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Comparison of 5 and 10 Storey Frame Buildings and 5 and 10 Storey Shear Wall-Frame Buildings Under the Effect of Maras Earthquake According to the Turkish Building Earthquake Code 2018

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ABSTRACT

In this study, the differences in the displacements, base shear forces, relative storey drifts and foundation stresses under different earthquake data on different storeys of shear wall frame systems and framed systems are investigated by using SAP2000 program. Within the scope of the study, four buildings with 5-storey frame, 5-storey shear wall frame, 10-storey frame and 10 storey shear wall frame are modelled. All four buildings were designed to be identical with 4 spans in X and Y directions and each span was designed as 5 meters. The height of each floor is designed as 3 meters for all four buildings. In sheared structures, shear walls are designed to be 4 meters from the corner columns to the columns closest to them. The earthquake data to be influenced on all four structures are the earthquake data from the Earthquake Hazard Map of Turkey published by AFAD at the coordinates of 41° latitude, 27° longitude of Kırklareli province, Luleburgaz district. Another earthquake parameter was taken from station 4615 during the earthquake in Kahramanmaras. The data recorded by station 4615 for the 7.6 Mw earthquake in Kahramanmaras was applied to all four structures. These two earthquake data were imposed on these four structures in order to compare the resulting displacements, relative storey drifts, base shear forces and foundation stresses. Since the structures are all symmetrical in both X and Y directions, only one direction of the displacements was calculated. As a result, when both the earthquake data from the Earthquake Hazard Map and the Kahramanmaras earthquake data were applied to these four structures, it was observed that the maximum values of the displacements occurred at the top floors of all structures and the effect of the Kahramanmaras earthquake data was higher in the displacements, relative storey drifts, base shear forces and foundation stresses than the effect of the other earthquake data.

Keywords: Turkish Building Earthquake Code 2018, Kahramanmaras earthquake, storey displacements, relative storey drifts.

INTRODUCTION

Seismic tremors caused by cracks in the earth are called earthquakes. Approximately 500 thousand earthquakes occur on Earth every year. Today, earth scientists design new earthquake regulations or revise existing ones according to past earthquakes. Today, the regulation used in Turkey is the Turkish Building Earthquake Regulation and the last revision was made in 2018. Turkey is an earthquake country. When the Earthquake Hazard Map of Turkey prepared by geoscientists is examined, it is seen that there are three major fault lines in Turkey. These are the North Anatolian Fault Line, the East Anatolian Fault Line, and the West Anatolian Fault Line.

Earthquake regulations in the world vary according to countries and regions. In our country, earthquake regulations are prepared by the Ministry of Interior Disaster and Emergency Management Presidency. The most basic regulations used by civil engineers are TS500 (2000), TS498 and Turkey Building Earthquake Regulations (TBDY). TS500 is a standards directive covering the design of reinforced concrete structures to be manufactured and the general rules of construction. However, TS500 does not cover the design of all reinforced concrete structures. TS498 covers the types and values of loads acting on structures.

In the first article of TBDY (2018), its purpose is to determine the necessary rules and minimum conditions for the design and construction of all or parts of all public and private buildings and building type structures to be rebuilt, modified, enlarged, and for the evaluation and strengthening of the performance of existing buildings under earthquake effect.

Millions of earthquakes have occurred since the world has existed. According to the United States Geological Survey (USGS, 2022), 500,000 earthquakes occur annually, of which 100,000 are felt. These earthquakes in the past have brought great destruction from time to time, caused the deaths of countless people and caused great material damage. With the developing technology, mankind has obtained scientific data about past large-scale earthquakes and regulations have been published and standards have been set to minimize destruction and loss of life in large-scale earthquakes. These continue to be updated as technology develops, and scientific studies increase. In Turkey, Disaster and Emergency Management Presidency (AFAD, 2023) has prepared Turkey Earthquake Hazard Map reflecting the seismicity of Turkey and earthquake fault lines. With this map, it has become possible to access the earthquake data of any location in every province and district in Turkey.

Literature Review

Akçora (2020) In his study in 2020; Based on the location of Yıldız Technical University Davutpasa campus, he modelled a 30-storey reinforced concrete structure with a height of 108 m, 2 floors basement and 30 floors above ground, and made earthquake calculations of this structure, which is considered a high-rise building according to TBDY 2018. The results obtained from these calculations show that the plastic deformation and rotation values are in accordance with the limits given in TBDY 2018.

Baykan (2022) modelled a 5-storey building based on Bolu province location. This structure was analysed according to different soil classes and according to Turkey Earthquake Regulation 2007 and Turkey Building Earthquake Regulation 2018 with different earthquake data.

Nomanoglu (2023) modelled 6 different buildings according to TBDY 2018 regulation and made earthquake calculations. By changing the shape and location of the shear wall, which is the load-bearing element in these modelling, he compared the effects of the loads of seismic waves acting on the earth on these building models. Dynamic and static analyses of reinforced concrete frame and shear wall frame systems were performed using equivalent seismic load and mode coupling methods. In addition, he investigated the structural defects in different models and presented various solutions for their revision.

Sağlam (2023) modelled a 27-storey reinforced concrete building based on the location of Kaynarca District of Sakarya Province and performed earthquake analysis with data from 11 earthquakes. In the results of the non-linear inelastic calculation method analysis, it was determined that the relative storey drifts exceeded the limits of TBDY 2018 regulation. On the other hand, it was determined that the shear wall strain data could not meet the limits of TBDY 2018 regulation.

Kocaman (2023) based on the elastic spectrum data of the February 2023 earthquake in Kahramanmaras, he examined the vertical elastic spectrum and changes in beam shear forces of a 7-storey building on various soils in Istanbul. He evaluated the data obtained.

Tekdemir (2020) modelled a 4-storey reinforced concrete building and four 5-storey reinforced concrete buildings using SAP2000 (2020) analysis program and analysed the structures using linear and nonlinear calculation methods, Equivalent Earthquake Load and Mode Coupling methods and compared the results obtained.

Varol (2019) modelled 4 buildings in different regions with high earthquake risk and analysed the inelastic safety coefficients and earthquake load reduction coefficients by using thrust curves. He calculated the capacities of the base shear forces in the buildings with the data obtained about the behaviour of these structures according to sudden seismic waves. He calculated the ductility and stiffness coefficients of the structure in various directions.

MATERIALS AND METHODS

In this study, foundation stresses, storey displacements, relative storey drifts and base shear forces values of 4 buildings including 5-storey frame, 5-storey frame with shear walls, 10-storey frame and 10-storey frame with shear walls analysed and compared under two different earthquake data within the scope of TBDY 2018. The number of X and Y direction openings of the 4 structures in the study are equal and the openings are 4 m each. Two of the buildings are 5 storeys and the other two are 10 storeys with equal storey heights of 3m. Earthquake data at the coordinates of 41° latitude, 27° longitude of Luleburgaz district of Kırklareli province were selected from the Earthquake Hazard Map of Turkey shared by AFAD. The other earthquake parameters were taken from station 4615 during the earthquake in Kahramanmaras. The data recorded by station 4615 for the 7.6 Mw earthquake in Kahramanmaras were applied to all four structures. In the continuation of the study, data on storey displacements, relative storey drifts, base shear forces and foundation stresses were obtained by acting two different earthquake data on the four structures. In the conclusion section, a comparison of the obtained data is made.

Since all four structures in the study are symmetrical in X and Y directions, only one direction of the displacements in the structures is calculated.

Design Parameters of the Systems

The main principles specified in the Turkish Building Earthquake Code will be applied in the construction of the structures and in obtaining the data planned for comparison. The building importance coefficient, earthquake design class, building height classes of the structures to be designed using the earthquake code should be analysed. Building importance coefficient will be determined according to Table 1.

Earthquake Design Classes are determined according to the Building Use Classes of the Turkish Building Earthquake Code. Earthquake Design Classes will be selected according to Table 2.

Table 1. Building importance coefficient (TBDY, 2018)

Building Usage Classification	Building Usage Purpose	Building Importace Factor
BKS=1	A) Places which will be used immidiatly after earthquake. Like Hospitals, fire fighting building, PTT, Power Station, rescue stations, police stations, communication, operation centers, structures containing high toxic materials. B) Schools, dormitories, jails, militery buildings. C) Muesuems D) toxic, blasting material containing buildings	1.5
BKS=2	Shopping Centers, Sport Complexes, Cinema, Theatre	1.2
BKS=3	Building which are not included in first and second catagories like residence buildings, offices, hotels, industrail buildings	1.0

Table 2. Earthquake Design Classes (TBDY 2018)

Short Period Design Spectral acceleration coefficient (S_{DS}) at Earthquake Ground Motion level of DD-2	Building Usage Class	
	BKS=1	BKS=2,3
$S_{DS} < 0.33$	DTS=4a	DTS=4
$0.33 \leq S_{DS} < 0.50$	DTS=3a	DTS=3
$0.50 \leq S_{DS} < 0.75$	DTS=2a	DTS=2
$0.75 \leq S_{DS}$	DTS=1a	DTS=1

Building Height Classes are divided into eight different classes according to their heights in the Turkish Building Earthquake Code. Building Height Classes to be selected according to the Turkish Building Earthquake Code will be selected based on the Earthquake Design Classes in Table 2. Building Height Classes are determined according to Table 3.

Table 3. Building height classes (TBDY, 2018)

Building Height Category	Building Allowable Height According to Building Height Category and Seismic Design Category (m)		
	DTS= 1, 1a, 2, 2a	3, 3a	4, 4a
BYS=1	$H_N > 7$	$H_N \leq 91$	$H_N \leq 105$
BYS=2	$56 < H_N \leq 70$	$70 < H_N \leq 91$	$91 < H_N \leq 105$
BYS=3	$42 < H_N \leq 56$	$56 < H_N \leq 70$	$56 < H_N \leq 91$
BYS=4	$28 < H_N \leq 42$	$42 < H_N \leq 56$	
BYS=5	$17.5 < H_N \leq 28$	$28 < H_N \leq 42$	
BYS=6	$10.5 < H_N \leq 17.5$	$17.5 < H_N \leq 28$	
BYS=7	$7 < H_N \leq 10.5$	$10.5 < H_N \leq 17.5$	
BYS=8	$H_N \leq 7$	$H_N \leq 10.5$	

In order to calculate the relative storey drifts of the building, the relative storey drift at floor "i" of the building, δi(X), for the typical earthquake direction (X) according to the Turkish Building Earthquake Code, shall be calculated by Eq. 1.

Equation. 1. Relative storey drift

$$\delta_i^{(X)} = \frac{R}{I}\Delta_i^{(X)}$$

The total equivalent earthquake data (base shear force), V_{tE}(X), acting on the whole building for the typical (X) earthquake direction shall be calculated by Eq. 2.

Equation. 2. Base shear force

$$V_{tE}^{(X)} = m_t\, S_{aR}\,(T_p^{(X)}) \geq 0.04\, m_t\, I\, S_{DS}\, g$$

Where S_{aR} $(T_p^{(X)})$is the Reduced Design Spectral Acceleration calculated according to $T_p^{(X)}$, the dominant vibration period in the (X) earthquake direction,

S_{DS}; short period design spectral acceleration coefficient,

m_t; total mass,

I; building importance coefficient,

G; is the acceleration of gravity.

2.2. Defining Response Spectra to SAP2000 Program

The earthquake data (ETSx, ETSy) of Kahramanmaras earthquake station number 4631 obtained for ZD soil class and the earthquake data (Ex, Ey) obtained according to the coordinates of 41° latitude, 27° longitude of Luleburgaz district of Kırklareli province (Ex, Ey) were defined in the fields specified in the response spectrum definition interface in SAP2000 program for all four structures.

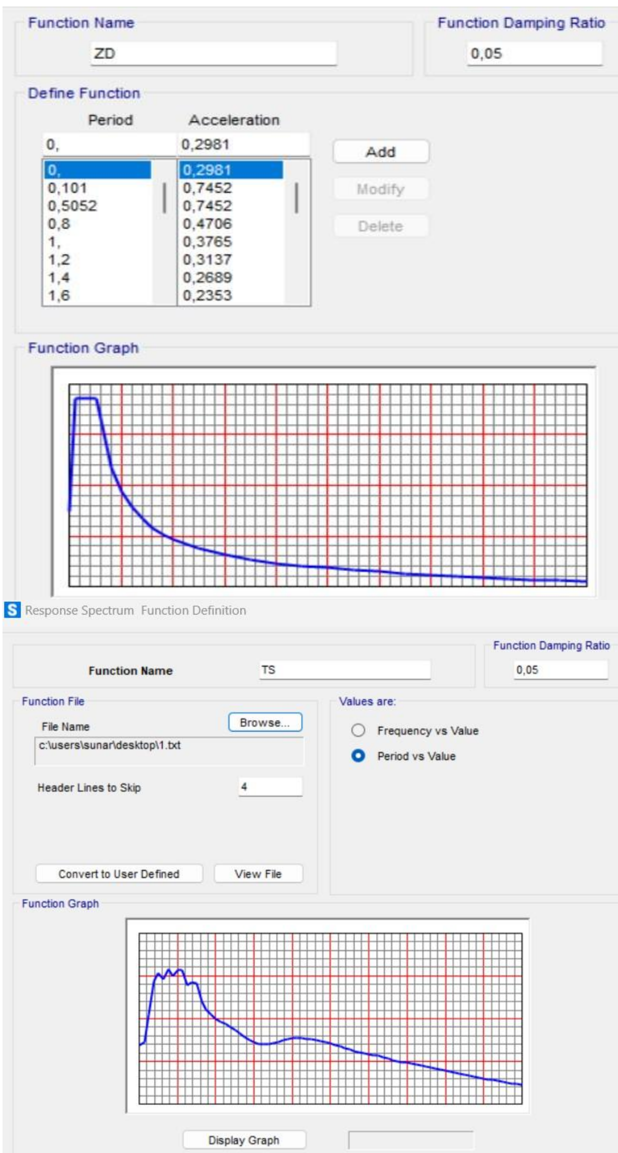

Figure 1. Elastic design spectrum (ZD) and Kahramanmaras Earthquake design spectrum (TS)

2.3 Modelling of structures and defining the loads to be used in the structure

The structural system elements and dimensions of all four structures to be used in the analysis are designed equally.

Column dimensions are 90×90cm and beam dimensions are 50×80 cm in all four structures. The slab type to be used in all structures is slab, and the slab thickness is determined as 15cm. The shear wall thickness used in shear wall framed buildings is 35cm. The foundation type of all structures was determined as the same and raft foundation, and the foundation thickness was determined as 120cm.

Figure 5 showed 2-dimensional and 3-dimensional sap2000 program visualization of the 10-storey shear wall frame system building.

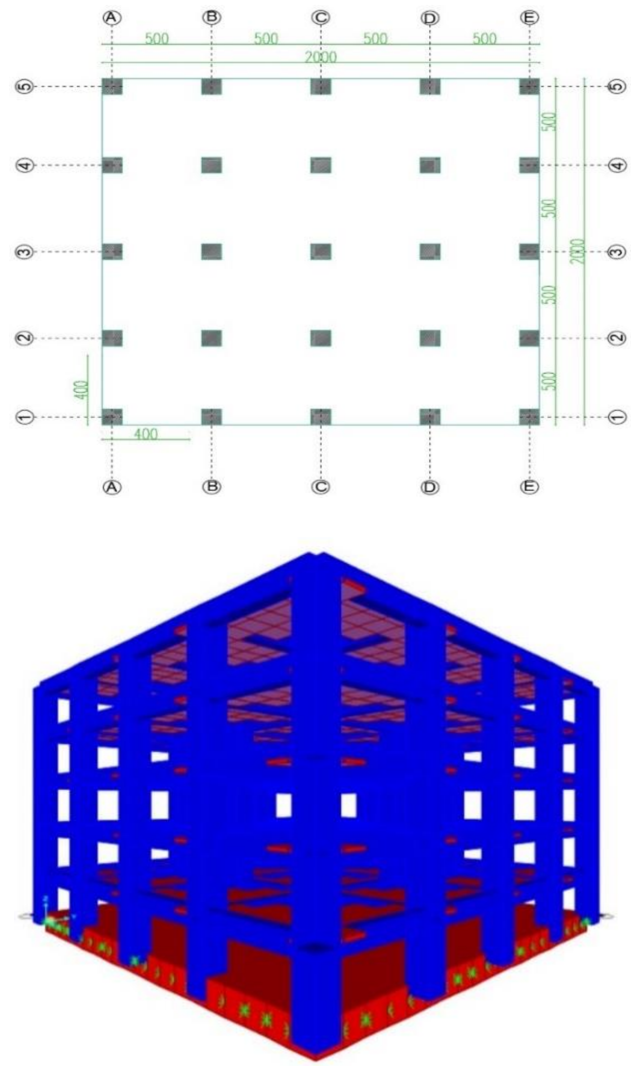

Figure 2. 2-dimensional and 3-dimensional sap2000 program visualization of 5-storey framed system structure.

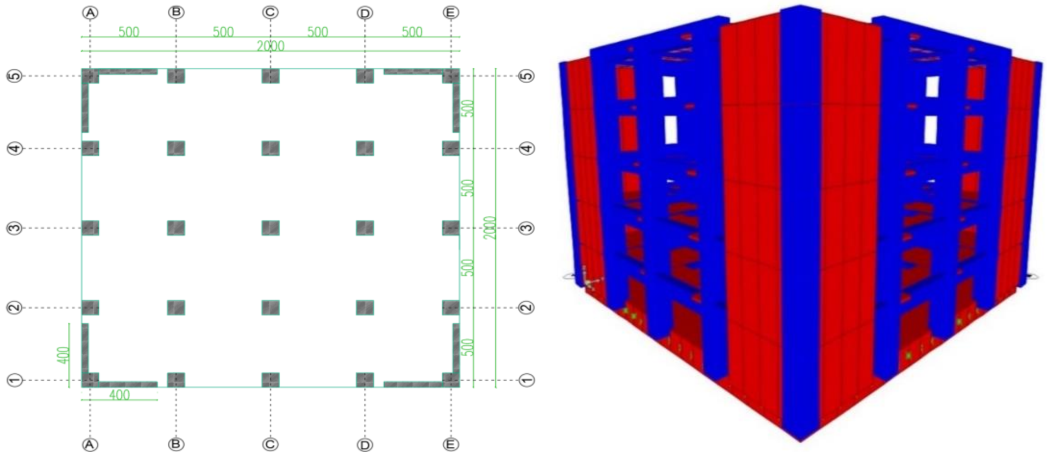

Figure 3. 2-dimensional and 3-dimensional sap2000 program visualization of 5-storey shear wall frame system building.

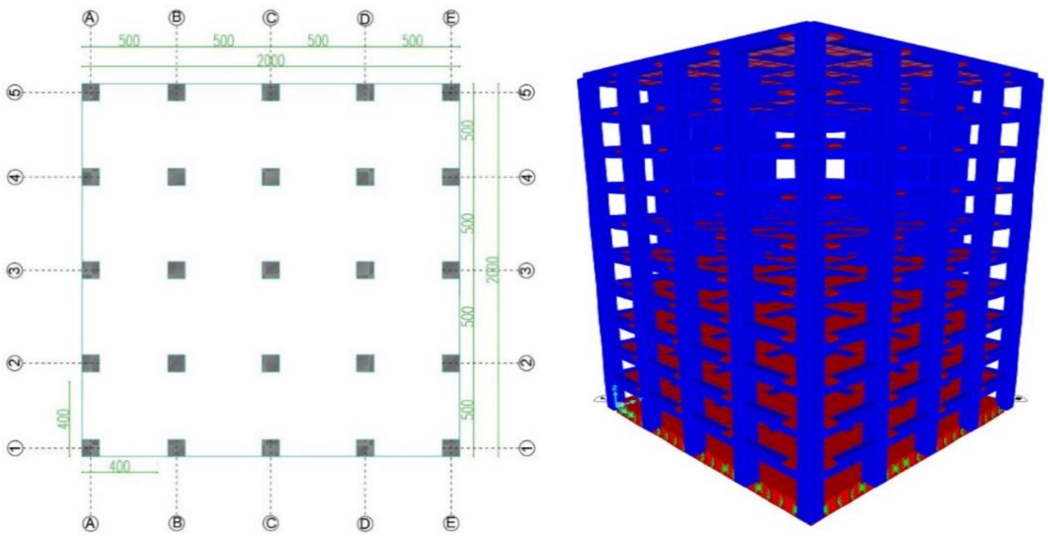

Figure 4. 2D and 3D sap2000 program visualization of 10 storey framed system structure.

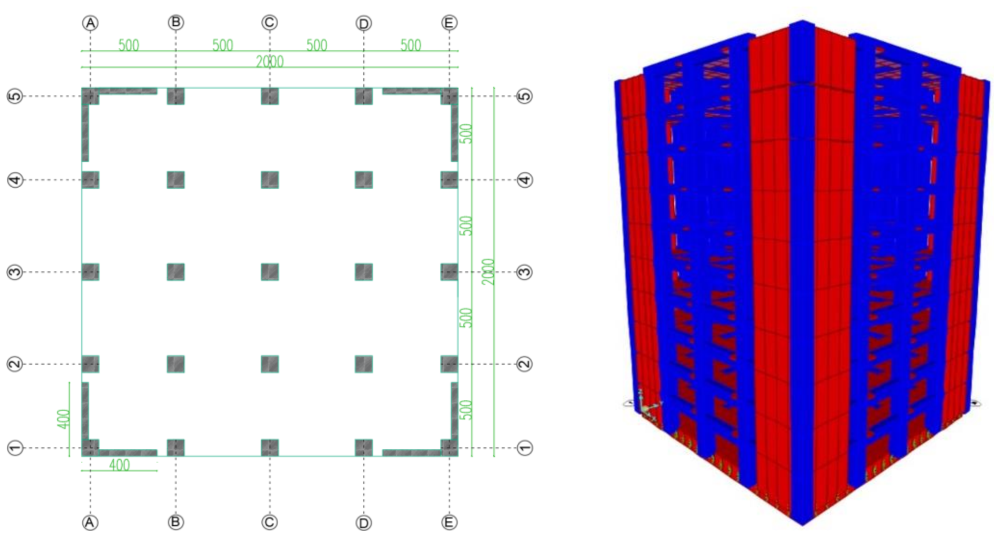

Figure 5. 2D and 3D sap2000 program visualization of 10 storey framed system structure

Table 4. Loads used in the structure

Load Type	Symbol	Unit	Load
Self-weight	G	kN	Software-defined
Live load	Q	kN/m2	3.0
Cover	G	kN/m2	2.0
Wind	W	kN	Software-defined
Ex	Quake	kN	Software-defined
ETSx	Quake	kN	Software-defined
Ey	Quake	kN	Software-defined
ETSy	Quake	kN	Software-defined

RESULT AND DISCUSSIONS

As a result of the analyses, it is seen that the displacement ratios of ETSx compared to Ex increase by 58% for the 5-storey frame structure and 61% for the 5-storey sheared structure, while they increase by approximately 53%~54% for the 10-storey frame structure and 57%~58% for the 10-storey sheared frame structure. Since the maximum displacements are identical in X and Y directions, the results of one-way earthquake data are shared. Figures 6-9 show the maximum displacements of 5-story frame, 5-story shear wall, 10-story frame, and 10-story shear wall structures, respectively. Considering the maximum displacement values, ETSx values were higher than Ex values in all four structures.

When the base shear forces for the four structures are analysed, it is seen that ETSx values increased by ~58% for 5-storey frame structure, ~61% for 5-storey shear wall structure, ~54% for 10-storey frame structure and ~58% for 10-storey shear wall structure compared to Ex values. Figures 10-13 show the base shear forces for 5-storey frame, 5-storey shear wall, 10-storey frame and 10-storey shear wall systems respectively.

The effects of Ex and ETSx earthquake data on the foundation stresses of the four modelled structures were investigated. Since the structures are symmetrical, only X-direction M11 and M22 moment diagrams are given. It was observed that ETSx earthquake data increased the foundation stress values by 61%~68% for 5-storey frame structure, 63%~68% for 5-storey sheared structure, 58%~64% for 10-storey frame structure and 60%~68% for 10-storey sheared structure compared to Ex earthquake data. As a result of the investigation, the principal stresses of the Ex earthquake data for the 5-storey frame structure are given in Figure 14 and the principal stresses of the ETSx earthquake data are given in Figure 15; the principal stresses of the Ex earthquake data for the 5-storey sheared structure are given in Figure 16 and the principal stresses of the ETSx earthquake data are given in Figure 17. For the 10-storey frame structure, the principal stresses of Ex earthquake data are given in Figure 18, the principal stresses of ETSx earthquake data are given in Figure 19, the principal stresses of Ex earthquake data for the 10-storey sheared structure are given in Figure 20, the principal stresses of ETSx earthquake data are given in Figure 21. The maximum M11 and M22 directional moments induced by Ex and ETSx earthquake data for the four structures are given in Table 5.

The relative story drifts induced by Ex, Ey, ETSx and ETSy earthquake data for all modelled structures are given in Figures 22-25, respectively.

The relative storey drifts of the four structures modelled with 5-storey frame, 5-storey shear wall, 10-storey frame and 10-storey shear wall are given in Figures 22-25 for the Ex, Ey, ETSx and ETSy earthquake data, respectively.

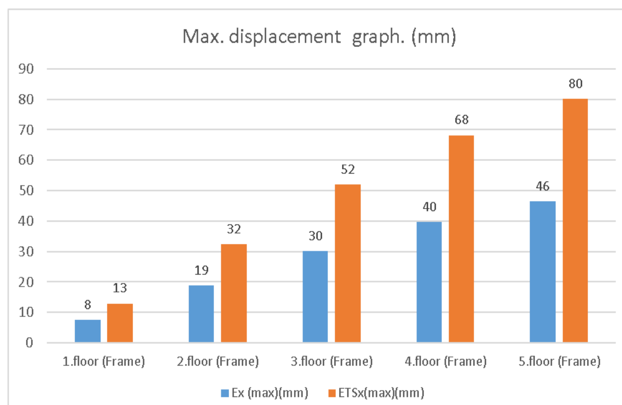

Figure 6. 5 Story frame building maximum displacement graphic.

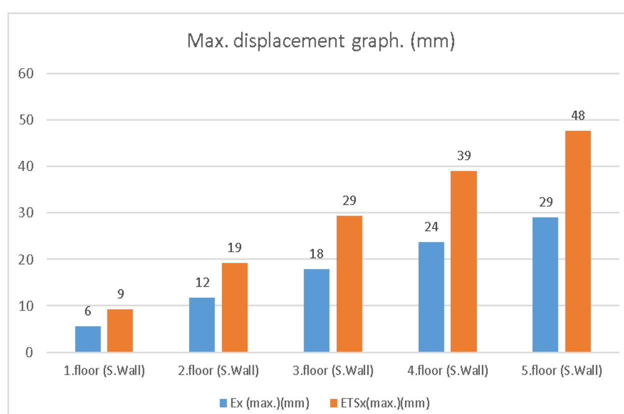

Figure 7. 5 Story Shear Wall- frame building maximum displacement graphic.

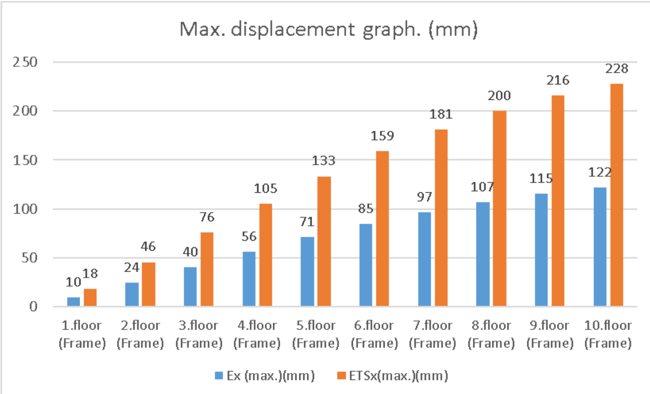

Figure 8. 10 Story frame building maximum displacement graphic.

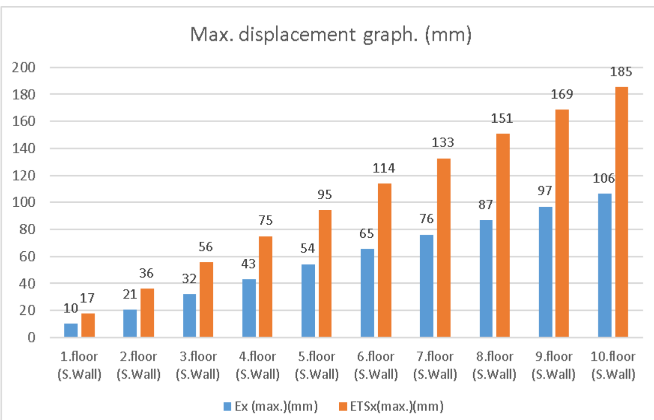

Figure 9. 10 Story Shear Wall- frame building maximum displacement graphic.

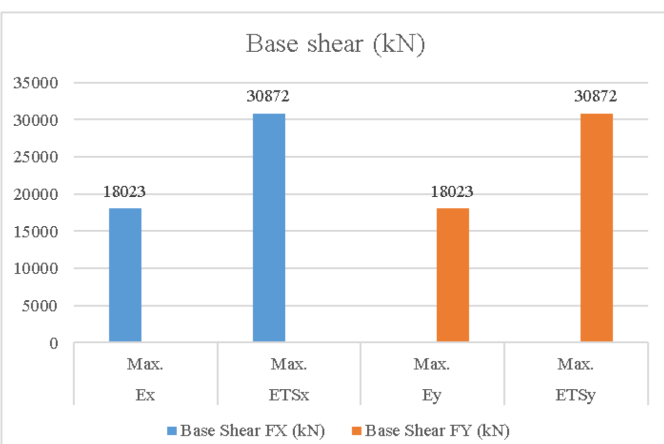

Figure 10. 5 Story frame building base shear graphic.

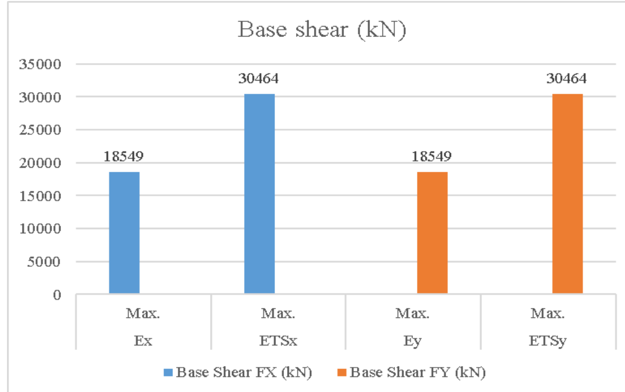

Figure 11. 5 Story shear wall-frame building base shear graphic.

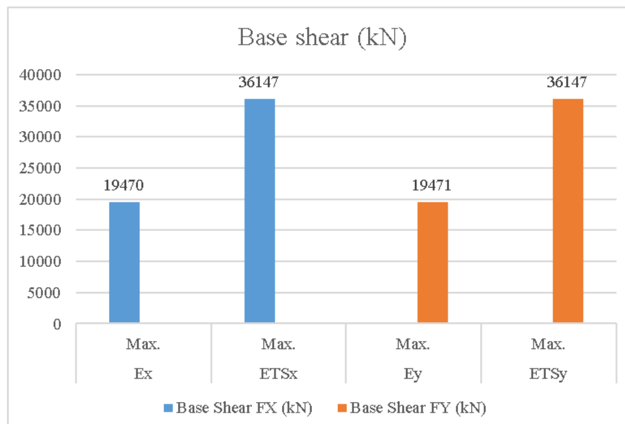

Figure 12. 10 Story frame building base shear graphic.

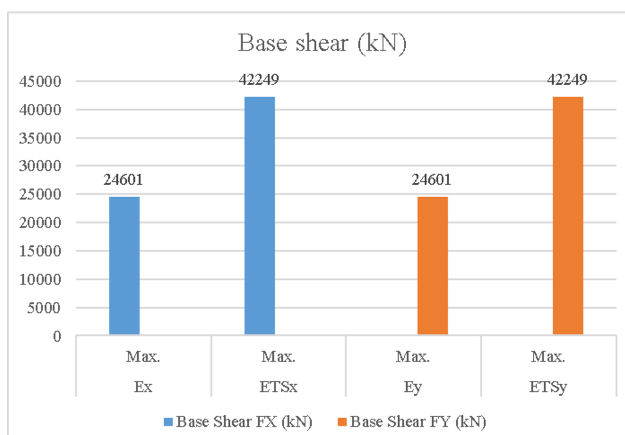

Figure 13. 10 Story shear wall-frame building base shear graphic.

Table 5. Maximum M11 and M22 directional moments at the foundation by Ex and ETSx earthquake

Loading types \ moment direction	5 Storey frame	5 Storey wall-frame	10 Storey frame	10 Storey wall-frame
Ex Combination \ (M11)	4608 KN-m/m	4730 KN-m/m	5944 KN-m/m	8101 KN-m/m
ETSx Combination \ (M11)	7570 KN-m/m	7495 KN-m/m	10224 KN-m/m	13461 KN-m/m
Ex Combination \ (M22)	1879 KN-m/m	1653 KN-m/m	3417 KN-m/m	2826 KN-m/m
ETSx Combination \ (M22)	2759 KN-m/m	2435 KN-m/m	5303 KN-m/m	4185 KN-m/m

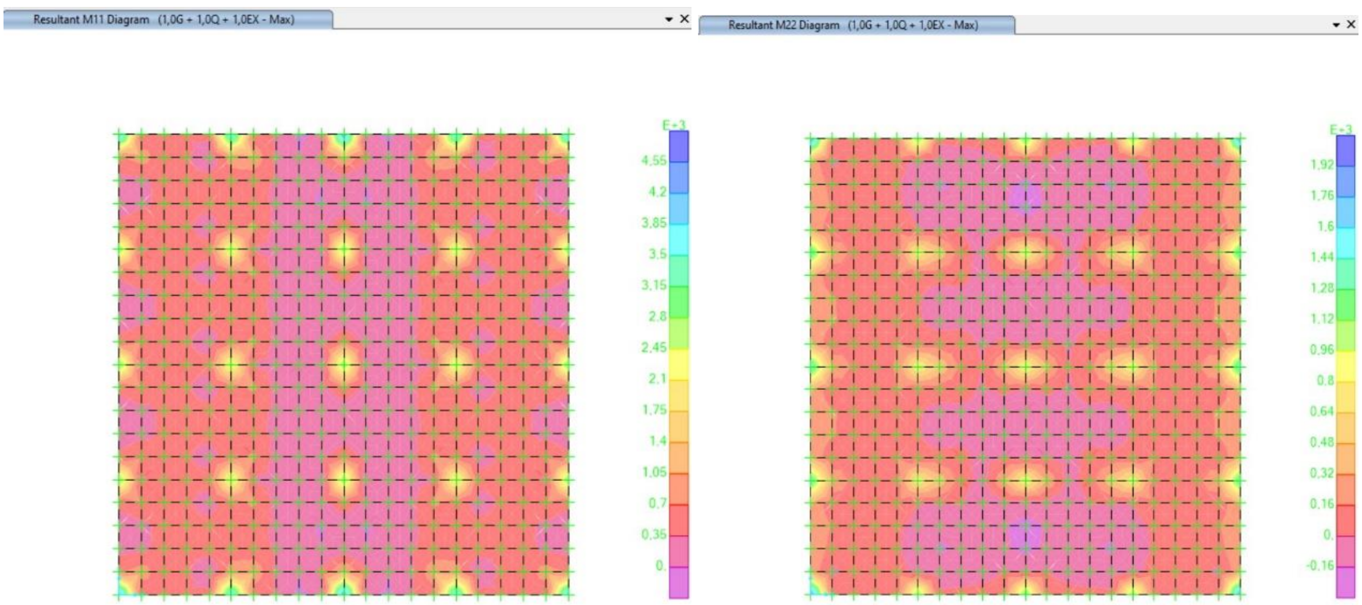

Figure 14. (M11) and (M22) diagrams of 1,0G + 1,0Q + 1,0EX combination 5 storey frame building

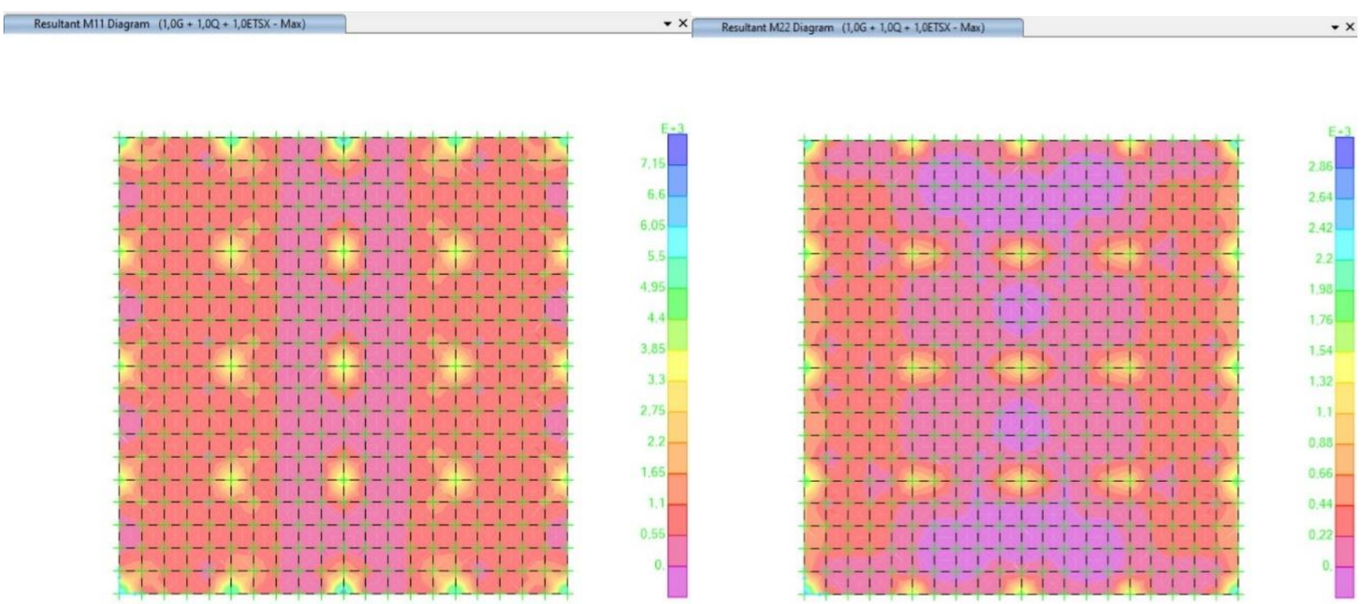

Figure 15. (M11), (M22) diagrams of 1,0G + 1,0Q + 1,0ETSX combination 5 storey frame building

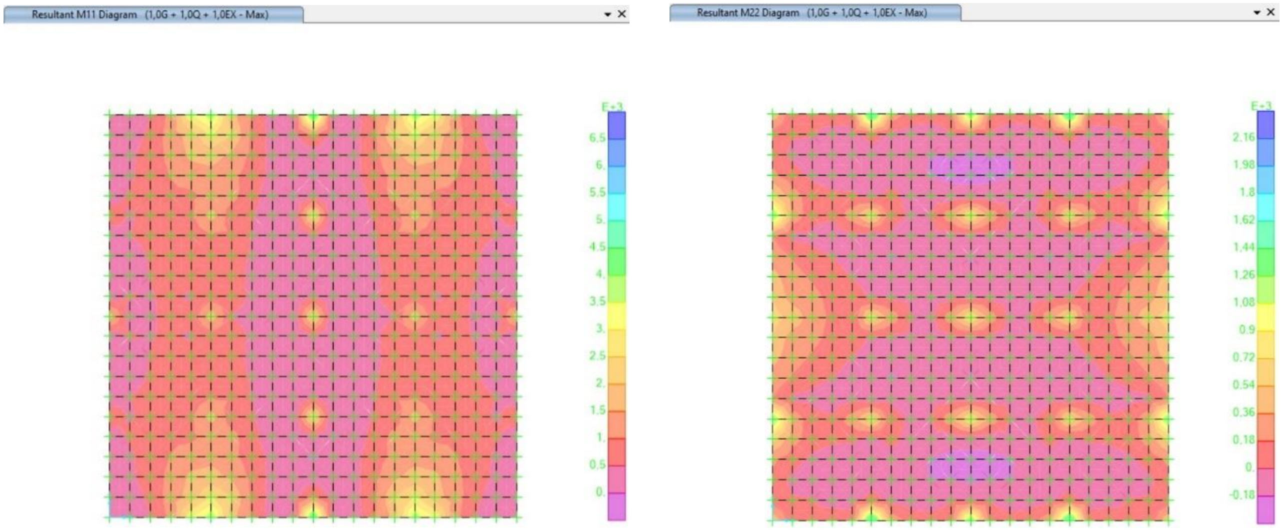

Figure 16. (M11), (M22) diagrams of 1,0G + 1,0Q + 1,0EX comb. 5 storey shear wall frame building.

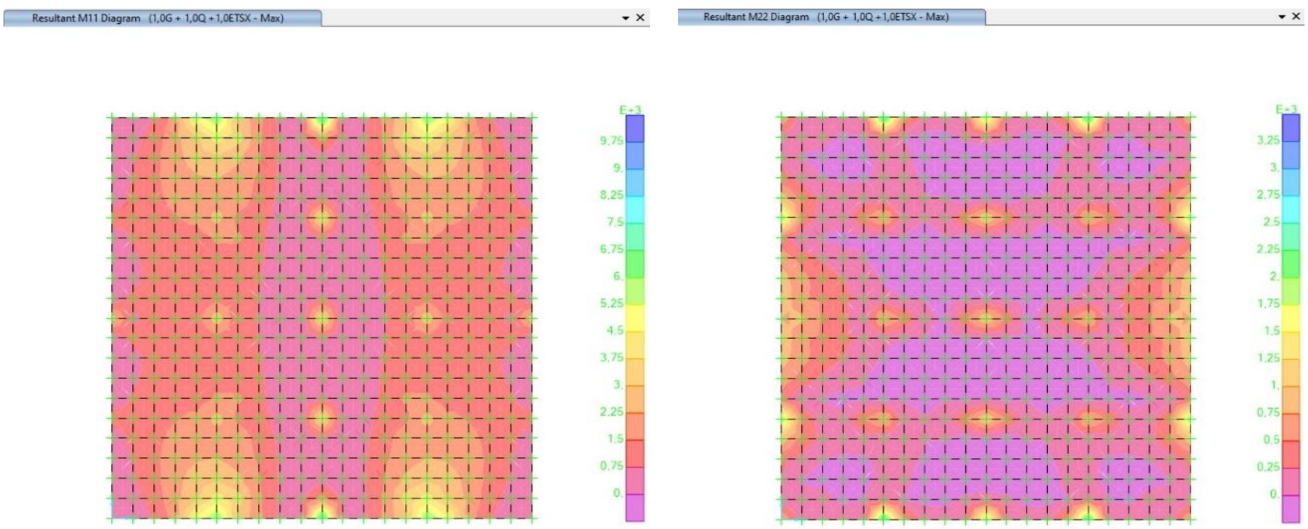

Figure 17. (M11), (M22) diagrams of 1,0G + 1,0Q + 1,0ETSX comb. 5 storey shear wall frame build.

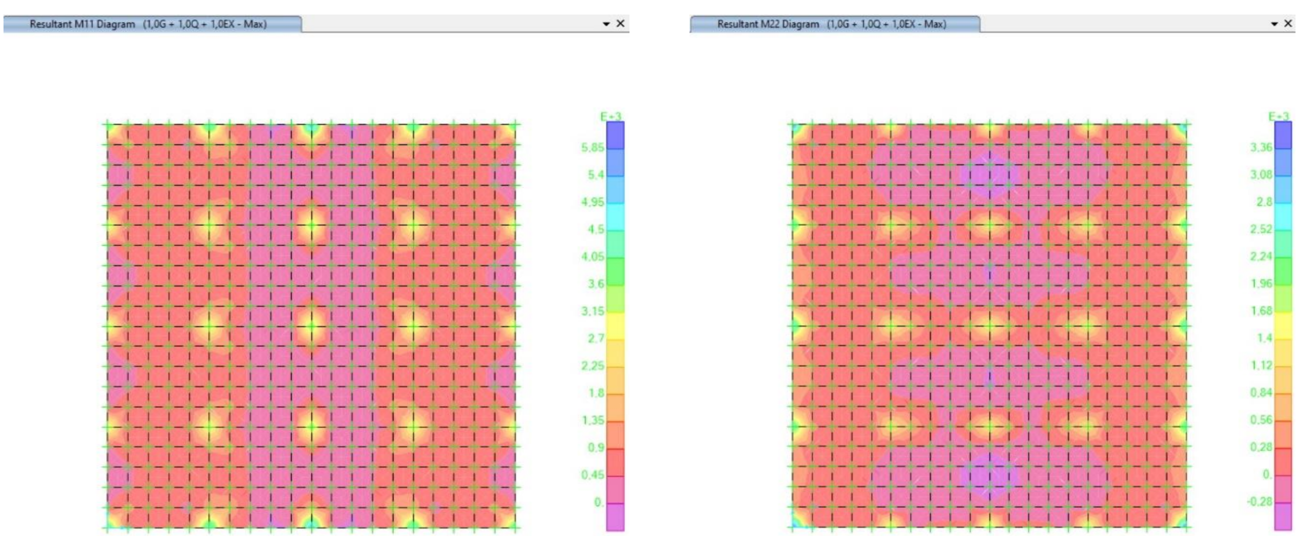

Figure 18. (M11), (M22) diagrams of 1,0G + 1,0Q + 1,0EX combination 10 storey frame building

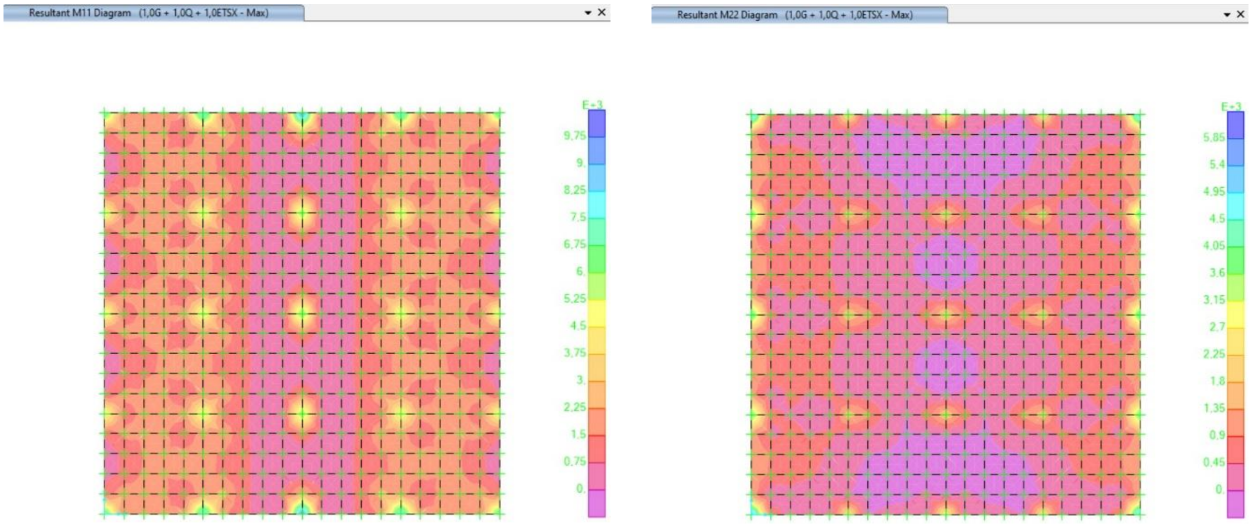

Figure 19. (M11), (M22) diagrams of 1,0G + 1,0Q + 1,0ETSX combination 10 storey frame building

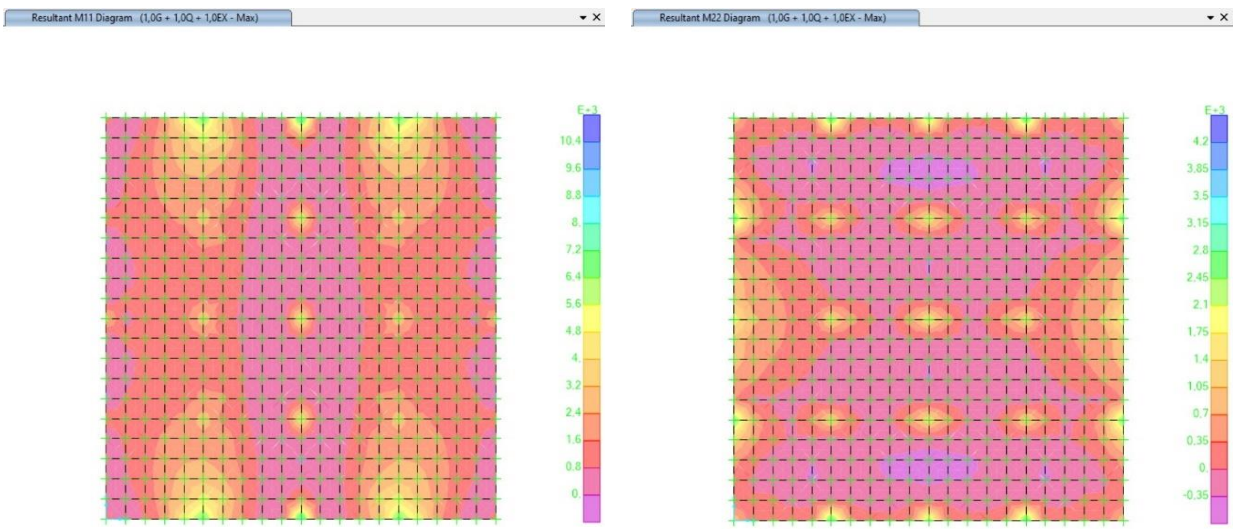

Figure 20. (M11), (M22) diagrams of 1,0G + 1,0Q + 1,0EX comb. 10 storey shear wall frame building

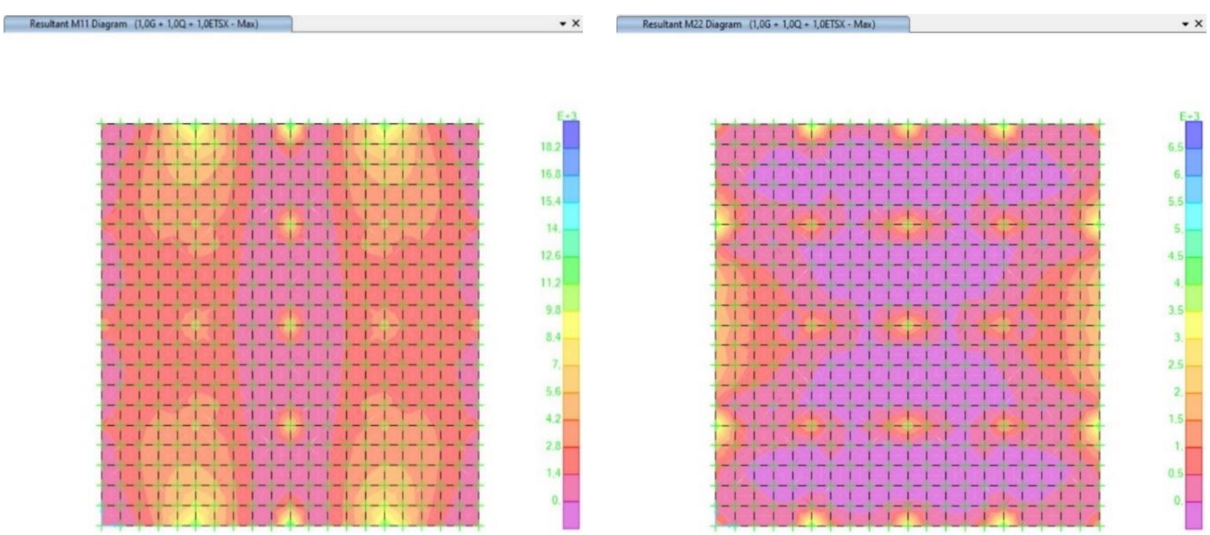

Figure 21. (M11), (M22) diagrams of 1,0G +1,0Q+1,0ETSX comb. 10 storey shear wall frame build.

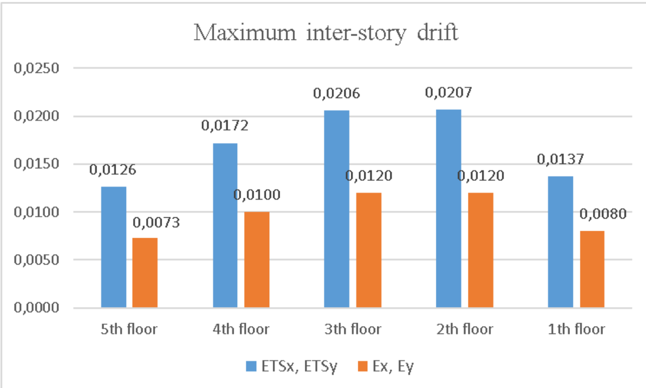

Figure 22. 5 Storey frame building inter-story drift graphic.

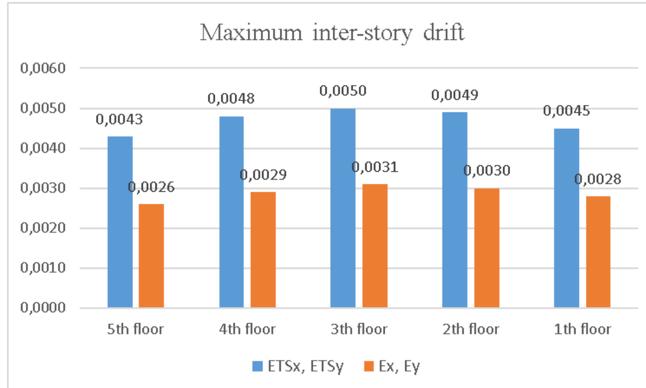

Figure 23. 5 Storey shear wall-frame building inter-story drift graphic.

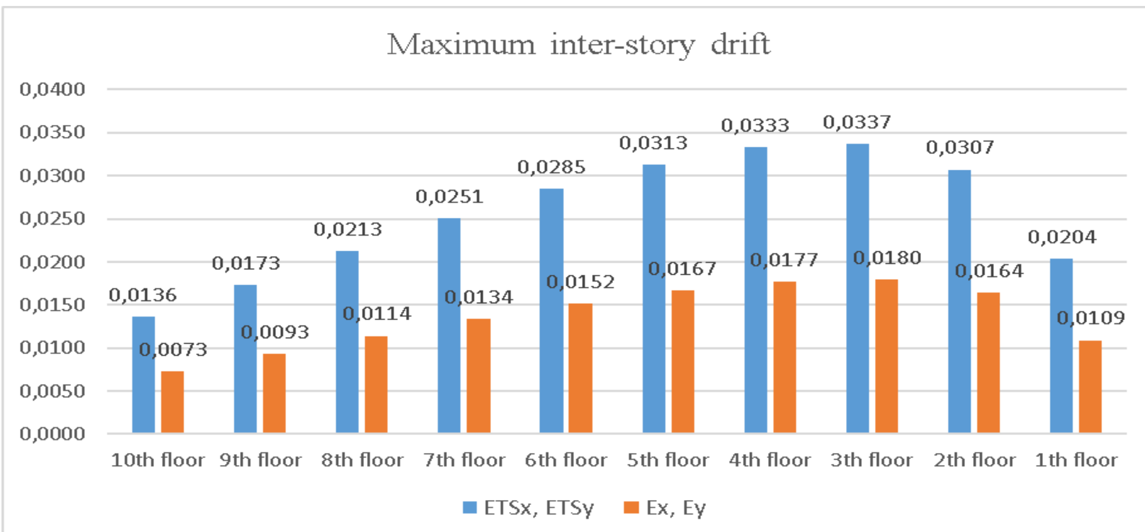

Figure 24. 10 Storey frame building inter-story drift graphic.

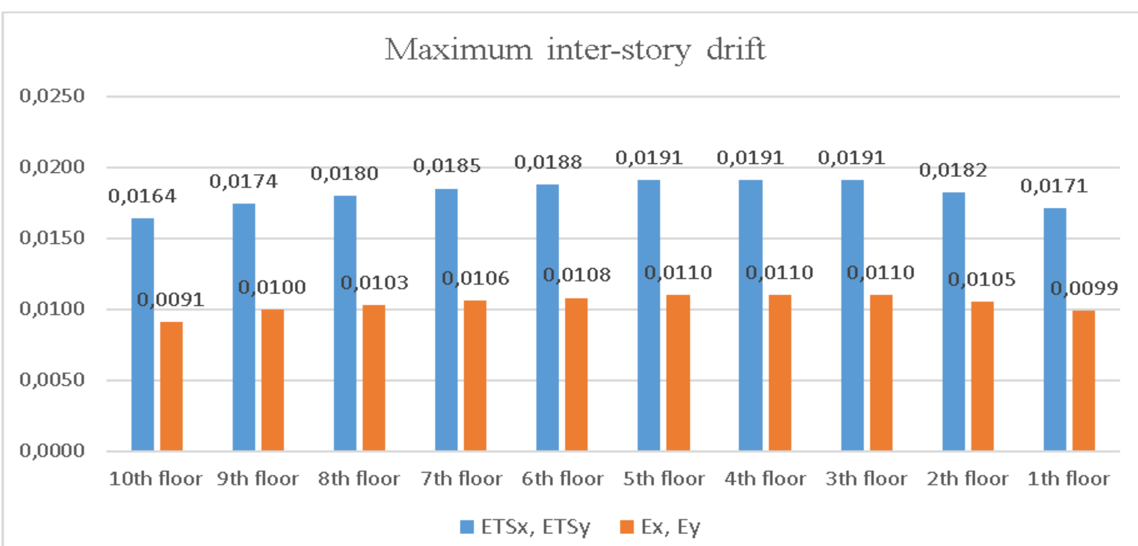

Figure 25. 10 Storey shear wall-frame building inter-story drift graphic.

CONCLUSIONS

In this study, earthquake data from the Earthquake Hazard Map published by AFAD by utilizing the Turkish Building Earthquake Regulation and the earthquake data from the coordinates of 41° latitude, 27° longitude of Kırklareli province, Luleburgaz district and the earthquake data taken from the station number 4615 of the 7.6 Mw earthquake in Kahramanmaras were acted on a 5-storey framed structure, a 5-storey shear wall structure, a 10-storey framed structure and a 10-storey shear wall structure. As a result of the data obtained, an increase of 50%~60% in storey displacements, 55%~60% in base shear forces, 58%~68% in foundation stresses and ~50% in relative storey drifts were observed in the structures affected by the data of Kahramanmaras earthquake compared to the structures affected by the data of Kırklareli earthquake. According to results obtained, the results of an earthquake of possible Maras earthquake magnitude in a different region were compared and reported. It has been determined that when an earthquake of the possible magnitude of Maras earthquake occurs, the displacements, base shear forces and earthquake loads in the structure increase visibly. In addition, according to the datas obtain, it has been determined that shear-frame building performed better than frame building. Also if we look at two different earthquake effects, it has been determined that the earthquake performance of high-rise buildings is better than low-rise buildings. In the future, in addition to this study, it is planned to compare the results obtained according to different earthquake loads in buildings with different soil classes and storey heights.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Author's contribution

Both authors contributed equally to this work.

Competing interests

The authors declare no competing interests in this research and publication.

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