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Research Article

Effect of configuration of shear walls at story plan to seismic behavior of high-rise reinforced concrete buildings

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ABSTRACT

In developing countries, the need for shelter, working area, shopping and entertainment centers is increasing due to the increasing population effect. In order to meet this need, it is necessary to turn to high-rise buildings. Significant damages have been observed as a result of insufficient horizontal displacement stiffness of high-rise buildings in major earthquakes in previous years. It is known that as the height of the structure increases, the displacement demand of the structure also increases. Since it is accepted that the structure will make inelastic deformation in the design of the structure, these displacements increase to very high levels as the number of stories increases. For this reason, damages can be much higher than expected. In order to limit the level of damage that may occur in high-rise buildings, the horizontal displacement of buildings is limited in many regulations in our age. This limitation is possible by increasing the rigidity of the structures against horizontal displacement. In recent years, the use of shear wall has increased due to the horizontal displacement limitation in the regulations. The use of shear walls in buildings limits the horizontal displacement. However, the choice of where the shear walls will be placed on the plan is very important. Failure to place the shear walls correctly may result in additional loads in the structure. It can also lead to torsional irregularity. In this study, a 10-storey reinforced concrete building model was created. Shear wall at the rate of 1% of the plan area of the building was used in the building. The shear walls are arranged in different geometric shapes and different layouts. The earthquake analysis of 5 different models were performed. Equivalent Earthquake Load, Mode Superposition and Time History Analysis methods were used for earthquake analysis. The results were compared and a proposal was made for the geometry and configuration of the shear wall.

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1. Introduction

Earthquake is an oscillatory motion caused by the release of strain energy under or in the earth's crust (Chen and Qian, 2002; Mo and Kuo, 1998). Earthquake oscillations cause large horizontal displacements in buildings. As a result of this, significant damages occur in the buildings. 95% of Turkey's population is at risk of earthquakes (Yaman et al., 2019). It is an important issue that the structures show the necessary performance during an earthquake. Adequate strength, rigidity and durability are expected from the structures during the earthquake (Chandiwala, 2012). The use of curtain wall elements that increase the horizontal displacement stiffness of buildings during earthquakes prevents story drift of buildings. (Aktan and Kiraç, 2010). The shear walls are vertical elements that resist the horizontal load in the buildings (Nainan and Alice, 2012). The shear walls are a preferred element type in the load-bearing system due to their high rigidity and strength (Firoozabad et al.,

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2012). When the earthquakes in the previous years are examined, it is seen that shear wall in buildings perform better than frame system. et al., 2013). Especially the increase in the height of the building makes the horizontal loads more determinant than the vertical loads in the buildings (Ucar and Merter, 2009). Therefore, in order to prevent story drift, many regulations contain rules limitation of story drift. The inelastic behavior is also limited by limiting the story drift.

The lack of clear information in the regulations regarding the use, placement and amount of shear walls to be used in reinforced concrete frame systems has led to the tendency of these studies. Young-Hun Oh examined the deformation capacity of the shear walls using a displacement-based approach (Oh et al., 2006). In Sakcalı et al.'s (2017) study, the earthquake performance of 8-storey reinforced concrete structures with different shear wall ratio examined. Halkude et al. in their study, the effect of the use of different lengths of shear walls in different places on the plan examined the earthquake performance (Halkude et al., 2015). In Gent Franch et al.'s (2008) study, they have tried to establish an acceptable connection with the ratio of shear wall to story area by modifying the vulnerability index value for masonry structures. In Rokanuzzaman et al.'s (2017) study, the effects of the configuration of the shear walls at story plan on the 16-storey building are examined under horizontal load.

In this study, the change of shear wall location in a 10-storey reinforced concrete building was investigated. Shear wall at the rate of 1% of the plan area of the building was used in the building. 5 different models have been created in terms of shear wall location. Models are analyzed according to Equivalent Earthquake Load (EEL), Mode Superposition (MS) and Time History Analysis (TH) methods on ETABS.

2. Material and Method

In this study, 5 different shear wall location have been created for a 10 storey reinforced concrete building. The three-dimensional view for the created models is given in Fig. 1. The story plans of the models according to the shear wall locations are given in Fig. 2.

For each model, 1.5 kN/m^2 dead load and 5 kN/m^2 live load were loaded on the story in addition to the self-weight of the building. The total length of the shear walls is the same for all samples. Additional infilled wall load is not added to the building. It was assumed that the structure was fixed in to the ground. The shear wall elements are modeled as shell elements. Column and beam dimensions were taken as 50x50 cm and 25x60 cm respectively. Slab thickness was taken as 15 cm. The short edge of the shear wall was accepted as 20 cm.

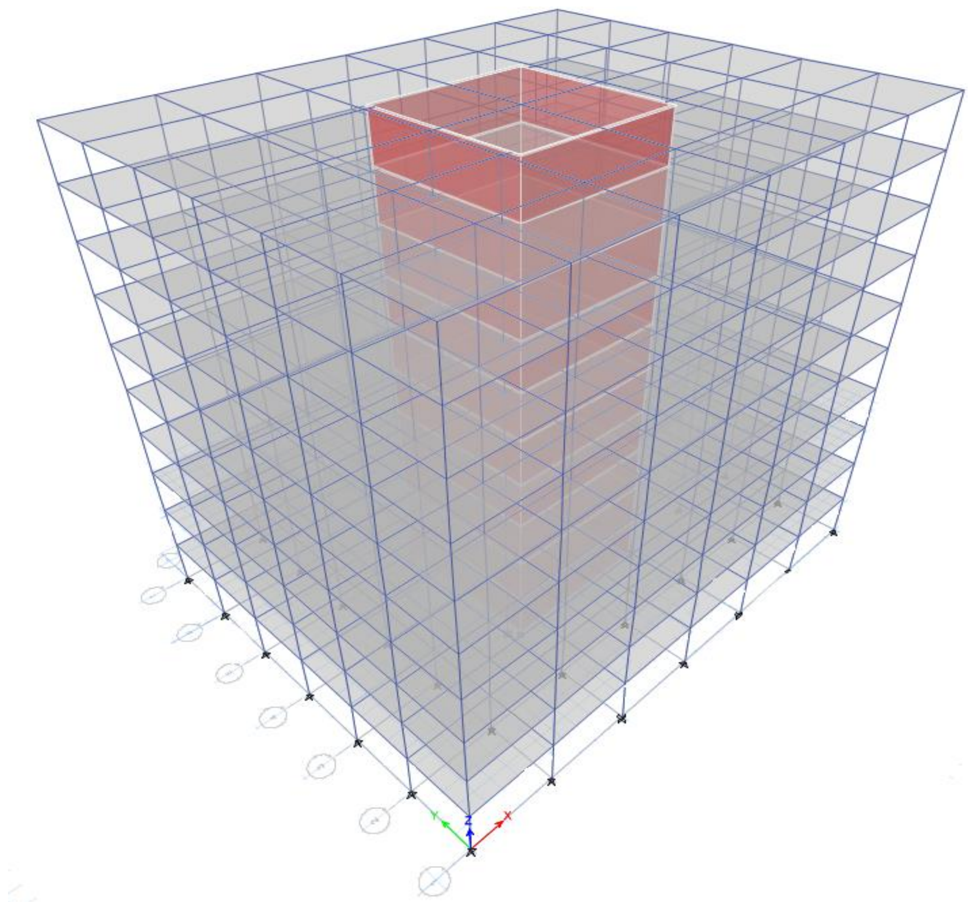


Fig. 1. Sample 5 (S5) 3D modelling.

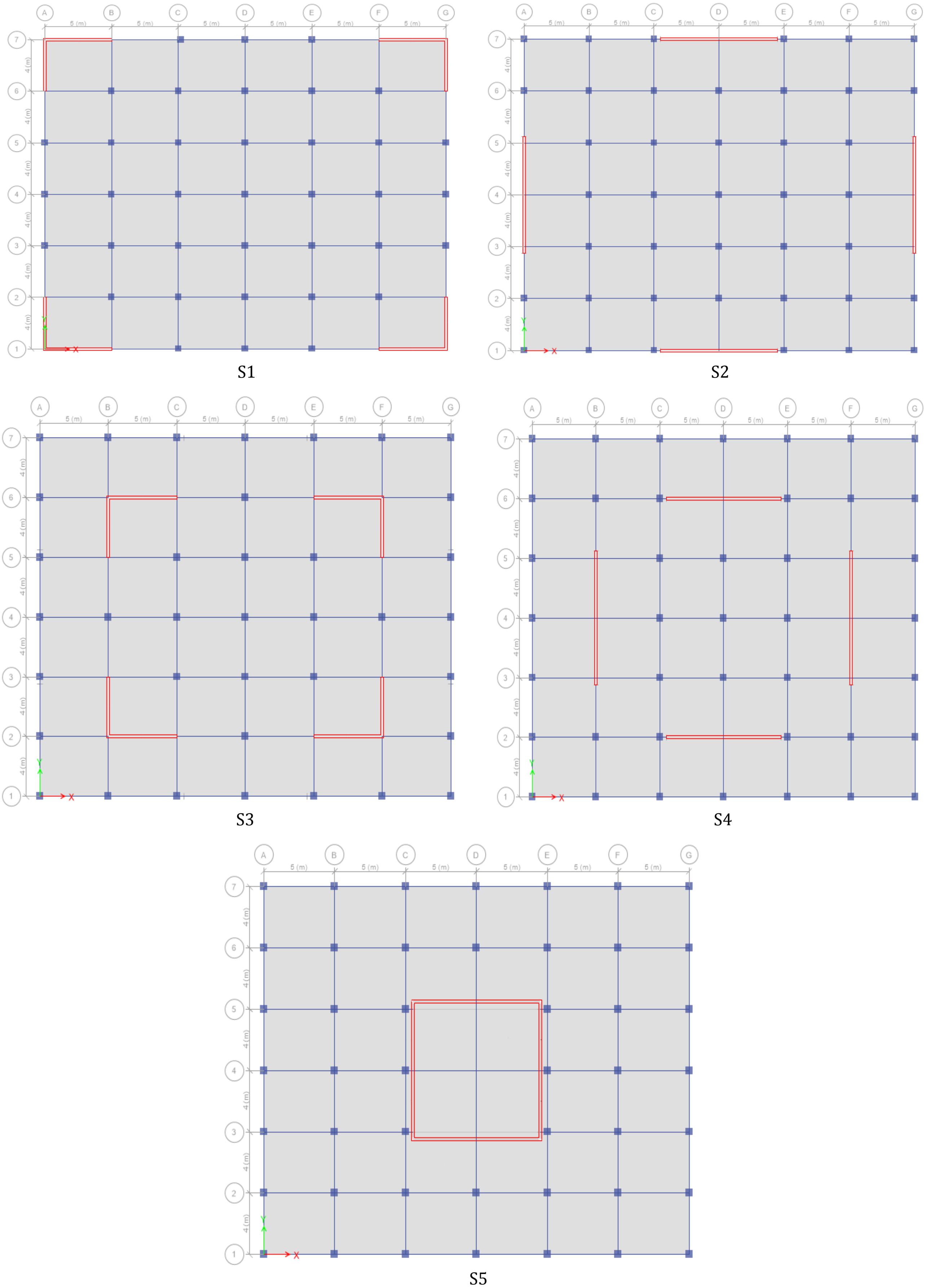


Fig. 2. Story plans of samples.

The earthquake parameters that will be used to calculate the earthquake load affecting the building are given in Table 1. Earthquake parameters given in Table 1 are obtained from Turkish Seismic Code – 2018 (TSC-2018).

Table 1. Seismic parameters.

Parameters	Value
Ground Seismic Motion Level	DD-2
Soil Classification	ZE
Latitude	40.667344°
Longitude	30.408702°
S_S	1.723
S_1	0.466
S_{DS}	1.3784
S_{D1}	1.0569
PGA	0.710
PGV	58.826

The earthquake acceleration record to be used in TH is given in Fig. 3. The earthquake acceleration record is scaled to TSC-2018 response spectrum created with parameters given in Table 1. In this way, two different result obtained from EEL and TH can be compared with each other.

3. Results and Discussions

As a result of the analysis, natural vibration periods of the samples are given in Fig. 4. Natural vibration periods of the buildings are obtained from modal analysis on ETABS program. Natural vibration period for x and y direction is obtained from mode 1 and mode 2 respectively. As can be seen from Fig. 4, the natural vibration period of the buildings decrease as the shear wall is taken inwardly from the external axis. As a result, the fact that the shear wall is on the external axis increases the natural vibration period of the building and causes it to be exposed to less earthquake force. The fact that the shear wall is in the center of the building makes the building more rigid.

The base shear forces obtained from EEL, MS and TH methods are given in Fig. 5.

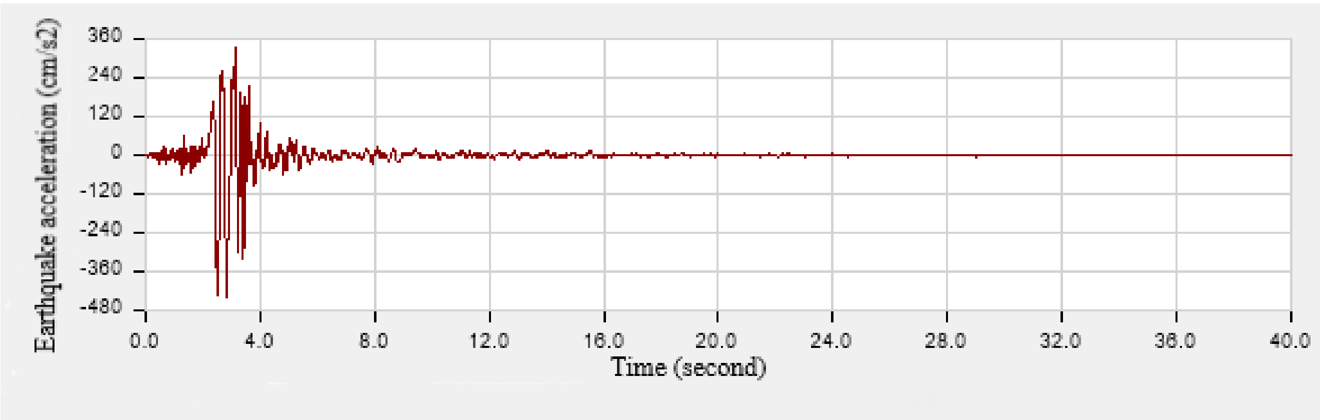


Fig. 3. ALTADENA - Earthquake acceleration record.

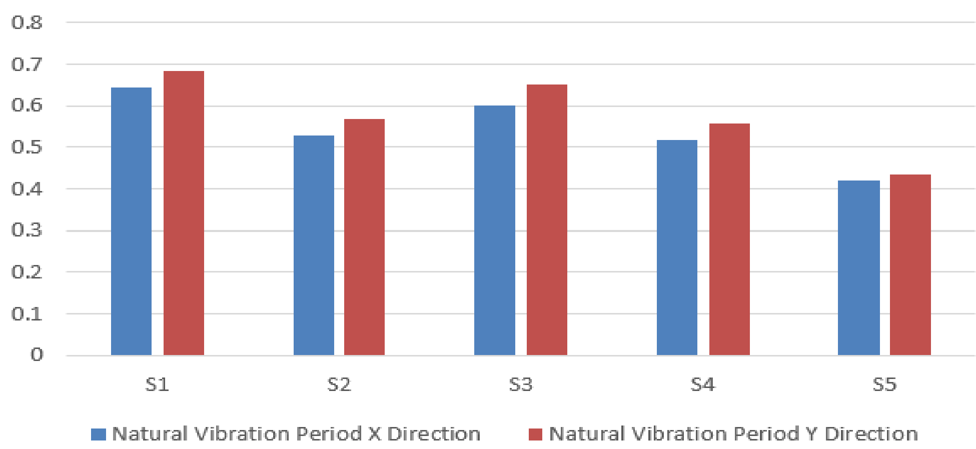


Fig. 4. Natural vibration period of models.

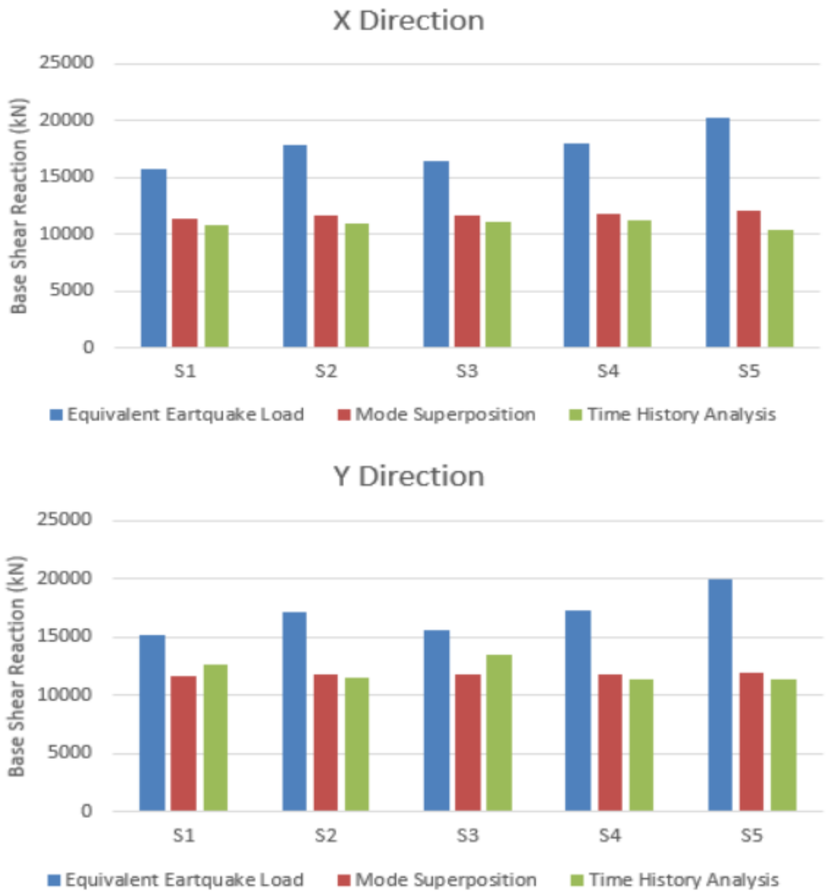


Fig. 5. Base shear force of models.

As shown in Fig. 5, the shear forces obtained in the EEL method were higher than the other two methods. It can be understood from this that the EEL method does not provide accurate results in multi-storey buildings. As seen in the analysis methods in MS and TH, the results were very close to each other. Placing the shear wall from the external axis to the internal axis increased the earthquake load affecting the building. Earthquake load increased in all three methods. In addition, it was observed that the earthquake load affecting the building decreased when the shear wall were placed at the corner of the building. When the natural vibration periods are examined, the earthquake load that affects the building increases as the natural vibration period of the building decreases. This occurs because the spectral acceleration increases as the natural vibration period decreases. Due to the relationship between the spectral acceleration-natural vibration period curves, the earthquake load affecting the building increases for a while. Fig. 6 shows that the shear forces affected to the stories are more variable than the other methods in the EEL method. This shows that the EEL method does not give correct results in multi-storey buildings. When the increase rates for earthquake load in the stories are examined, it can be said that it is approximately same for each method. The ratio of shear forces affecting to shear walls to the base shear force is given in Table 2 and Table 3.

Relative story drifts according to earthquake calculation methods are given in Fig. 7. For each method and direction (*X* and *Y*) are presented in separate graphs.

4. Conclusions

In this study, earthquake analysis was carried out for 5 different shear wall configurations. Results of the analyses are given below:

- The natural vibration period of the building decreases as a result of the shear wall being taken in from the external axis.
- The fact that the shear wall is on the external axis increases the natural vibration period of the building so that it is exposed to less earthquake load.
- The shear forces obtained by the EEL method were higher than the other two methods. It can be understood from this that the EEL method does not provide accurate results in multi-storey buildings.
- Placing the shear wall from the external axis to the internal axis increased the earthquake load affecting the building.
- It was observed that when the shear walls were placed at the corner of the building, the earthquake load affecting the building decreased.
- As the shear walls are placed from the external axis to the internal axis, the shear force ratio of the shear walls increases. In S5, this ratio increased to 0.95.
- Relative story drifts were maximized on the 6th story in all samples. In all samples, the limit value defined in TBDY-2018 has not been exceeded.
- When the relative story drift are examined, it is seen that the building behaves more rigid as a result of moving the shear walls from the external axis to the internal axis.

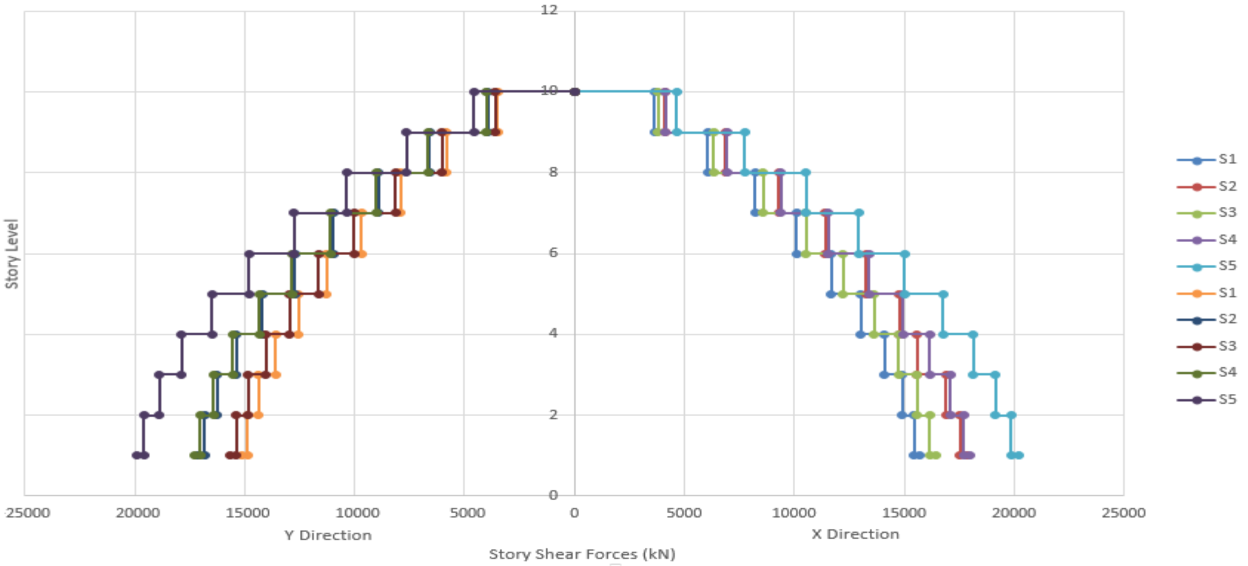
- If there is a problem with the relative story drift in the building, it would be more accurate to place the shear walls on the internal axis.
- If the earthquake load affected the building is high value while relative story drift is under the limitation of the relative story drift, it would be more accurate to move the shear wall to the external axis.

Table 2. Ratio of shear force acting on shear wall to base shear force for *x* direction.

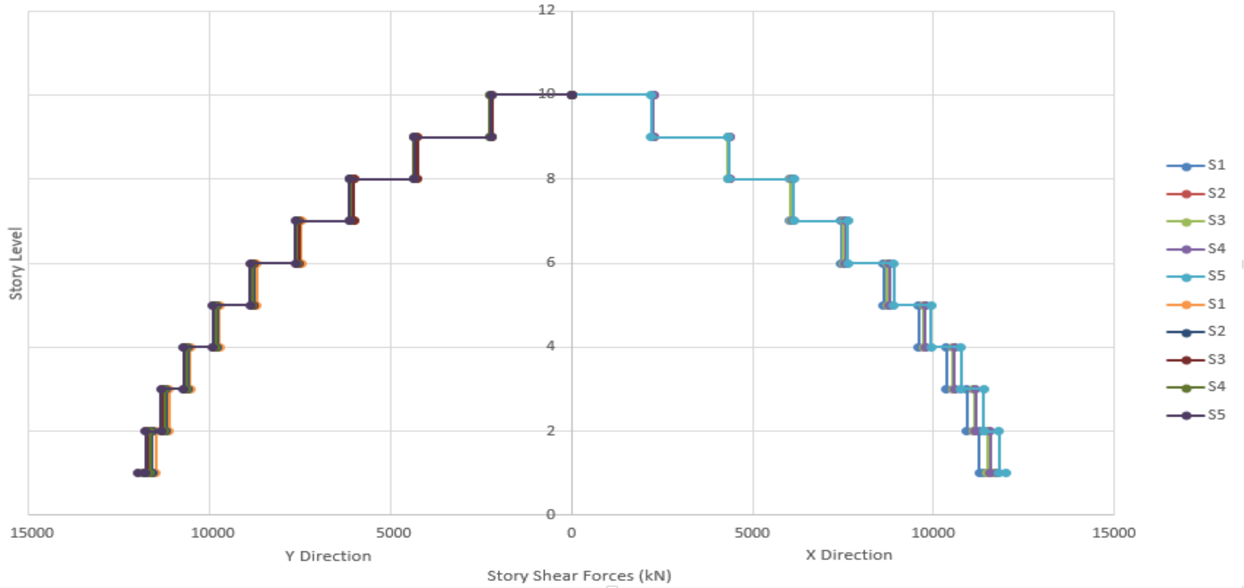
Number of Model	Type of Seismic Analysis	Shear Force Acting on Shear Walls (kN)	Base Shear Force (kN)	Ratio
S1	EEL	14193	15719	0.90
	MS	9819	11420	0.86
	TH	9405	10743	0.88
S2	EEL	16532	17828	0.93
	MS	10383	11685	0.89
	TH	9714	10953	0.89
S3	EEL	16143	16440	0.98
	MS	10804	11653	0.93
	TH	10228	11035	0.93
S4	EEL	17994	18024	0.99
	MS	11046	11755	0.94
	TH	10532	11215	0.94
S5	EEL	19257	20208	0.95
	MS	11457	12021	0.95
	TH	9897	10382	0.95

Table 3. Ratio of shear force acting on shear wall to base shear force for *y* direction.

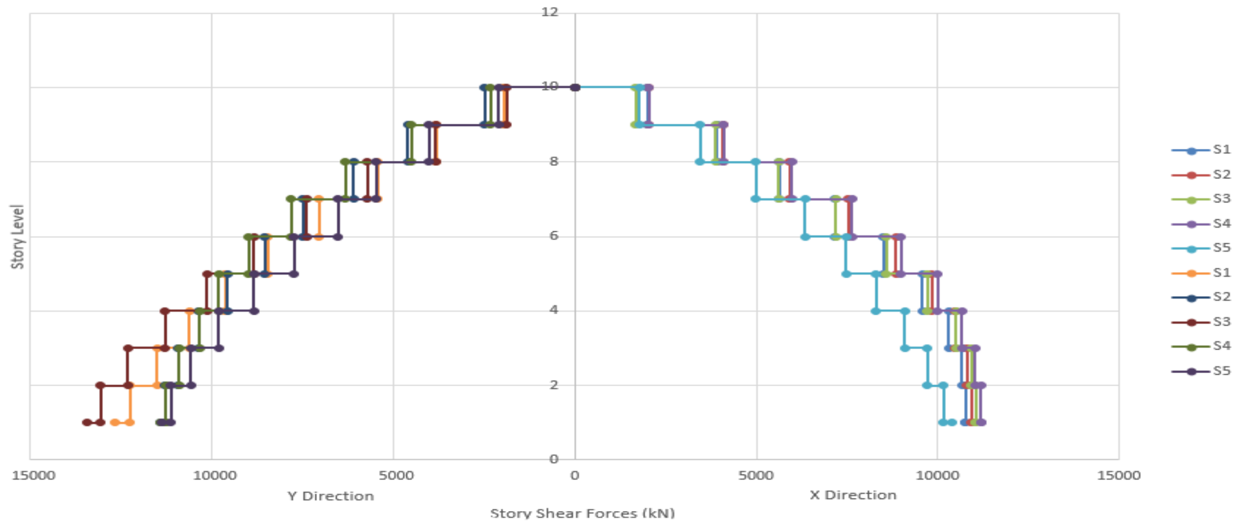
Number of Model	Type of Seismic Analysis	Shear Force Acting on Shear Walls (kN)	Base Shear Force (kN)	Ratio
S1	EEL	12974	15137	0.86
	MS	9403	11636	0.81
	TH	10267	12695	0.81
S2	EEL	15978	17127	0.93
	MS	10383	11685	0.89
	TH	10315	11445	0.90
S3	EEL	15244	15644	0.97
	MS	10642	11840	0.90
	TH	12086	13464	0.90
S4	EEL	16148	17318	0.93
	MS	11025	11819	0.93
	TH	10643	11418	0.93
S5	EEL	18976	19919	0.95
	MS	11403	11819	0.97
	TH	10861	11419	0.95



Equivalent Earthquake Load

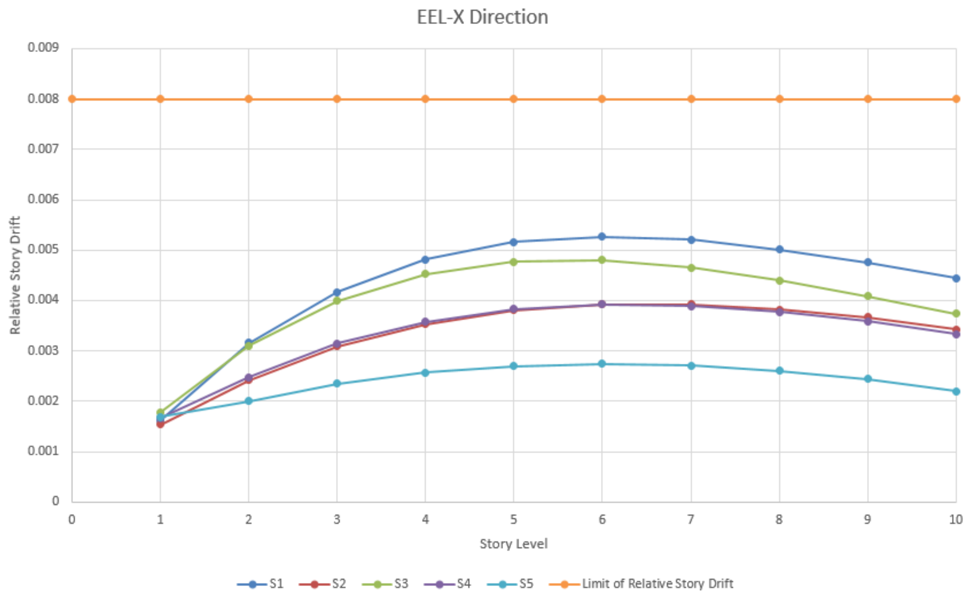


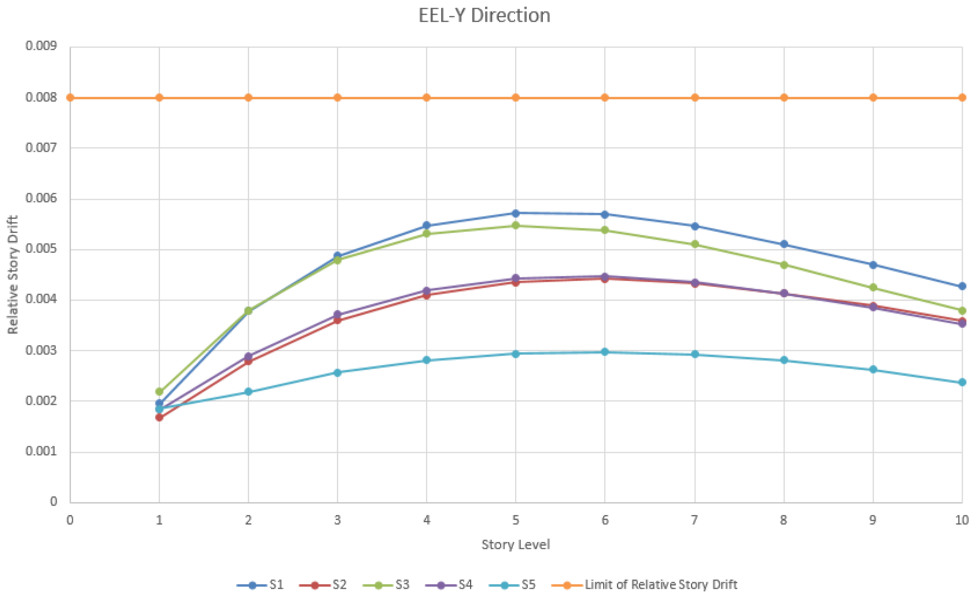
Mode Superposition



Time History Analysis

Fig. 6. Shear forces on each story of models.





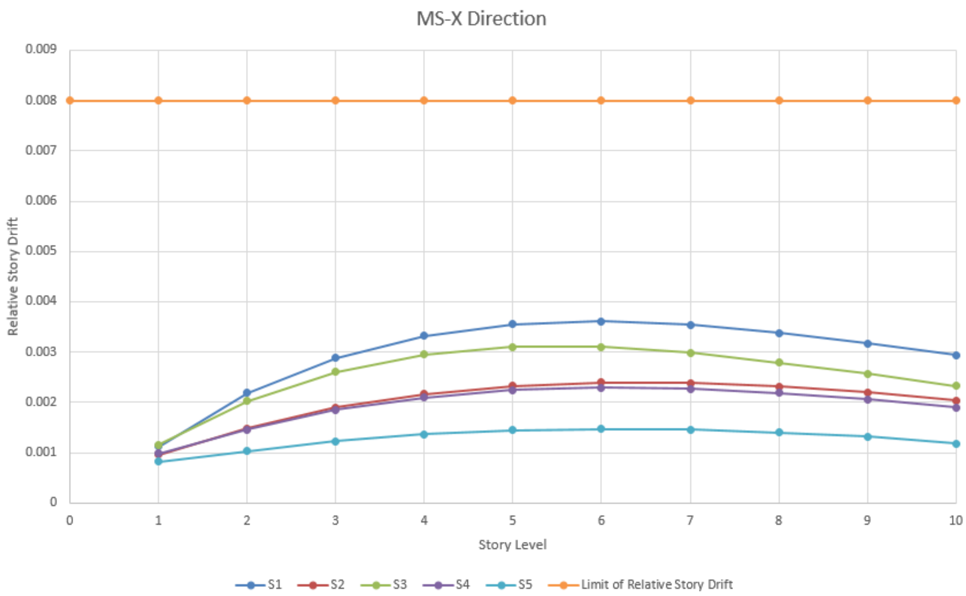


Fig. 7. (continued).

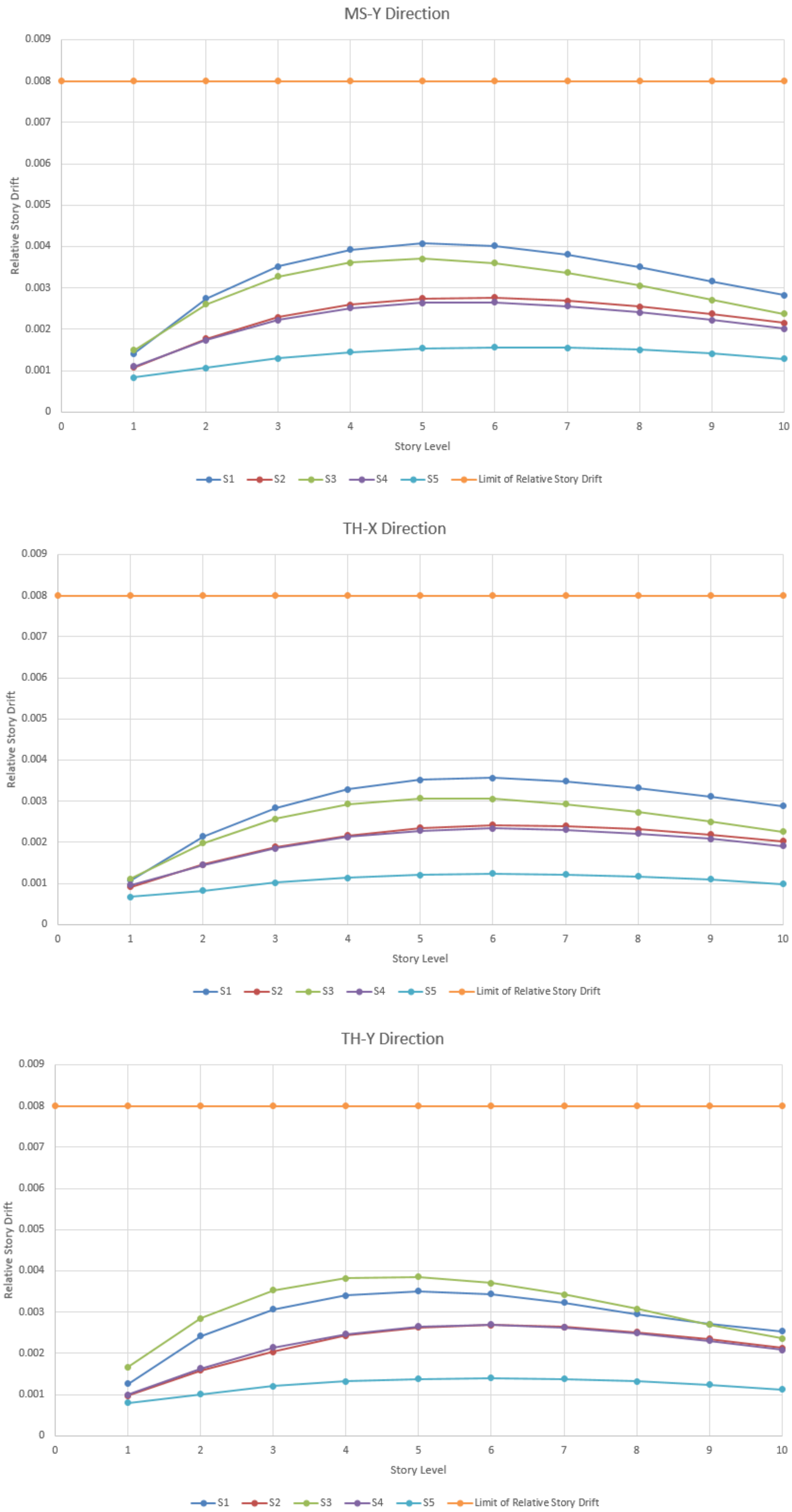


Fig. 7. Relative story drift.

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