DEVELOPMENT OF RESILIENT REINFORCED CONCRETE PUBLIC APARTMENT BUILDINGS BY USING WALL ELEMENTS INCLUDING NON-STRUCTURAL WALLS FOR DAMAGE REDUCTION IN EL SALVADOR

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ABSTRACT

In El Salvador, public apartment buildings have been designed using structural systems based on reinforced concrete block masonry wall or reinforced concrete moment-resisting frames that usually have non-structural walls. However, no design methodology has been proposed to date to consider the effect of non-structural walls, and it is still a common practice not to treat walls with large openings as structural walls, and their capacity is usually discarded in the design of the building. Past earthquakes have revealed that the structural systems mentioned above had a high level of damage to their components. Therefore, to obtain practical and economic structures of resilient buildings, this study proposes to use a new construction method recently developed in Japan that has not been used yet in El Salvador. For the implementation of the new construction method, first a methodology of design and numerical model was proposed, then, the accuracy of the model used was verified through the comparison with experimental data obtained from a full-scale static loading test on a five-story building, performed by the Building Research Institute (BRI) of Japan. Finally, with the appropriate numerical model, the seismic performance of the Target Building was improved by considering the effect of the non-structural walls. From these three aspects, the Target Building was designed in this study, which is planned for construction in 2019 in El Salvador.

Keywords: Resilience, Public Apartment Buildings, Wing Wall, Performance-Based Design.

1. INTRODUCTION

The Ministry of Public Works has planned for 2019 the construction of new public apartment buildings. However, the area where the Project will be developed is considered one of the zones within the Metropolitan Area of San Salvador with high seismic hazard. Also, the type of buildings considered for the Project (buildings between three and six-story) can have a seismic over-demand as a result of the amplification of the seismic wave related to site effects. These two factors can put at risk the success of the Project, but more important, can put in danger the lives of people if these buildings are not designed properly. Therefore, in this study it is proposed to apply the concept of resilience to the design and construction of public apartments buildings from two perspectives:

1. Contribute to the process of updating the Seismic Code of El Salvador by proposing an alternative seismic design methodology using Performance-Based Design and apply it in the design of RC Public Apartment Buildings.

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2. Use new construction methods framed within the conventional structural design, which may be economically more feasible in El Salvador compared to newly technology such as damper system or base isolation system. The above, with the objective of improve the seismic performance of Target Building by using wall elements including non-structural walls (see Figure 1).

For the application of the design methodology and the new construction method, from a Project which currently being executed by the MOP, it was selected a public apartment as Target Building (see Figure 2).

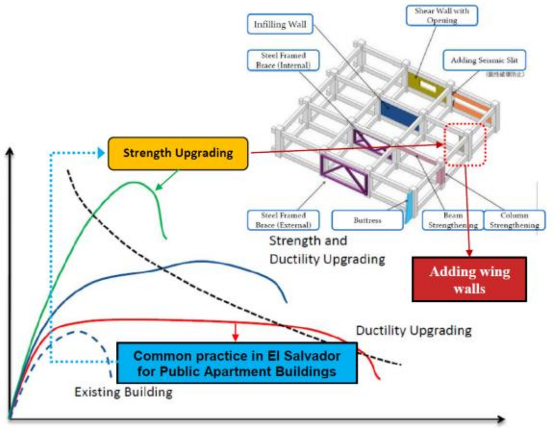


Figure 1. Enhancing the Seismic Performance of Target Building.

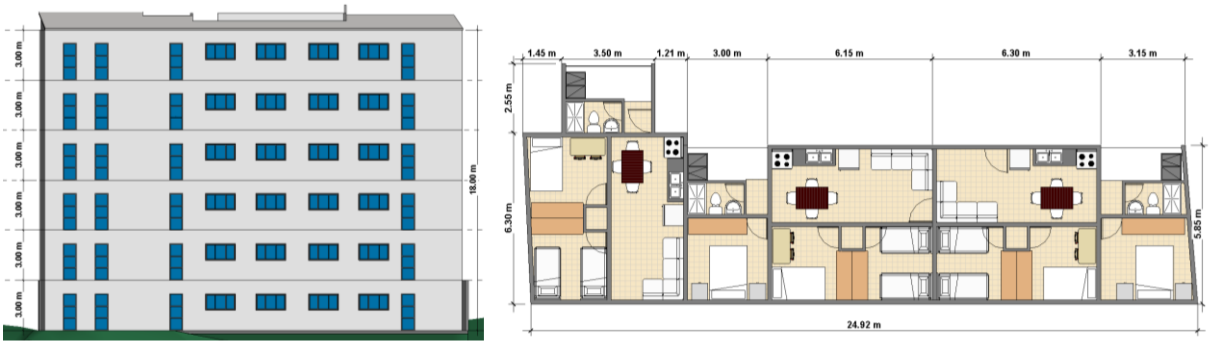


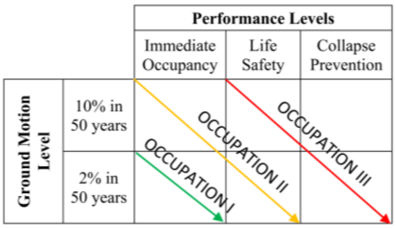
Figure 2. Elevation and plan view of Target Building.

2. METHODOLOGY

For the final design of the Target Building, the seismic design forces were first established using the Performance-Based Design philosophy. Then a numerical model was developed which was calibrated using experimental data. Subsequently, with the model created, the design of the Target Building was carried out, proposing a new construction method to improve the performance of the building compared to the original design established in the Project profile.

3. PERFORMANCE-BASED DESIGN

The determination of the Base Shear was made using the methods based on force (FBD) and displacement (DBD). The performance objectives used in the design are shown in Figure 3. For the design of the Target Building, the forces coming from the Direct Displacement-Based Design method were selected (see Figure 4).



	Performance Levels		
Type of structure	Immediate Occupancy	Life Safety	Collapse Prevention
RC Frames	0.01	0.015	0.02

Figure 3. Design objectives.

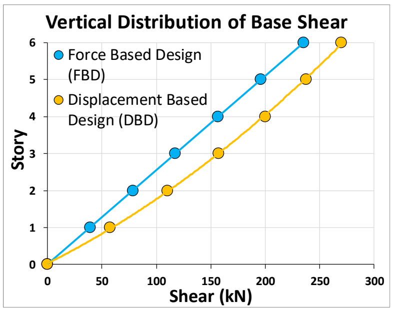


Figure 4. Comparison between Base Shear calculated with FBD and DBD for one frame.

4. NUMERICAL SIMULATION OF REINFORCED CONCRETE MOMENT-RESISTING FRAMES INCLUDING NON-STRUCTURAL WALLS

A numerical model was developed using the CANNY software, taking into account the following considerations:

Modeling of global system

The joints between columns with wing wall and beams are modeled as rigid zone, and the critical section of each structural element is established at the end of the edge of the rigid zone (see Figure 5).

Modeling of local system

Beam element is designed as a 2D line element with uniaxial bending and shear springs (US model). Two uniaxial hysteresis models were used. Both hysteretic models can be seen in Figures 6 and 7 (Li Kangning, 2018).

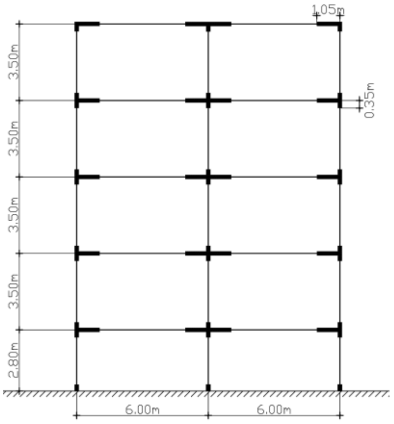


Figure 5. Global system for the specimen.

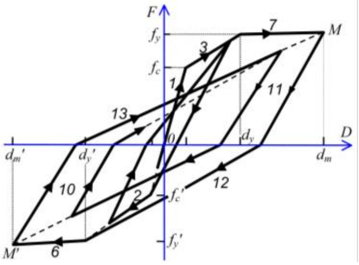


Figure 6. Flexural spring: Cross-peak trilinear model (CP3).

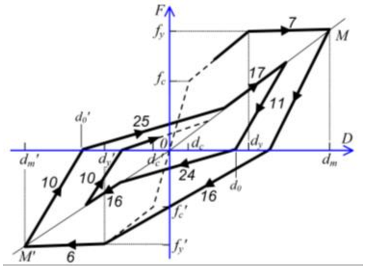


Figure 7. Shear spring: Cross-peak trilinear pinching model (CP7).

The column element is idealized by 3D beam line model. For nonlinear analysis, the multiaxial spring model (MS model) has been used for each material. For concrete and steel material, two hysteresis models were selected for each. Hysteretic models can be seen in Figures 8, 9, 10 and 11 (Li Kangning, 2018).

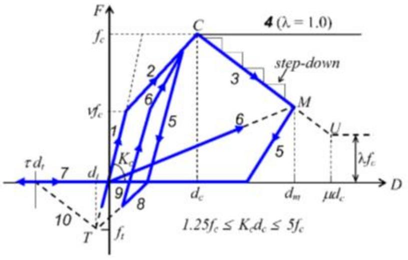


Figure 8. Concrete uniaxial spring model (US): Trilinear model (CS3).

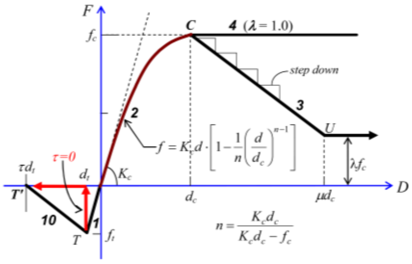


Figure 9. Concrete multiaxial spring model (MS): Exponential function model (CS4).

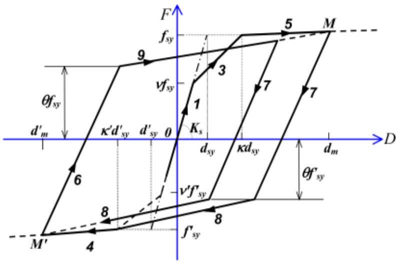


Figure 10. Steel uniaxial spring model (US): Trilinear/bilinear model (SS3).

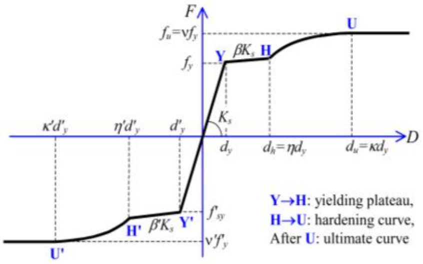


Figure 11. Steel multiaxial spring model (MS): Tanaka-CANNY (SR4).

The collision between the non-structural walls was represented by a shear spring applied to a diagonal line element. For the shear spring, a symmetric model was used which is an adapted version of the Multi-Linear Elastic Model with Gap (EM0). The shear spring models EM0 is shown in Figure 12 (Li Kangning, 2018). To see the behavior and failure mechanism of one of the interior columns with wing wall (in the 1st story) of the Target Building, a numerical simulation using FEM was performed with the general purpose finite element program LS-DYNA (see Figure 13).

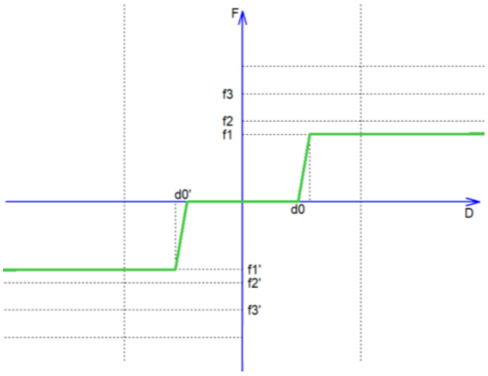


Figure 12. Shear spring model EM0 for collision of a non-structural wall.

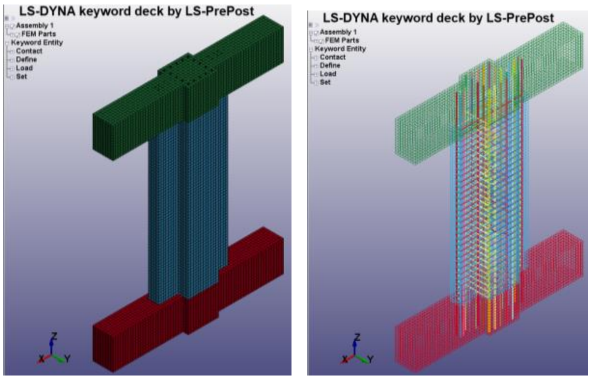


Figure 13. Finite element model of column with wing wall.

5. DESIGN OF TARGET BUILDING

In the profile of the Project it was established to construct the building using reinforced concrete block masonry wall, however this proposal was revised in this study and it was found that the building does not meet the expected low level of damage. Thus, to reduce the expected damage, a new construction method was applied to the Target Building, which is 100% adjusted to the architectural plan of the Project, that is, no dimension or distribution of spaces were modified (see Figure 14).

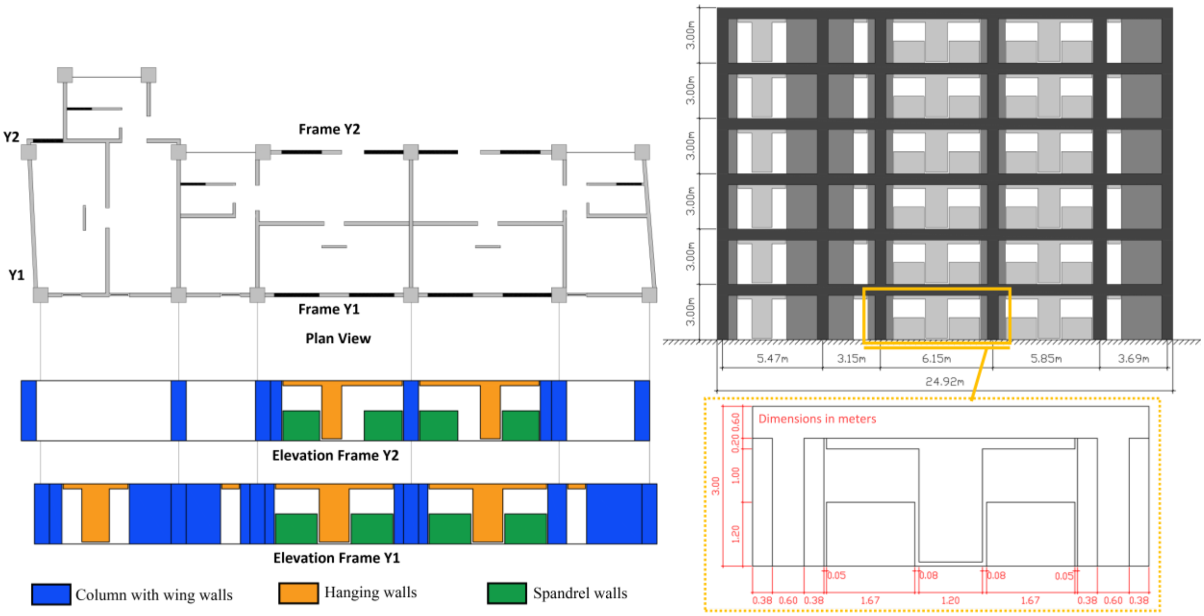


Figure 14. Plan view and elevation view of Target Building. Moment-resisting frame with wall elements and non-structural walls.

Figure 15 shows the overall analysis model of the system composed of columns, beams and non-structural walls, used for the design of the Target Building.

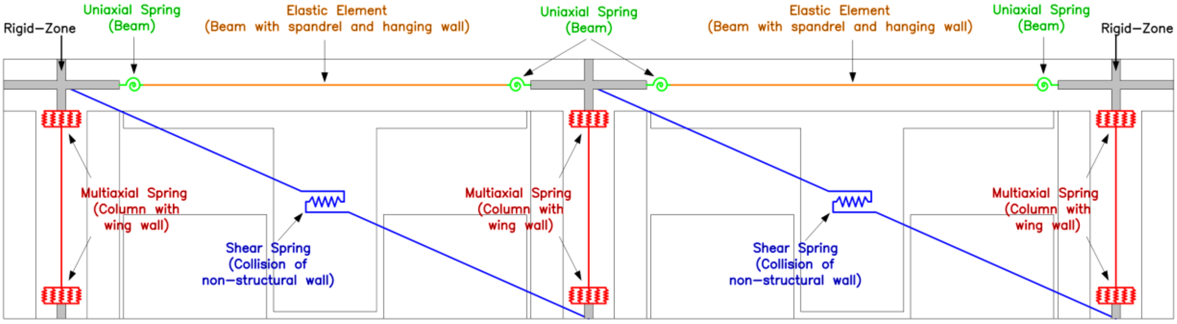


Figure 15. Overall analysis model for Target Building.

6. RESULTS AND DISCUSSION

In Figure 16 it can be seen that the numerical simulation has good agreement with experimental result regarding:

- Initial stiffness.
- Maximum strength and maximum displacement.
- The point which the mullion walls firstly hit against spandrels on the beam.

Figure 17 shows the performance of the Target Building, where it is observed that when the effect of non-structural walls was included, the seismic performance was increased, taking into account that the mechanism of failure of the building changed from ductile to brittle.

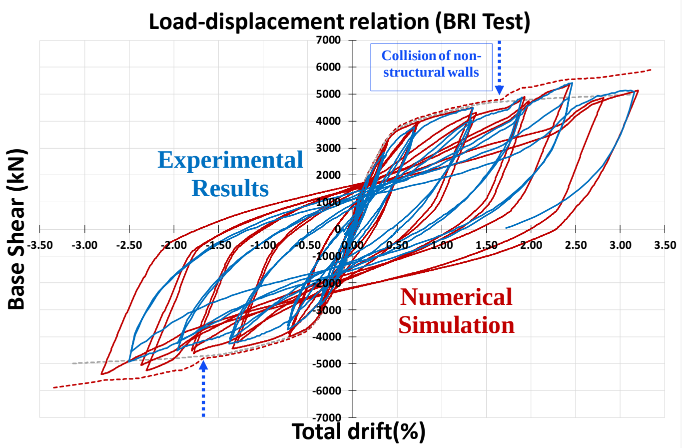


Figure 16. Comparison between numerical simulation and experimental results in specimen tested by BRI.

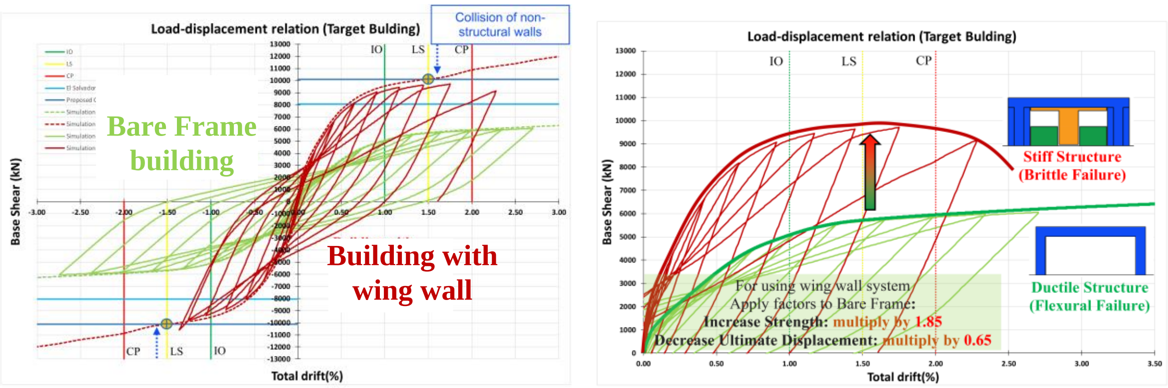


Figure 17. Improvement of the seismic performance of Target Building.

With the results obtained from the FEM analysis, it was confirmed that for the interior column of the Target Building, the steel reinforcement at wall edge of the wing wall yielded in tension side and suffered buckling in compression side, causing the spalling of the concrete. The way to avoid the yielding and buckling of steel reinforcement at the edge of the wing walls is under investigation in Japan, and there is a proposal developed in KUSUNOKI Lab that consists in inserting a seismic slit at the base of the wing wall and cutting the steel reinforcement at that point (see Figure 18). To study the effectiveness of this proposal, in 2019 a full-scale test will be carried out.

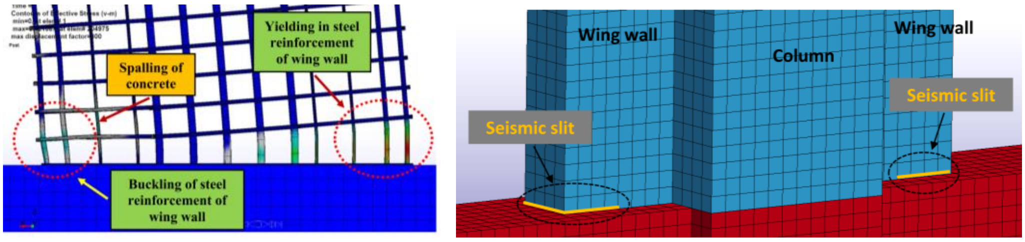


Figure 18. Failure mechanism of the column with wing wall and proposed modification.

7. CONCLUSIONS

- ✓ Compared to FBD, the DBD method increases the seismic load in the building by 25%.
- ✓ The numerical simulations performed have good agreement with the experimental results, so the analytical models used in this study are effective to evaluate the seismic performance of RC moment-resisting frame including the effect of non-structural walls.
- ✓ In this study it has been demonstrated experimentally (through the full-scale test conducted by BRI) and analytically verified (with the developed numerical model) that the RC non-structural walls would increase the stiffness and strength of the RC moment-resisting frames, indicating that the non-structural wall effects should be considered in the performance-based seismic design.
- ✓ When the new construction method used in this study wants to be considered, it is possible to quickly evaluate the effect of the non-structural walls in the Bare Frame building through the following factors deduced from the analysis:
  - Increase the strength of the Bare Frame building, by multiplying with 1.85.
  - Decrease the ultimate displacement of Bare Frame building, by multiplying with 0.65.
- ✓ It should be kept in mind that when considering the effect of non-structural walls on building performance, the structure failure mechanism is changed from a ductile failure to a brittle failure.
- ✓ It was verified that the columns with the wing wall would show strength deterioration after compression failure of the end section of the wing wall. Also, the column with the wing wall can also present a shear failure. However, because the RC moment-resisting frames with wall elements and non-structural walls is essentially a frame system, the building shows ductile behavior until maximum capacity because the contribution of the beams is dominant.

8. RECOMMENDATION

Further studies and experimental data should be done to improve the numerical models that include the effect of non-structural walls in RC moment-resisting frames.

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