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Seismic Performance of Reinforced Concrete Shear Walls with Eccentric Openings

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ABSTRACT: The strong earthquakes recorded worldwide have shown that the damages and the failure mechanisms of the reinforced concrete structural walls depend on a series of factors, such as the shape in plan and elevation, the dimensions of the walls and openings. During the past several decades, extensive experimental and analytical studies have been conducted on the behavior of structural walls with openings. This paper describes an analytical study carried out on of reinforced concrete walls with eccentric opening. In order to achieve this goal, variations in various parameters including changes in the aspect ratio of the openings, the stiffness of the link beam, the aspect ratio of the openings with simple connection at the both end of link beams and the aspect ratio of the walls are studied. Story drift, center of mass displacement, shear and moment in coupling beams and axial load in columns which coupled with shear wall are analyzed and compared together. The results showed that by decreasing the aspect ratio of the openings (ho/lo), the axial load in the column coupled with the wall decreases and with increasing rigidity of the link beam the shear forces in link beam increased and center of mass displacement and story drift are reduced. The strength of structural wall components becomes different in pull/push loading direction due to the eccentric opening location. Also, seven buildings have been compared, decreasing the wall aspect ratio from the axial forces in the column and shear forces in the link beam decreases.

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1. INTRODUCTION

Mid-rise to high-rise buildings in Chile are predominantly of reinforced concrete construction. Most of these buildings use structural walls to resist both gravity loads and earthquake forces. Dual systems of walls and frames are occasionally used in newer construction. Typical wall cross-sectional area–to–floor area ratios are high compared with values commonly used in U.S. concrete building construction. The good performance of the majority of these buildings during the March 3, 1985, earthquake suggests that walls with limited detailing may be an effective construction form for earthquake resistance. Although buildings in Chile are designed for roughly the same lateral forces as those in regions of high seismic risk in the United States, the typical structural wall in a Chilean building does not require boundary elements or special transverse reinforcement [1]. Openings are usually avoided in RC structural elements, whenever possible, in order to minimize unfavorable effects of discontinuous regions. However, in recent years there has been increasing interest in enlarging spaces by connecting adjacent rooms through creating openings in existing solid walls. These openings are a source of weakness and can size-dependently reduce the structures' stiffness and load-bearing capacity. It is generally believed that effects of small openings can often be neglected, while a large opening usually significantly alters the structural system, but there is no clear definition of the size threshold in the literature [2]. Walls with openings are considered to be composed of vertical and horizontal wall segments. A vertical wall segment is a wall segment bounded horizontally by two openings or by an opening and an edge. Similarly, a horizontal wall segment is bounded vertically by two openings or by an opening and an edge. Some walls, including some tilt-up walls, have narrow vertical wall segments that are essentially columns, but whose dimensions do not satisfy requirements of special moment frame columns. In consideration of these, ACI 318 defines a wall pier as a vertical wall segment having $l_w/b_w \leq 6.0$ and $h_w/l_w \geq 2.0$. The lower left vertical wall segment in may qualify as a wall pier. Special provisions apply to wall piers (Fig.1) [3].

2. METHODOLOGY, RESULTS AND DISCUSSION

Etabs software was used to model reinforced concrete buildings with dual systems of walls and frames. The RC shear walls have been simulated with shell structural elements. To investigate the eccentric opening effect on the behavior of shear wall, all data of stories horizontal center of mass displacements, stories drift ratio, axial forces in columns that coupled with shear walls, and bending moments and shear forces in link beams were recorded and so that all models could be compared

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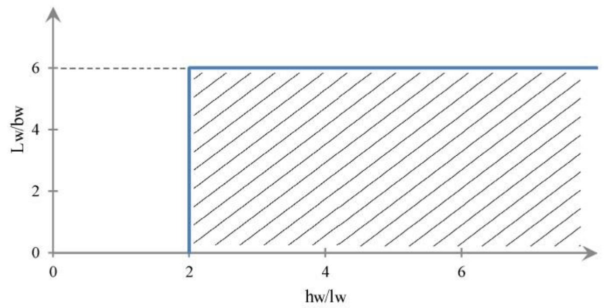

Fig. 1. Shaded area defines wall pier aspect ratio

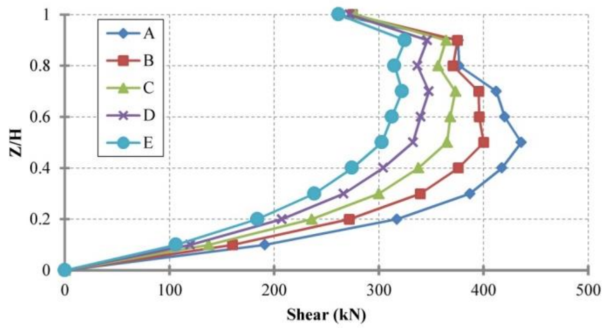

Fig. 2. Shear forces in link beams

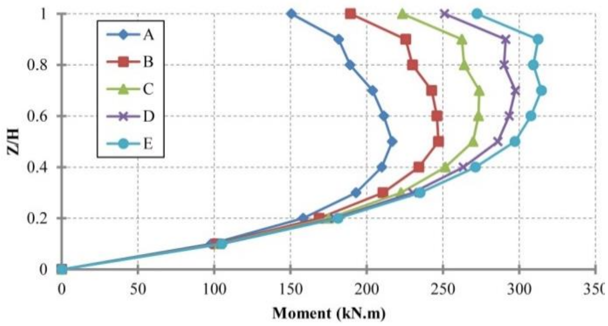

Fig. 3. Bending moment in link beams

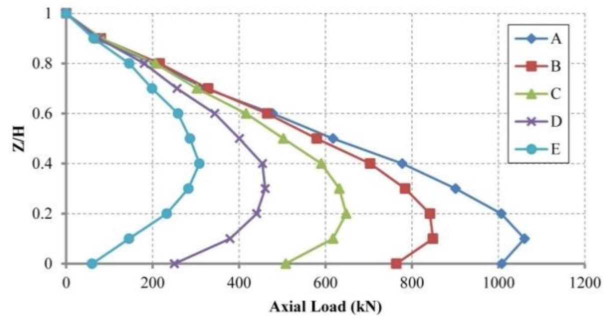

Fig. 4. Axial forces in wall pier

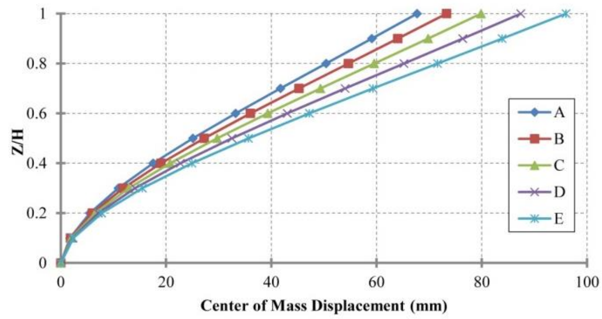

Fig. 5. Center of mass displacement

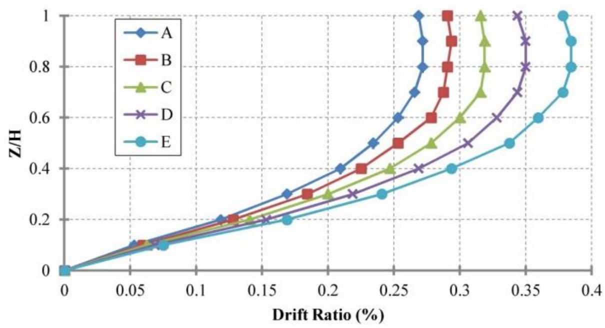

Fig. 6. Story drift ratio

under same conditions. In order to achieve these goals, the aspect ratio (height/length) of openings is examined in the first step. In the second step, the effect of the variation of stiffness in the link beam is checked. In the third step Effect of aspect ratio of openings with simple joint at both ends of link beam is investigated. The last step in the aspect ratio of the wall with eccentric openings has been investigated. It should be noted that in the extended abstract, only the details of the first step and last step are described.

As described, in the first step only aspect ratio of the openings are changed. Aspect ratio of eccentric opening 2.75, 2.20, 1.83, 1.57 and 1.38 are named with A, B, C, D and E, respectively. Figs. 2 to 5 describe the results of this analysis. In the present figures, the results are expressed in terms of the height of the story from the base (z) to the total height of the building (H). The wall pier is meant to be a slender vertical wall segment formed by an eccentric opening at the edge of the wall.

As described, in the last step only aspect ratio of the shear walls are changed. Aspect ratio of wall 4.21, 3.80, 3.37, 2.95, 2.53, 2.10, 1.68, 1.26, 0.84 and 0.42 are named with A, B, C, D, E, F and G, respectively. Figs. 6 to 9 describe the results of this analysis. Pull loading direction is defined as loading from the side of the eccentric opening and the opposite direction is the push loading direction.

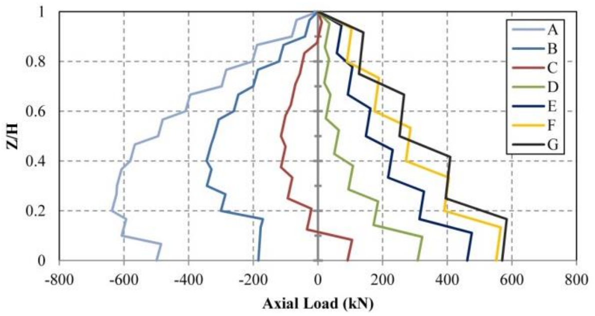

Fig. 6. Axial forces in wall pier in pull loading direction

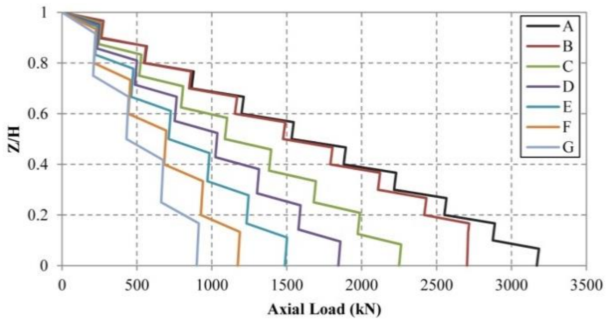

Fig. 7. Axial forces in wall pier in push loading direction

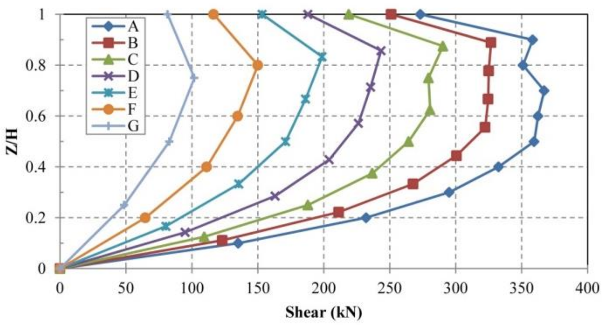

Fig. 8. Shear forces in link beams in pull loading direction

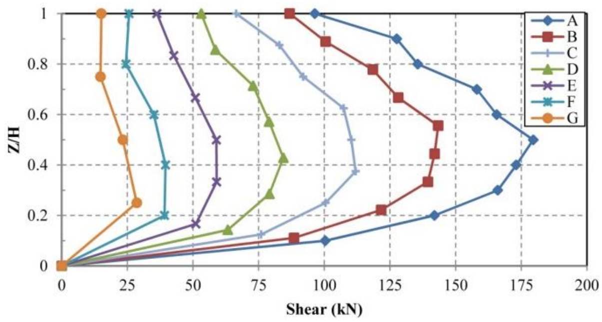

Fig. 9. Shear forces in link beams in push loading direction

3. CONCLUSIONS

According to the numerical analyses of this study, it must be said that the shear force and axial force in link beam and wall pier become different in pull/push loading direction due to the eccentric opening location respectively. Moreover, the shear strength obtained by loading from opening side is obvious larger than that obtained by reverse direction loading.

The results showed that by decreasing the aspect ratio of the openings (h_o/l_o), axial force in the columns has been reduced. By reducing the wall aspect ratio, in pull loading direction, the force in the columns tends from tensile to compression. Also, in pull loading direction shear force in the link beams is about twice the opposite loading direction. In general, the axial force status in wall piers in pull loading direction of the columns is somewhat unpredictable. Reducing the opening aspect ratio improves and reduces the lateral displacement of the stories.

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