Effects of configurations of shear walls on system behavior under seismic load

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Abstract

The main purpose of this study is to examine the effects of configurations of structural walls on the seismic behavior of multi-storey RC buildings. For this purpose, four different structural systems for buildings are considered. One of them is a frame system and the others are three different structural walls systems. Totally, four different buildings having 6, 10 and 12 stories are considered for analysis. The SAP2000 structural analysis program is used for analysis and the IDS-99 package program is used for determination of cross sections of columns, beams, slabs and structural walls. Finally, shear forces, bending moments and displacements obtained by seismic analysis for selected three columns in four different buildings, also forces and bending moments obtained for structural walls in three different structural wall systems are compared.

Keywords: RC structural walls, seismic design, Turkish seismic design code, structural analysis.

1 Introduction

In seismic zones, building resistance to earthquakes is often ensured by adopting structural systems where seismic actions are assigned to structural walls, designed for horizontal forces and gravity loads, while columns and beams are designed only for gravity loads. These systems, being stiffer than earthquake resisting frames, allow a better displacement control, limiting damage in internal partition walls and non structural elements. On the contrary, frame structures generally exhibit greater ductility, at the expense of large displacements and interaction problems between structural and non-structural elements (Riva et al. [1], Ghobarah and Youssef [2], Wang et al. [3], Salonikios [4]). The simple
example to prove stability of shear walls is a railway compartment or a bus coach, which will be subjected to lot of vibrations and base excitations (like artificial earthquakes) during their service period. They are built of so-called stiffened plate system. That means, it is made of a simple steel tin plate stiffened (strengthened / reinforced) by a grid of steel structural angles or channels. Similarly, in shear wall system, it is made of concrete or masonry wall panels, which are reinforced, with a grid of steel rods. Hence, a shear wall system can effectively withstand earthquake forces. Their supporting area (total cross-sectional area of all shear walls) with reference to total plan area of building is comparatively more reinforced concrete frame structures.

Figure 1: Floor plans of four different buildings and direction of earthquake ground motion.
Seismic behavior of structural walls has been successful and shown superior performance during severe earthquakes, both, from a serviceability as well as a safety standpoint (Kongoli [5], Hidalgo et al. [6]). Experiences from past earthquakes clearly indicate that the installation of structural walls may increase the overall rigidity of buildings, thereby reducing seismic distortion. Many experimental and analytical studies have been performed for recent years to investigate their non-linear behaviors (Mazars et al. [7], Myslimaj and Tso [8], Brun et al. [9], Boroschek and Yañez [10], Paulay and Priestley [11], Pilakoutas and Elnashai [12], Tasnimi [13]).

In this study, the importance is focused on effects of configurations of structural walls on the seismic behavior of buildings. However, seismic analysis is carried out by considering Turkish seismic design code [14].
2 Structural data

In this study, four types of buildings are considered. The first building is typical framed structure and it is named as FB (Fig. 1a). Other three types of buildings consist of reinforced concrete frame with structural walls. At the first frame-structural wall building, structural wall elements are at the edges of buildings and it is named as FWB1 (Fig. 1b). At the second frame-structural wall building, structural wall elements are inside of buildings and it is named as FWB2 (Fig. 1c). At the third frame-structural wall building, structural wall elements are at the edges and inside of buildings and it is named as FWB3 (Fig. 1d). Columns and structural walls are located symmetrically in plan geometry of the buildings. Thickness of slabs is taken to be 0.13 meters. The dimensions of structural walls, beams and columns are determined by using a structural analysis program (IDS-99 [15]).

3 Mathematical modeling and computational details

SAP 2000 [16] structural analysis program is used for analysis of all buildings. Degrees of freedom at the base nodes are fixed, for other nodes are left free. Columns and beams are modeled with frame element, slabs and structural walls are modeled with shell element. Slabs also have been considered as a rigid diaphragm. Mode number is taken to be 7 in modal analysis. In the analysis, Young’s Modulus and unit weight of concrete are taken to be 28500 MPa and 25 kN/m³, respectively. In this paper, earthquake ground motion is applied at direction y. In this study, Mode Superposition Method is used for seismic analysis of buildings and the modal responses to the each component of ground motion are combined using SRSS.

Figure 2: Shear forces, bending moments and displacements in selected three columns of six storey four different buildings.
4 Evaluation of results obtained by seismic analysis

Shear forces, bending moments and displacements in S3, S7, S9 columns of six, ten and twelve storey four different buildings are illustrated in Figs. 2, 3 and 4. According to Fig. 2, the largest shear force is obtained 178.7 kN in S9 column of FB at the ground and the 1st floor levels. Also, the maximum difference of shear forces is obtained 69.40% in S3 column between FB and FWB3 at the ground floor level. The largest bending moments is obtained 357 kNm in S9 column of FB at the ground floor level. The maximum difference of bending moments is obtained 65.78% in S3 column between FB and FWB3 at the ground floor level. The largest displacement is obtained 0.03727m in S7 column of FB at the 6th floor level. The maximum difference of displacements is obtained 64.33% in S7 column between FB and FWB2 at the 1st floor level. According to Fig. 3, the largest shear force is obtained 416.3 kN in S9 column of FWB2 at the 1st and 2nd floor level. The maximum difference of shear forces is obtained 64.33% in S9 column between FWB2 and FWB3 at the 1st floor level. The largest bending moment is obtained 629 kNm in S9 column of FWB2 at the 2nd floor level. The maximum difference of bending moments is obtained 60.43% in S9 columns between FWB2 and FWB3 at the 1st floor level. The largest displacement is obtained 0.0593m in S3 and S9 columns of FB at the 10th floor level. The maximum difference of displacements is obtained 45.73% in S7 column between FB and FWB2 at the 1st floor level. According to Fig. 4, the largest shear force is obtained 511.8 kN in S9 column of FWB2 at the 2nd and 3rd floor levels. The maximum difference of shear forces is obtained 67.18% in S9 column between
FWB2 and FWB3 at the 1st floor level. The largest bending moment is obtained 690.4 kNm in S9 column of FWB2 at the 5th floor level. The maximum difference of bending moments is obtained 55.19% in S9 column between FWB2 and FWB3 at the 3rd floor level. The largest displacement is obtained 0.0705m in all selected columns for FB at the 12th floor level. The maximum difference of displacements is obtained 39.43% in all selected columns between FB and FWB2 at the 1st floor level.

Figure 4: Shear forces, bending moments and displacements in selected three columns of twelve storey four different buildings

Forces and bending moments obtained for W1 and W2 structural walls in three different six, ten and twelve storey structural wall systems are illustrated in Fig 5-6 and Fig. 7-8 respectively.

Figure 5: Forces (kN/m) for per length of W1 structural wall in six (a), ten (b) and twelve (c) storey three types of structural wall buildings.
Figure 6: Bending moments (kNm/m) for per length of W1 structural wall in six (a), ten (b) and twelve (c) storey three types of structural wall buildings.

According to Fig. 5 and 6 (0 at y axes corresponds to ground floor), the largest force is obtained 4305.55 kN/m at the ground floor in FWB1 for six storey structural wall building. Also, the maximum difference of forces is obtained 84.45% between FWB1 and FWB2 at the 5th floor. The largest bending moment is obtained 24.71 kNm/m at the 5th floor in FWB1 for six storey structural wall building. The maximum difference of bending moments is obtained 52.97% between FWB1 and FWB3 at the 5th floor. The largest force is obtained 4878.22 kN/m at the ground floor in FWB2 for ten storey structural wall building. Also, the maximum difference of forces is obtained 83.56% between FWB1 and FWB2 at the 9th floor. The largest bending moment is obtained 25.89 kNm/m at the 2nd floor in FWB2 for ten storey structural wall building. The maximum difference of bending moments is obtained 59.19% between FWB2 and FWB3 at the 3rd floor. The largest force is obtained 4703.70 kN/m at the ground floor in FWB2 for twelve storey structural wall building. Also, the maximum difference of forces is obtained 82.83% between FWB1 and FWB2 at the 11th floor. The largest bending moment is obtained 27.87 kNm/m at the 2nd floor in FWB2 for twelve storey structural wall building. The maximum difference of bending moments is obtained 62.76% between FWB2 and FWB3 at the 10th floor.

Figure 7: Forces (kN/m) for per length of W2 structural wall in six (a), ten (b) and twelve (c) storey three types of structural wall buildings.
According to Figs. 7 and 8, the largest force is obtained 1387.87 kN/m at the ground floor in FWB2 for six storey structural wall building. Also, the maximum difference of forces is obtained 97.97% between FWB2 and FWB3 at the ground floor. The largest bending moment is obtained 263.42 kNm/m at the 3rd floor in FWB1 for six storey structural wall building. The maximum difference of bending moments is obtained 82.06% between FWB1 and FWB2 at the 4th floor. The largest force is obtained 2036.62 kN/m at the ground floor in FWB2 for ten storey structural wall building. Also, the maximum difference of forces is obtained 99.15% between FWB2 and FWB3 at the ground floor. The largest bending moment is obtained 300.63 kNm/m at the 4th floor in FWB1 for ten storey structural wall building. The maximum difference of bending moments is obtained 78.12% between FWB1 and FWB2 at the 8th floor. The largest force is obtained 2112.69 kN/m at the ground floor in FWB2 for twelve storey structural wall building. Also, the maximum difference of forces is obtained 97.88% between FWB2 and FWB3 at the ground floor. The largest bending moment is obtained 304.99 kNm/m at the 4th floor in FWB1 for twelve storey structural wall building. The maximum difference of bending moments is obtained 75.98% between FWB1 and FWB2 at the 10th floor.

Figure 9: Periods for six (a), ten (b) and twelve (c) storey four different buildings.
For seven modes, periods obtained for six, ten and twelve storey four different buildings are illustrated in Fig. 9.

As seen from Fig. 9, periods of frame buildings are the largest of all. When number of stories of building is increased, the difference of periods between frame and the other structural wall buildings is decreased. For example, differences of the periods are 29.69%, 17.65% and 14.72% for 1\textsuperscript{st} mode between six, ten and twelve storey FB and FWB1 buildings, respectively.

5 Conclusions

The following conclusions can be drawn from this paper:

- FWB2 is the most rigid system of all, so it has the lowest displacements. For example, S9 column which is between two W1 structural walls has the lowest displacement for ten storey FWB2 system. On the other hand, S9 column has the largest member forces for ten storey FWB2 system. Because S9 column is very close to W1 structural walls (approximately 1,50 m), it gets most of loads of earthquake like structural walls. It works approximately as a part of W1 structural wall.
- FWB1 and FWB3 systems have very closer member forces.
- The maximum differences of shear forces, bending moments occur at lower floor levels in the selected three columns.
- The periods are close to each other for 1\textsuperscript{st}, 2\textsuperscript{nd} and 3\textsuperscript{rd} modes, while the periods are close to each other for 4\textsuperscript{th}, 5\textsuperscript{th}, 6\textsuperscript{th} and 7\textsuperscript{th} modes. For example, the periods are 0.7759 sec., 0.6695 sec., 0.6247 sec., 0.2846 sec., 0.2598 sec., 0.2301 sec. and 0.1771 sec. for 1\textsuperscript{st}, 2\textsuperscript{nd}, 3\textsuperscript{rd}, 4\textsuperscript{th}, 5\textsuperscript{th}, 6\textsuperscript{th} and 7\textsuperscript{th} for six storey FB system, respectively.
- Because W1 and W2 structural walls are very close to each other in FWB2 system, they develop a very rigid system like a core system. Therefore, FWB2 system has the largest forces for W1 and W2 structural walls in six, ten and twelve storey three different structural wall systems.
- FWB1 and FWB3 systems have very closer forces for W1 structural wall in six, ten and twelve storey three different structural wall systems.
- Because the structural walls are far away from each other in FWB3 system, its rigidity isn’t as much as the other structural wall systems. Therefore, FWB3 system has the lowest forces for W2 structural wall in six, ten and twelve storey three different structural wall systems.
- FWB1 system has the largest bending moments for W2 structural wall in six, ten and twelve storey three different structural wall systems. On the other hand, FWB2 system has the lowest bending moment for W2 structural wall in six, ten and twelve storey three different structural wall systems.

References


