SEISMIC PERFORMANCE EVALUATION OF A TYPICAL LOW-RISE REINFORCED CONCRETE BUILDING IN THE PHILIPPINES

Melanie Pagcaliwangan* **Supervisor: Tatsuya AZUHATA****
MEE16713 **Masanori TANI*****

ABSTRACT

The Republic of the Philippines is vulnerable to different disasters including earthquakes due to its geographical location. The risk exposure that the country is facing put the safety of existing structures in line especially those in the Metropolitan Region. The most common type of building in the Philippines is a reinforced concrete framing with masonry walls as partitions and exterior walls. Concrete hollow block is frequently used material in building construction. However, these walls are not considered in practical design since it is a non-load bearing element in the structure. In this study, a seismic evaluation on a two-story RC structure was conducted considering the effects of secondary walls in terms of strength, ductility and failure mechanism of the structural members. Since there were no available guidelines in seismic evaluation in the Philippines, the JBDPA Standard were adapted. The main frame had 21MPa compressive strength while the walls had 6.9MPa. The capacities of bare frame and frame considering walls were investigated using the JBDPA Method and analyzed by Response 2000 Software.

Keywords: Seismic evaluation, Non-structural walls, Ductility.

1. INTRODUCTION

The country has experienced destructive earthquakes, such as the 1976 Ms7.9 Moro Gulf Earthquake, 1990 Ms7.9 Luzon Earthquake, 2015 Bohol Earthquake, wherein thousands of people died, infrastructures and buildings collapsed and severely damaged as well as tremendous amount of economy loss. At present, there is no available guideline or standard for seismic evaluation of existing buildings in the Philippines. In line with this, a seismic performance evaluation using the Japanese Standard as a reference was conducted in an existing typical low rise reinforced concrete structure in the Philippines. The applicability of this tool can be examined in this study. By applying an established guideline, the adequacy of the seismic design of the structure can be estimated, and compared to Japanese Code. This may also initiate a future adaptation of seismic screening of structures in the Philippines, since both countries have a high seismicity. The main objective of this study is to investigate more precisely the effect of walls in the seismic performance of a typical low-rise reinforced concrete structure in the Philippines. Specifically, to study the contribution of the walls in the strength of columns and beams, ductility indices, as well as failure modes of the structure, to conduct cross section analysis of frames using Response 2000 Software, to determine the performance point of the structure by Push Over Analysis in STERA 3D, lastly to compare the analyses of framing with and without secondary walls.

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*Department of Public Works and Highways, Philippines.
**International Institute of Seismology and Earthquake Engineering, Building Research Institute, Japan.
***Assoc. Professor, Graduate School of Architecture and Architectural Engineering, Kyoto University, Japan.

2. METHODOLOGY

2.1. Schematic Diagram of Research Procedure

The procedure for this study is summarized below:

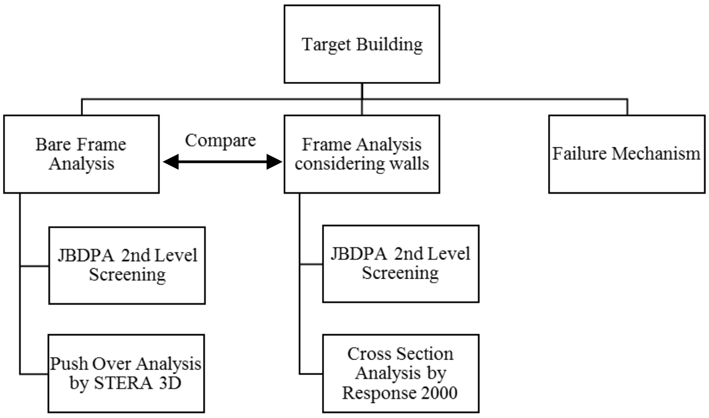


Figure 1. Flowchart of Research Study.

2.2. Bare Frame Analysis

In the bare frame analysis, the capacity of columns was calculated when all masonry walls are neglected. The ultimate strength of columns, ductility index and seismic index of structure will be identified under the condition of Second Level Screening. The seismic index of structure, *Is*, is calculated in each story and given by Eq. (1):

$$I_S=E_0 S_D T \quad (1)$$

S_D is the irregularity index based on the engineering judgment of plan irregularity and unbalance distribution of stiffness. T is the time index wherein the effects of structural defects are examined such as cracking, deflection, and aging. The calculated *Is* was compared to the seismic demand index, I_{so} of JBDA Standard in Eq. (2). Whereas, E_S is basic seismic demand index, C_G is the correction factor for geology, C_I is the importance factor.

$$I_{S0}=E_S C_G C_I \quad (2)$$

In addition to this analysis, a non-linear static push over analysis by STERA 3D was also completed to plot the demand capacity curve of the structure.

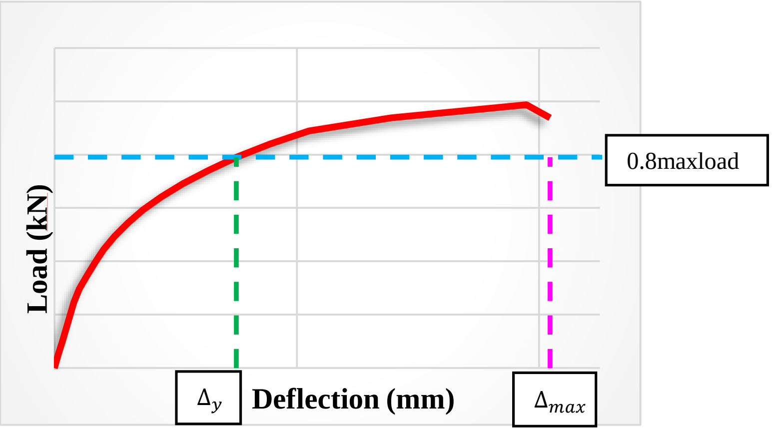
2.3. Frame Analysis with Walls

In the second case of evaluation, the same process of second level screening of JBDPA Standard was conducted. However, the effects of masonry walls were considered.

The strength of structural members was calculated considering the material properties of the concrete and reinforcement of the walls. The material of this masonry walls is a concrete hollow block (CHB) having a compressive strength of 6.9MPa and a reinforcement yielding strength of 230MPa. Since the height of the walls varies, the detail of reinforcement is standard and remains the same depending on its corresponding length.

For a more accurate analysis of bending capacities of cross section of columns with wing walls as well as beams with spandrel and hanging walls, Response 2000 Software was utilized. Response 2000 is a free software developed at the University of Toronto by Evan Bentz supervised by Professor Michael P. Collins. It enables the user to have a non-linear 2D cross sectional analysis of reinforced concrete elements subjected to shear, moment and axial load.

The software generated a Moment-Curvature Relationship and a Load-Deflection Plot of a cross section. In line with this, the ductility factor was estimated using Eq. (4) and this was related to ductility index, F, in Eq. (5):



$$\mu = \frac{\Delta_{max}}{\Delta_y} \qquad (4)$$

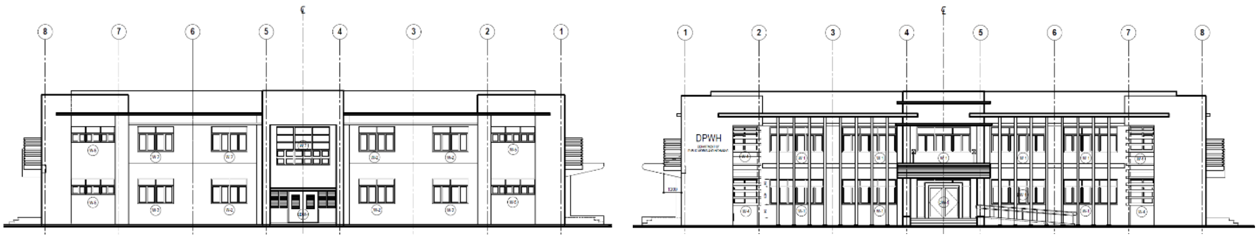
$$F = \frac{\sqrt{2\mu - 1}}{0.75 \times (1 + 0.05\mu)} \qquad (5)$$

The ductility index was compared to the calculated indices from Bare Frame Analysis. With this, it was approximated how the walls affected the ductility of columns.

Figure 2. Load-Deflection Plot from Response 2000.

3. DATA OF THE TARGET BUILDING

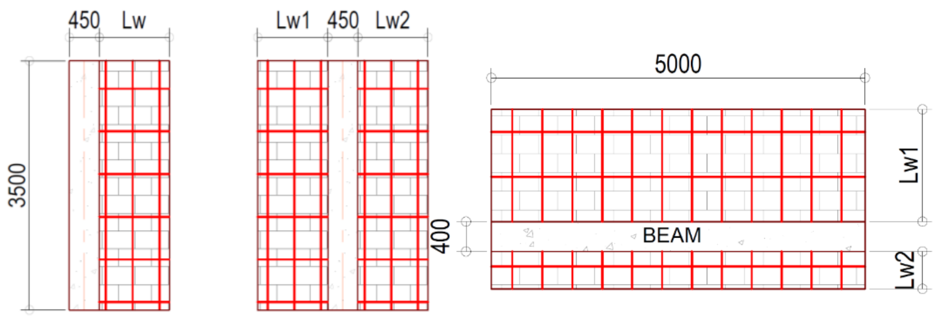
The target structure is a two-story reinforced concrete building which was used in project implementation of Department of Public Works and Highways (DPWH) throughout the country. The building has standard engineering plans to be used as an office of different district and regional branches of DPWH.



(a) (b)

Figure 3. Rear (a) and Front Elevation (b) of the Target Building.

The total height of the structure is 7meters, having a story height of 3.5meters on each floor. The calculated service loads were 6.95kPa and 6.43kPa for the second floor and first floor, respectively. The compressive strength of concrete in this building is 21MPa and reinforcement yielding strength of 275MPa for main bars and 230MPa for secondary bars.



The reinforcement of the walls was 10mmØ with spacing of 600mm o.c. for horizontal, and 400mm o.c. for vertical bars. The strength of the walls is 6.9 MPa.

Figure 4. Reinforcement details of secondary walls.

4. RESULTS AND DISCUSSION

4.1. Push Over Analysis by STERA 3D

For the push over analysis, a static load distribution of UBC with target drift of 1/50 at an incremental step of 500 was applied to the structure.

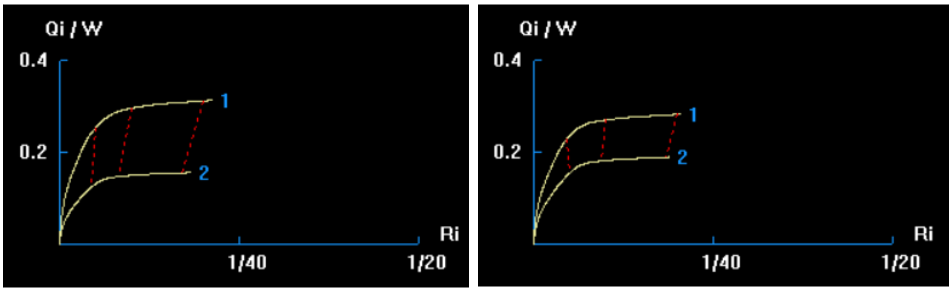


Figure 5. Drift-Story Shear Relationship of Longitudinal (a) and Transverse (b) Direction.

Based on the result of STERA 3D, the maximum drift of this structure at the top was 14/653 (≈0.0214) roughly achieving the target drift of 1/50 (=0.02).

The calculated base shear coefficient under the provisions of NSCP 2010 (National Structural Code of the Philippines) for this particular building was 0.189 and the standard base shear factor for moderate earthquake motions of low-rise buildings in Japan is 0.2 (C_0=0.2). As shown in Figure 5, the base shear coefficient for this building is higher than 0.2, thus, meeting the minimum requirement for both the Japanese and the Philippine seismic code.

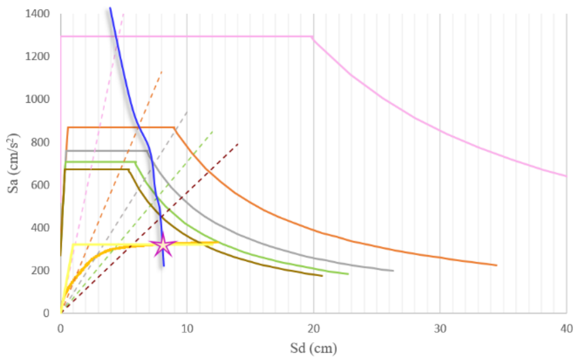


Figure 6. Performance Point.

The performance point of the building was determined by the intersection of the demand curve and capacity curve as shown in Figure 6. The assumed yield displacement was 1cm and with this, the line of stiffness was drawn until the ductility factor μ = 5. For each point in the demand curve, the approximate displacements were 4.5cm, 6cm, 7.5cm, 7.8cm, and 8cm, respectively. Finally, the performance point of the structure was identified to be at the displacement of 8cm.

4.2. Second Level Screening by JBDPA Method

The vertical elements of the target building along the longitudinal direction were analyzed using the Second Level Screening of JBDPA Standard. This method assumes that the horizontal elements are strong enough not to fail.

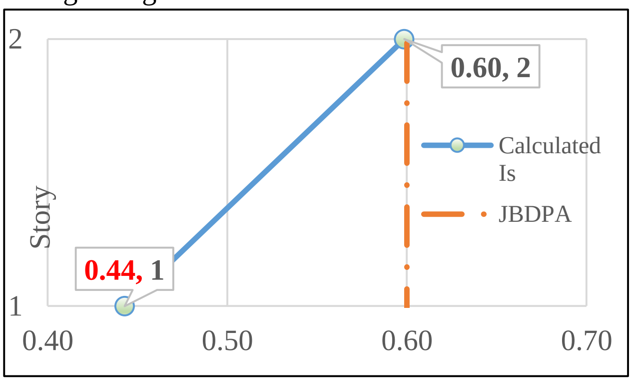


Figure 7. I_S vs I_{S0} of the Target Building neglecting Walls.

In the bare frame analysis, case, the considered clear height of the column is 3.5meters. All the columns were governed by the flexural failure mode. The ductility index of all columns was found to be 3.2 and only one group was established. However, the first floor of the target building failed to meet the seismic demand index of E_S=0.6 of the Japanese Standard. Therefore, the first floor was judged inadequate in terms of seismic safety.

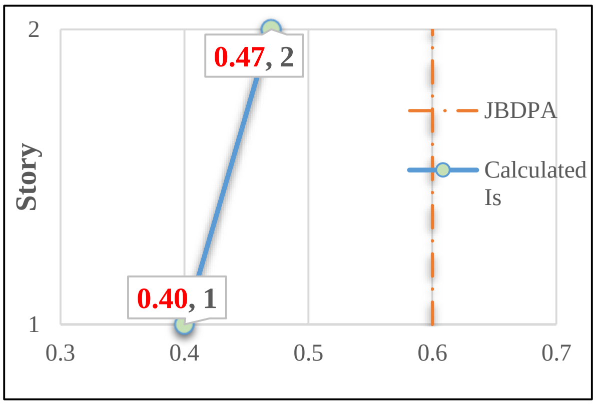


Figure 8. I_S vs I_{S0} with Walls (JBDPA).

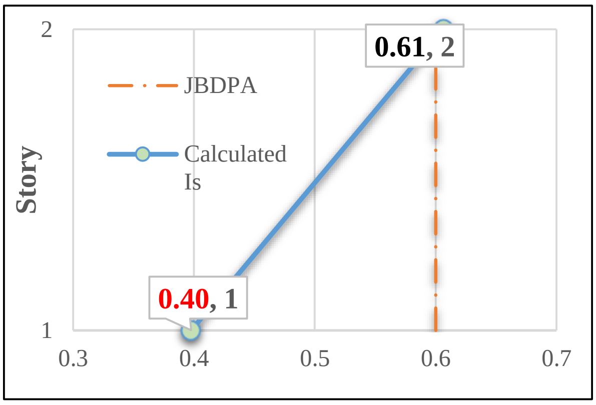


Figure 9. I_S vs I_{S0} with Walls (Response 2000).

For the analysis of frame with walls, the seismic index was calculated by using the ultimate strengths of vertical members from the formula of JBDPA method, and secondly, incorporating the values of flexural strengths of cross sections from Response 2000 to JBDPA. Some columns had shear failure mode as well as flexural. Considering the result of the JBDPA, I_S have been affected by the contribution of wing walls negatively as a whole. However, a more precise evaluation by Response 2000 showed that the walls did not have an effect on the I_S the structure.

4.3. Effects of Secondary Walls

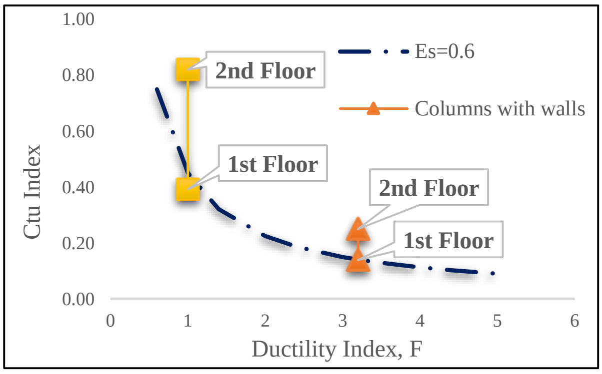


Figure 10. Ctu vs F Index (JBDPA).

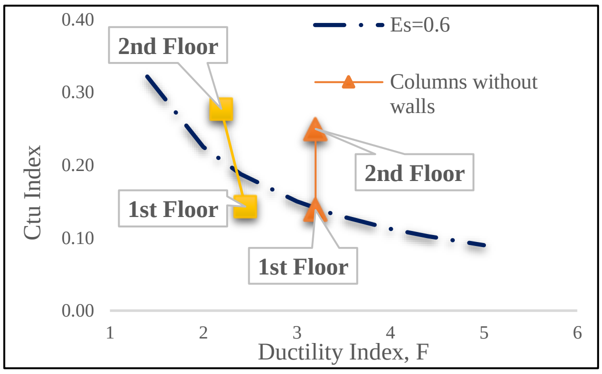


Figure 11. Ctu vs F Index (Response 2000).

As the results the seismic screening, it was found out that the strength index of columns with secondary walls was higher compared to the bare columns. However, the ductility index was lower. Moreover, since Response 2000 considered the actual compressive strength of the wing walls, which was very low, the strength index of the members was not likely to differ that much comparing to bare columns.

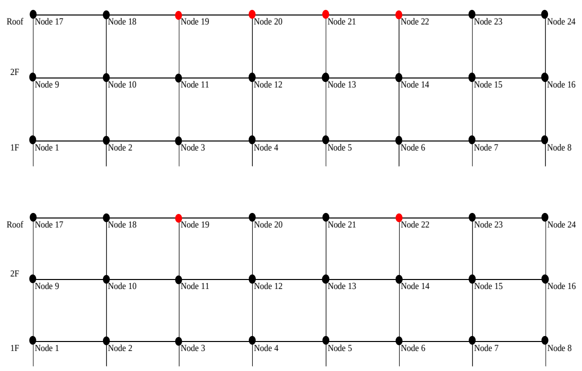


Figure 12. Failure Mechanism Without Walls.

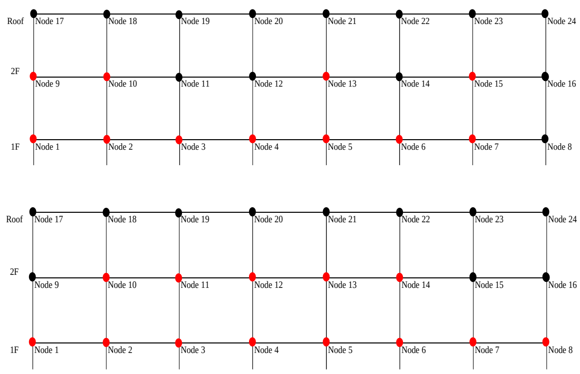


Figure 13. Failure Mechanism with Walls.

The failure mechanism of beam-column joint was analyzed on longitudinal direction for each floor. The red marks were the beam-column joints that had column failure, while black marks were beam failure. Based on the results of frames without walls, there were no column failure mode at the 1st and 2nd floor since the beam-column joint on these levels were supported by upper and lower columns. As for frames with the consideration of the walls, the majority of beam-column joints at the first level had column failure mode. This is due to the contribution of the spandrel walls on the strength of the beams as well as wing walls on the strengths of columns resulting to a less ductile behavior of the frames.

5. CONCLUSIONS

Generally, secondary walls are neglected in practical design in the Philippines. In this particular study, the target building was evaluated under two cases: frame analysis without secondary walls and frame analysis considering secondary walls. The walls made of concrete hollow blocks are non-load bearing walls with a very low compressive strength.

It was found out that the strength index of columns was higher when wing walls were considered. However, this was not enough to influence the seismic index of structure. For JBDPA Method, both floors were below the minimum requirement of E_S=0.6. The approximation method by JBDPA assumed that the walls are reinforced concrete walls. Most likely, a discrepancy may arise if the same method will be applied to masonry walls. On the other hand, the ductility index of the columns was reduced when the walls were considered.

The failure mode of the vertical members also changed when wing walls were considered. All of the columns in bare frame analysis had flexural failure mode but when walls were considered, shear failure mode occurred. Shear failure reduces the deformation capacity of the vertical members resulting to column failure of the structure.

6. RECOMMENDATION

This individual study focused on the effects of non-structural walls in terms of strength of structural members, ductility, and failure mechanism in the seismic performance of the target building. However, beams were neglected in the seismic screening assuming that they are strong enough not to yield. For a more precise seismic evaluation, it is recommended to conduct the third level screening in the future works to understand the behavior of the structure when beams are considered.

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