IMPROVING DISPLACEMENT PERFORMANCE OF MULTI-STORY BUILDING WITH U-SHAPED SHEAR WALL BY VARIOUS METHODS

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ABSTRACT

The general objectives of this study are to improve the displacement performance of the structure with the U-shaped shear wall by various methods, i.e. additional shear wall, increasing the section of the existing shear wall and viscous wall damper. U-shaped shear walls are used for the elevator shaft, and they provide additional stiffness in both directions to the buildings. Viscous wall damper absorbs the energy by the high-viscosity fluid during the earthquakes and winds. It is sometimes necessary to improve the displacement performance of the building during the design phase, and unfortunately, this improvement can be done by limited options due to architectural demand. Therefore, three 12-story buildings are designed by the mode-superposition method according to the Turkish Seismic Design Code, and the evaluation of the target buildings has been made using the Japanese design response spectrum to see the response of the buildings. Additional shear wall, increasing the section of the existing shear wall and viscous wall damper methods are applied to the buildings with U-shaped shear walls which one of the buildings has an eccentricity in the plan. Comparison of the seismic behaviors of the target buildings, including displacement and inter-story drift have been done using selected recorded and artificial ground motions by nonlinear time history analysis. IdeCAD structural software was used for design, and STERA 3D was used for observing the displacement performance of the target buildings. Cost comparison of three methods used in this report has been performed.

Keywords: Displacement, U-shaped shear wall, viscous wall damper, NTHA.

1. INTRODUCTION

Lateral deflection is the behavior of the structure under lateral loads. Moreover, lateral deflection between two adjacent stories is defined as story drift. When an earthquake occurs, major lateral forces that can damage structural elements, nonstructural elements and adjacent structures affect the structure. Keeping lateral deflection and drift under control is very important for mid-rise and high-rise structures to prevent collapse. If the lateral deflections of any structure become too large, it is likely to collapse.

Each code has a limitation regarding a story drift ratio, and therefore story drift of the structure must be checked according to the seismic design code of the country where the structure is. If the story drift is larger than value described in the related seismic design code, some measures must be taken to reduce it. Sometimes, modifying a plan of the buildings can be very limited after receiving architectural drawings, and although structures require a retrofit, it can be limited to only a few components of the building. Moreover, the displacement performance of the structure should be improved by limited options such as additional shear wall, increasing the section of the existing shear wall and viscous wall damper.

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2. DATA

There are three target buildings which are designed according to the Turkish Seismic Design Code. All target buildings are accepted that they are in first seismic zone. Soil type and the local site affecting the design response spectrum were selected as Z2 and B, respectively. The number of stories of all buildings is identical and it is 12. The height of stories of all buildings is same, that is 3 m. The dimension of the buildings is 24.8 m x 24.8 m that are square shaped. There are five spans on the buildings, and the length of each span is 4.8 m. The dimensions of the columns are 80 cm x 80 cm, the dimensions of the beams are 50 cm x 50 cm and slab thickness is 15 cm. The concrete strength of the buildings is 60 MPa which is high-strength concrete because of the height of the buildings. The steel strength is 420 MPa, and all reinforcement bars are ribbed. Besides, the concrete safety factor is 1.5, and steel safety factor is 1.15.

The first building is a 12-story simple framed mid-rise building without shear wall (SF), the second building is a 12-story simple framed mid-rise building with U-shaped shear wall symmetrically positioned (SWS) and the third building is a 12-story simple framed mid-rise building with U-shaped shear wall eccentrically positioned (SWE). The plans of the buildings are shown in Figure 1, 2 and 3.

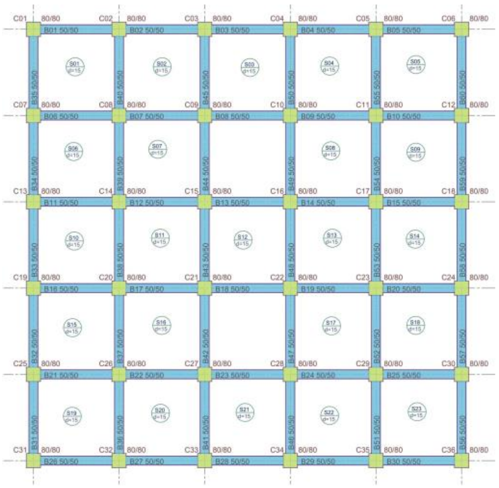

Figure 1. The plan of SF.

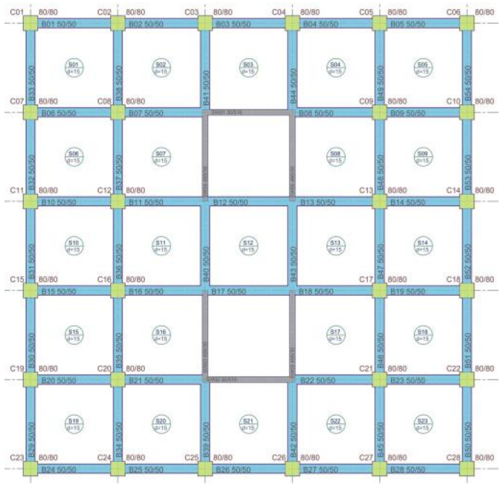

Figure 2. The plan of SWS.

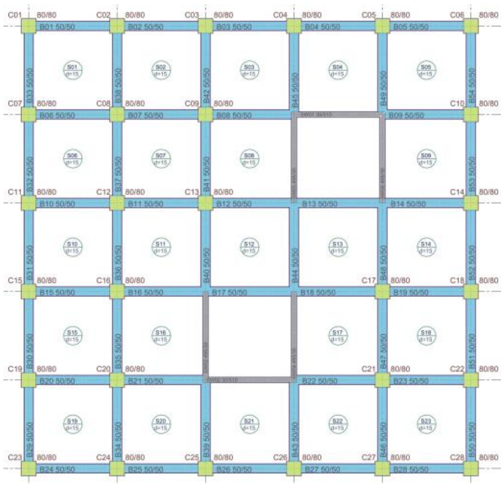

Figure 3. The plan of SWE.

SWS and SWE have U-shaped shear wall that consist of two shear wall of 30 cm x 465 cm and one shear wall of 30 cm x 510 cm. The U-shaped shear walls are symmetrically positioned in SWS. One of the U-shaped shear walls were slid throughout the X direction in SWE as seen in Figure 3.

3. DESIGN OF THE TARGET BUILDING

3.1. Design method

In the Turkish Seismic Design Code, methods to be used for the seismic analysis of buildings are equivalent seismic load method, mode-superposition method, and analysis methods in the time domain. For target buildings, mode-superposition method was used.

3.2. Design phase

While calculated the building weight, dead load and live load was selected based on Turkish Seismic Design Code. Live load participation factor is 0.3, importance factor is 1.0 because usage of buildings is residence. For design, elastic acceleration spectrum was applied.

After designed, Beam rebars are five pieces of 22 mm at upper and lower regions. The stirrup is two pieces of 8 mm with 10 cm in confinement zones and 20 mm on the remainder of the beam for all target buildings. The stirrup of columns is 10 mm, and spacing is 8 cm in confinement zones and 16 cm on the between two confinement zones. Besides, the stirrup spacing is 10 cm throughout beam depth. For SWS, wall end zones rebars are 20 pieces of 14 mm through critical wall height, and they are ten pieces of 14 mm remainder of height. Web reinforcements are 14mm with 10 cm spacing in both directions from base story to the fifth story. Moreover, from the sixth story to the eleventh story, they are 14 mm with 20 cm spacing. Horizontal web reinforcements are assumed to extend towards wall end zones. For SWE, wall end zones rebars are 20 pieces of 14 mm through critical wall height, and they are ten pieces of 14 mm remainder of height as shown in Figure 21. Web reinforcements are 14mm with 10 cm spacing in both directions from base story to the fifth story. Moreover, from the sixth story to the eleventh story, they are 14 mm with 20 cm spacing. Horizontal web reinforcements are assumed to extend towards to wall end zones.

4. ASSESSMENT AND IMPROVEMENT OF DISPLACEMENT PERFORMANCE OF THE TARGET BUILDINGS

4.1. Strong ground motions

Three synthetic ground motions and three recorded ground motions are required for Nonlinear Time History Analysis (NTHA) based on the Japanese Seismic Design Code (Nakai et al., 2012). These synthetic ground motions are generated compatible with design acceleration response spectrum of the Japanese Seismic Design Code. To generate synthetic ground motions, the El Centro 1940 N-S, Kobe 1995 N-S and Tohoku 1978 N-S was used which are three of the major earthquakes. Acceleration and velocity values of synthesized ground motions and recorded ground motions are shown in Table 1.

Table 1. Acceleration and velocity of synthesized ground motions and recorded ground motions.

Ground Motion Types	**Ground Motion**	**V (m/s)**	**A (m/s^2)**	**Duration (s)**
Artificial	Synthesized ground motion 1	0.94	5.14	120.0
	Synthesized ground motion 2	1.09	6.63	120.0
	Synthesized ground motion 3	0.90	4.93	120.0
Recorded	El Centro 1940 NS	0.50	4.89	53.8
	Kobe 1995 NS	0.50	4.51	50.0
	Tohoku 1978 NS	0.50	3.53	41.0

On the other hand, three recorded ground motions are scaled to be 0.5 m/s as of their maximum velocity.

4.2. Evaluation of the target buildings

SF, SWS, and SWE that were designed according to the Turkish Seismic Design Code are evaluated by NTHA. This evaluation is based on the Japanese Seismic Design Code. Three recorded ground motions and three synthesized ground motions that already were generated are used. N-S components of these ground motions are acted to the building in the Y direction. In this study, only one direction is considered.

When analysis is performed, STERA 3D, software used for NTHA, has some basic assumptions such as beam element is taken into account by the model with nonlinear flexural springs at the both lower and upper ends and a nonlinear shear spring in the middle of the element, column element is considered by multi spring model with nonlinear axial springs in the middle of the element, wall element is considered by multi spring model with nonlinear springs in the sections of the both lower and upper ends and nonlinear shear spring in the middle of the wall panel that is between two boundary columns (Saito, 2015).

4.3. Improvement of displacement performance

Three methods are applied to the SWS and SWE to improve their displacement performance, i.e. additional shear wall, increasing the section of the existing shear wall and the VWD. Only the Kobe 1995 NS component will be used for evaluating these three methods.

4.3.1. Additional shear wall

It is known that shear walls contribute the stiffness of the building. Therefore, additional shear walls marked with a rectangle are placed on the SWS as shown in Figure 4. Additional shear walls thickness is 0.30 m, and their length is 4 m. Reinforcement bars of the additional shear wall of each floor are 14mm in diameter at 100 mm interval on both directions. Longitudinal rebars of boundary columns of the shear wall are placed eight pieces of 14 mm in diameter with 100 mm interval from base story to the fifth story and 200 mm interval from the sixth floor to the eleventh floor. Additional shear walls marked with a rectangle are placed on the SWE as shown in Figure 5. Additional shear walls thickness is 0.30 m, and their lengths are 4 m and 4.4 m. Reinforcement bars of the additional shear wall of each floor are 14mm in diameter at 100 mm interval on both directions.

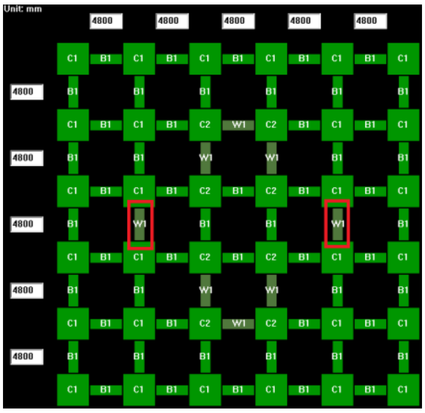

Figure 4. The plan of the SWS with additional shear walls.

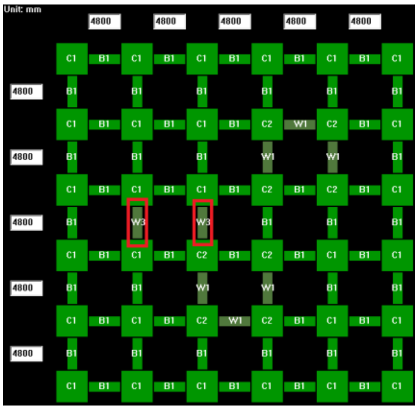

Figure 5. The plan of the SWE with additional shear walls.

When placed in additional shear walls in the SWE, eccentricity reduction was considered.

4.3.2. *Increasing the section of the existing shear wall*

In this method, the existing shear walls thicknesses have been increased from 0.30 m to 0.60 m. Other than that, no parameters have not been changed.

4.3.3. *Viscous wall damper*

Viscous damper absorbs energy due to an earthquake, wind forces or other types of horizontal forces. That device does not add stiffness to the structure; however, it decreases forces and accelerations. Besides, the viscous damper is more effective to reduce drift (Kelly, 2007).

Two viscous wall damper (VWD) placed in SWS and SWE. The dimension of the VWDs that are shown in Figure 6 and Figure 7 was selected 2.4 m x 2.4 m from company catalog. The distance between the bottom face of the beam and ground is 2.5 m. Therefore, 0.10 m additional steel plate will add to the VWD. The stiffness, the damping and the damping exponent of VWD are 65,320 kN/m, 2,714 kN-(sec/m^2)$^\alpha$, 0.5, respectively (DIS,2017).

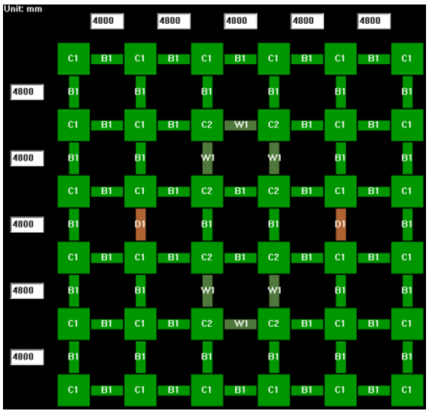

Figure 6. The plan of the SWS with VWD.

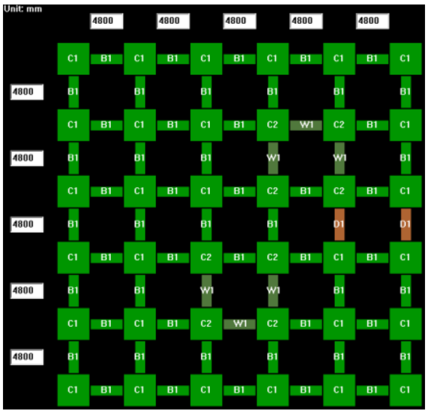

Figure 7. The plan of the SWE with VWD.

4.4. Cost

4.4.1. *12-story SWS*

The additional shear wall cost is 4,284.14 TL (134,307.76 JPY), increasing the section of the existing shear wall cost is 4,536.00 TL (142,203.60 JPY), and VWD cost is 176,500.00 (5,533,275.00).

4.4.2. *12-story SWE*

The additional shear wall cost is 4,498.35 TL (141,023.15 JPY), increasing the section of the existing shear wall cost is 4,536.00 TL (142,203.60 JPY), and VWD cost is 176,500.00 (5,533,275.00).

5. RESULTS AND DISCUSSION

5.1. Displacement and inter-story drift

As seen Figure 8, all methods succeed in reducing the displacement of SWS.

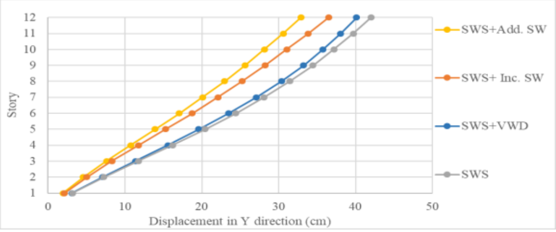

Figure 8. Displacement of each floor of SWS and three methods.

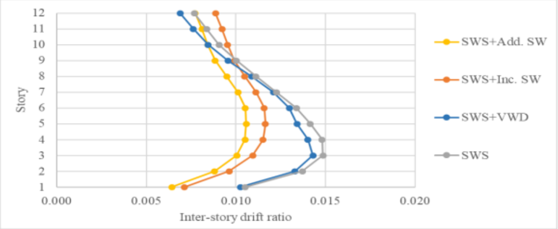

Figure 9. Inter-story drift ratio of SWS and three methods.

The additional shear wall reduces the displacement more than the other methods. The inter-story drift of the SWS and three methods are shown in Figure 9. VWD reduces the inter-story drift parallel to SWS inter-story drift. However, the additional shear walls and increasing the section of the existing shear walls are good on lower floors; they perform very bad performance on upper floors.

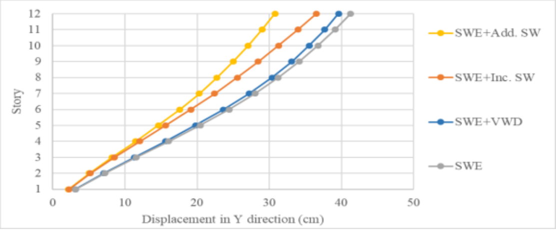

Figure 10. Displacement of each floor of SWE and three methods.

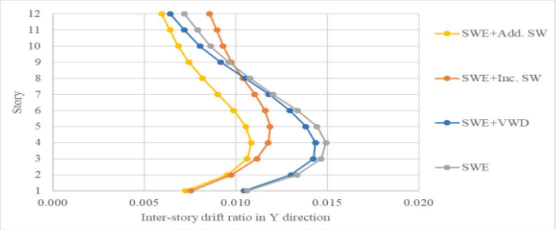

Figure 11. Inter-story drift ratio of SWE and three methods.

As seen in Figure 10, all methods succeed in reducing the displacement of SWE. The additional shear wall reduces the displacement from 41 cm to 31 cm. VWD almost has same values with SWE. It just reduces the displacement from 41 cm to 40 cm. Figure 11 shows that the additional shear wall reduces inter-story drift from 0.007 to 0.006 at 12th story, however, increasing the section of the existing shear wall increases inter-story drift from 0.007 to 0.009 at 12th story.

6. CONCLUSION

All methods reduce the top displacement in the Y direction of the buildings. To put in additional shear wall shows better displacement performance than the other two methods. The VWD performs particularly well to reduce the drift ratio of upper stories. Increasing section of the existing shear wall does not perform well on the upper floor. The methods of reducing the eccentricity distance of the structure are more efficient than others to lessen the displacement of the building.

The additional shear wall cost is lower than the other methods. VWD is very expensive compared to the additional shear wall and increasing the thickness of the existing shear wall.

7. OUTLOOK ON FUTURE RESEARCH

VWD shows better performance to reduce the inter-story drift ratio on the upper floor, and the additional shear wall has a good performance to reduce the inter-story drift ratio on the lower floor. Therefore, combining both the additional shear wall and VWD should be investigated.

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