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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 an important issue that must be addressed. School buildings have two significant functions in post-disaster scenario, namely: educational and emergency. The failure of structures disrupted the operation particularly on the post-disaster functions of school buildings. A two-level prioritization matrix is used to rank the importance of each building inside the Pangasinan State University-Urdaneta City Campus in the Philippines. Seismic risk scores are plotted against the Post-disaster Functional Asset Value (PDV) in x and y axis, respectively to identify the most vulnerable and important buildings. In this method, the uses of space of the structure and its structural vulnerability using rapid visual screening are the main factors in categorizing the eleven (11) buildings in the study. The two target structures, namely: Engineering Building 2 and four-story Administration Building are old and newly constructed buildings, respectively. These structures are essential in post-disaster activities. Seismic performance evaluation of these two buildings is conducted by following the concept of Japan Building Disaster Prevention Association (JBDPA) Standard. The 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. It focuses on the reinforced concrete structures with the concrete wall. Therefore, the strength index of masonry infill walls especially those with openings were determined from the equations of various experts. The proposed Usage index was used in calculating the seismic demand index of structure, Iso. 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 Structural Earthquake Response Analysis (STERA) 3D. Retrofitting the two vulnerable buildings by installing concrete shear walls resulted into an upgraded structural strength and denotes an earthquake-resistant structure. JBDPA Standard was found useful in the Philippines since many existing reinforced concrete school buildings with masonry infill wall need further evaluation.

Keywords – JBDPA standard; post-disaster functional asset value, masonry infill wall

I. PANGASINAN STATE UNIVERSITY, URDANETA CITY CAMPUS

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 important function in post-disaster activities. Schools are often used as evacuation centers. However, when schools are damaged, the school's mission of continuously providing quality education will be disrupted. Pangasinan State University (PSU), Urdaneta City campus is one of the nine (9) branch campuses of PSU and it is located at National Road, Barangay San Vicente, Urdaneta City, Pangasinan, Philippines. It has a total land area of twenty-five thousand four hundred ninety-nine square meters (25, 499 m2). The city has a geographical coordinates of 15.9835° N and 120.6334° E. A case study was conducted to guide the school administrators in determining which of the school facilities need immediate action.

II. SEISMIC PERFORMANCE EVALUATION

2.1 Japan Building Disaster Prevention Association (JBDPA) Standard

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. The Post-Disaster Functional Asset Value (PDV) refers to the combined values obtained from educational and emergency functions which signify the importance of the school buildings in post-disaster activities. The study of Ilumin and Oreta (2018) furtherly describes the significance of a structure wherein the importance ratings of various uses of space together with their equivalent area occupied and actual capacities are considered in the ranking of the buildings. In a post-disaster scenario, school buildings have two important functions which are educational and emergency. 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.

2.2. Methodology

The two regular geometric shape 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 retrofitting was analyzed using STERA 3D and verified the structural integrity of the strengthened buildings using the second level screening.

2.3. Post-disaster functional asset value (PDV) index

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 2. 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 1 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.

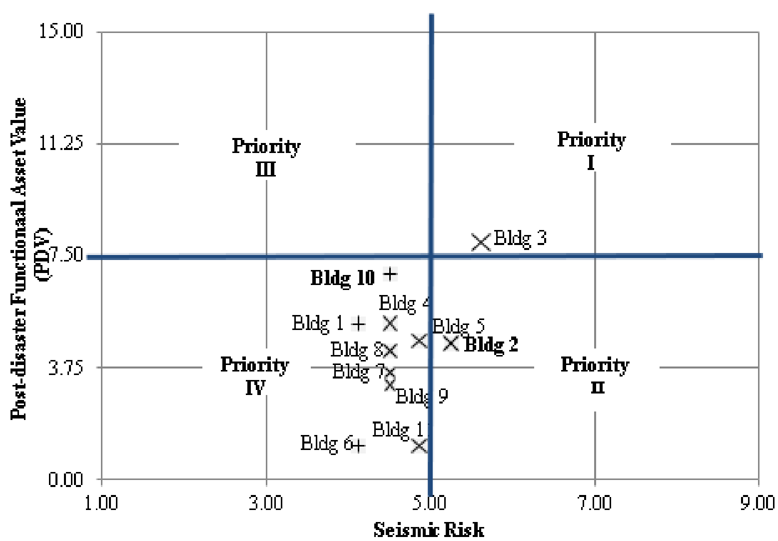

Figure 1. Seismic risk scores are plotted against the PDV values in x and y axis, respectively.

(a) (b)

Figure 2. (a) Building 2 (b) Building 10

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

3.4 Following the concept of the JBDPA Standard

Seismic index of structure, Is, connotes the actual lateral loads resisting capacity of an existing building and can be calculated using Eq. (1) where Eo refers to basic seismic index. 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. In judging the seismic safety of a structure, this index should be equal to or greater than the seismic demand index, Iso, to conclude that the building is structurally sound. The seismic demand index of structure, Iso, was determined using Eq. (2). 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.

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

$$I_{so} = E_S \cdot Z \cdot G \cdot U \quad (2)$$

III. PUSHOVER ANALYSIS USING STERA 3D

The pushover analysis was conducted using the structural earthquake response analysis (STERA) 3D to analyze the structural response of the target buildings before retrofitting. The yield strength of the main reinforcements in columns was equal to 275 MPa. The influence of reinforced masonry infill walls to the structures was modeled aside from the bare frame. Moreover, the area of the structural steel of the four-story building was taken into consideration. This is to compare the result gathered from the second level screening and to determine if they have corresponding outcome.

3.1 Engineering Building 2 and Administration Building

The building's maximum deformation capacity was analyzed using the pushover analysis wherein the gradual loading was exerted. Figure 3 shows that severe damage was concentrated at the first floor of the Engineering Building 2. In STERA 3D, red color indicates a ductility factor greater than 5 and when it was associated to the ductility index, it can induce large displacement. This means that the structure will suffer significant deformation wherein possibility of collapse is high. Furthermore, the yellow color connotes minimal cracking. The second level screening which is a detailed inspection method presented the same result in which the longitudinal direction of the first floor needs retrofitting.

The newly constructed soft story building was also analyzed using pushover analysis. The result showed that this building has a few severe damages at the first floor while the rest of its floors has minor damages as shown in Figure 4. Even though there was a few red color which means serious damage on the particularly area, still strengthening must be considered. The result from the second level screening gave the same remarks that first story should be retrofitted.

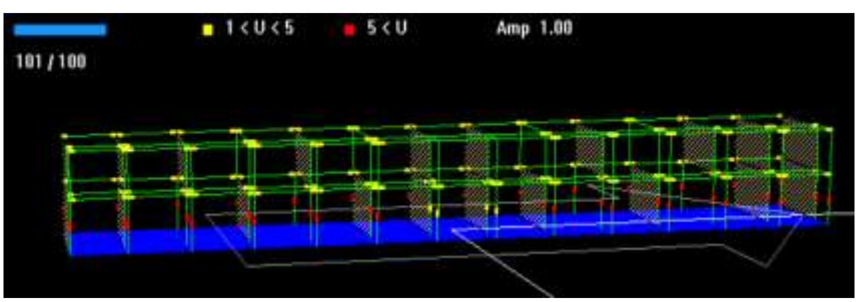

Figure 3. Pushover analysis of the Engineering Building 2.

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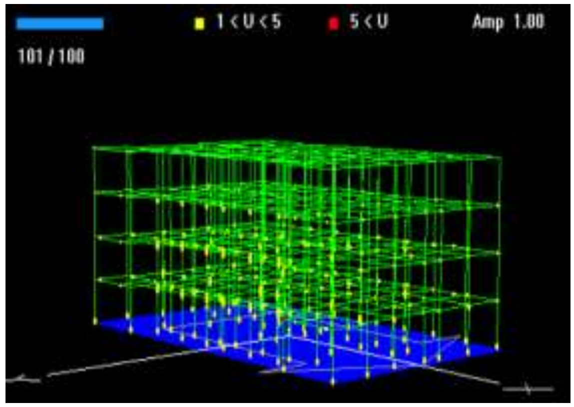


Figure 4. Pushover analysis of the Administration Building.

IV. RESULTS AND DISCUSSION IN 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 Eo. 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 stories of these two buildings along the longitudinal direction need to be retrofitted.

4.1 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 written by Saito (2017) was used to fully understand the notion behind the gathered results. Figures 5 and 6 show the location of the four and three RC shear panels of the Engineering Building 2 and Administration Building, respectively. 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.

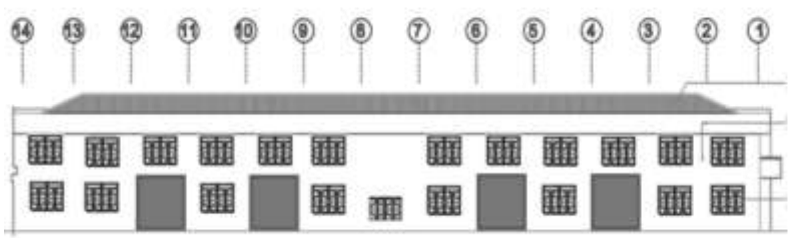


Figure 5. Rear elevation of the Engineering Building 2 showing the location of shear walls.

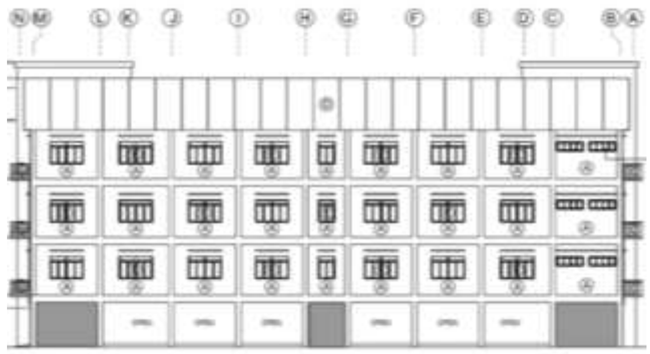
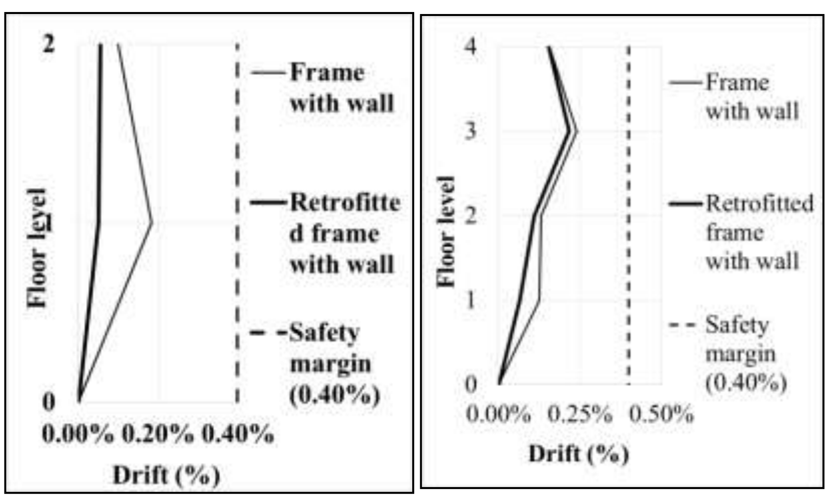


Figure 6. Rear elevation showing the location of shear walls.

4.2 Dynamic Analysis using Stera 3D

The Stera 3D was utilized to analyze the behavior of the structures which were included in this study. The strong ground motion data of the 2013 Bohol earthquake from the Philippine Institute of Volcanology and Seismology (PHIVOLCS) was used in the dynamic analysis. The data was filtered using a 4th order Butterworth bandpass between 0.4-50.0 Hz. The reverse fault incurred 7.2 magnitude with a depth of 10 km and an intensity VII which means destructive, was noted in Central Visayas, Philippines. The tremor had a peak ground acceleration of 214 gal.

Retrofitting these two vulnerable buildings by installing concrete shear walls resulted into an upgraded structural strength. This denotes a resilient school building where the safety of the employees and students were ensured. Significant improvement on seismic performances of Engineering Building 2 and Administration Building are shown in Figures 7a and 7b, respectively.



(a) (b)

Figure 7. (a)Maximum inter-story drift of Engineering Building 2 at longitudinal direction for 2013 Bohol response spectrum (b) Maximum inter story drift of Administration Building at longitudinal direction for 2013 Bohol response spectrum.

V. CONCLUSIONS AND RECOMMENDATIONS

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, Is, which affects its actual seismic performance. Moreover, the usage index, U, equal to 1.4 and 1.7 increased the seismic demand index, Iso, 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. 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. 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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