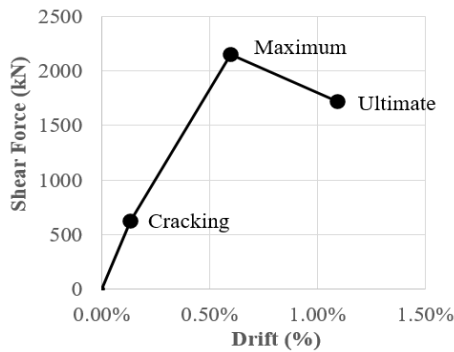


Figure 3. Backbone curve of the frame with reinforced masonry infill wall based on Sugano (2018).

The equations based on experiments from Sugano (2018) were applied to plot the backbone curve of the frame with reinforced masonry infill wall of the Bldg 2 showing the three deformation stages which are in cracking, maximum, and ultimate as presented in Figure 3. The equation in determining the shear force at maximum denoted that the lateral reinforcements specifically the distance between the two horizontal reinforcing bars significantly influenced the result where the contribution of reinforcements was emphasized. The force at the ultimate stage was defined by considering 80% of the shear force at maximum.

3.2. Retrofitting by Installing Reinforced Concrete Shear Panel

The vulnerable buildings were retrofitted using the reinforced concrete shear wall to upgrade their seismic capacity. The contributions of the infilled shear panels to the vertical members of structures were verified utilizing the second level screening. Furthermore, they were modeled in STERA 3D and the technical manual version 5.8 which was also produced by Saito (2017) was used to fully understand the notion behind the gathered results. Figures 4 and 5 show the location of the four and three RC shear panels of the Engineering Building 2 and Administration Building, respectively. According to Sugano (2018), the connection failure with assumed ductility index equal to 1.0 will cause the concrete shear panel to have a shear sliding failure at the connection. The existing boundary columns will also experience the failure mode such as punching failure, flexural or shear failure. The 16mm diameter anchors served as connectors to be installed around the existing frame with the effective embedment length of 160mm. Figure 6 shows the improved strength of the structures indicating the effectiveness of RC shear wall.

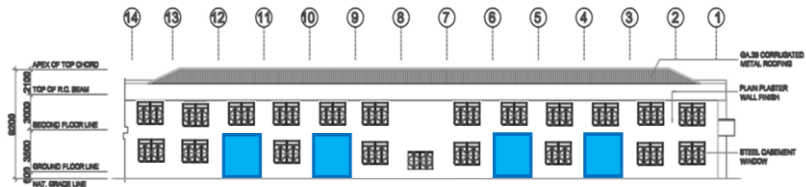


Figure 4. Rear elevation of the Engineering Building 2 showing the location of shear walls.

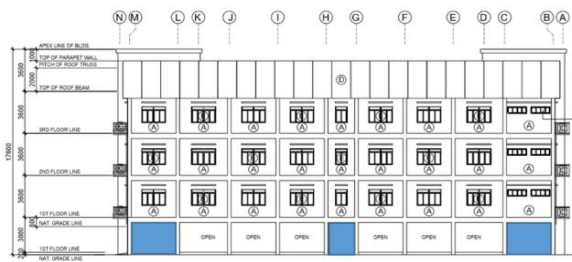


Figure 5. Rear elevation showing the location of shear walls.

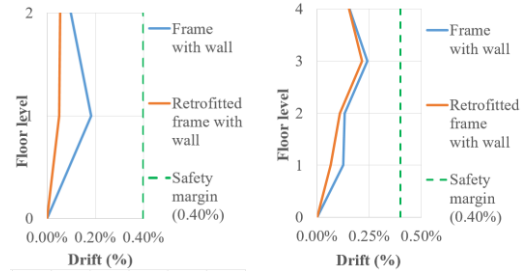


Figure 6. Maximum inter-story drifts of Bldg 2 (left) and Bldg 10 (right).

4. CONCLUSIONS

Detailed investigation of the facilities of Pangasinan State University with reinforced masonry infill wall is very effective to scrutinize their actual seismic capacity. The equation applied to the soft story building with an irregularity index, S_D , equal to 0.90 considerably influenced the outcome. It resulted into a smaller value of the seismic index, I_s , which affects its actual seismic performance. Moreover, the usage index, U , equal to 1.4 and 1.7 increased the seismic demand index, I_{so} , of structures. Retrofitting the vulnerable building using RC shear wall ensures an earthquake-resistant structure. Therefore, the safety of the building stakeholders is guaranteed where school buildings can also be used as a temporary shelter.

5. RECOMMENDATIONS

The efficacy of following the concept of the JBDPA Standard to evaluate in detail the seismic performance and retrofit the vulnerable buildings has been proven. Therefore, this should be carried out in all the reinforced concrete structures instead of the rapid visual screening. This detailed inspection is a vital tool to trace a more precise usage index for each structure where it can give an accurate standard level for a building to be safe. Post-disaster functions of the school building should be considered to define the appropriate Usage index, U , to be used. Moreover, buildings with reinforced masonry infill wall need further study. Sufficient laboratory experiment is necessary on the different types of walls with openings to have adequate information on their real behavior.

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