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Analysis of multi-storey steel structures with different bracing types

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Abstract

Purpose: This study was carried out to show the effect of steel bracing systems on a multi-storey steel structure in terms of base shear forces, displacements and structure weights.
Study design/methodology/approach: Analysis of two different structures with 20 floors, 3 meters in height and 60 meters in total building height, 5 spans in both directions and 30 meters in both directions, without braces and with central X braces, were analyzed with the SAP2000 program under the influence of constant load, live load, snow load and horizontal loads, as well as 2 different ground classes and 2 different spectrum acceleration coefficients, taking into account the ÇYTHYE-2016 and TBDY 2018 regulations.
Findings: According to the findings obtained, it was determined that the weight of the structure decreased due to the reduction of the cross-sections formed by the use of the diagonal system of the X diagonal system compared to the unbraced system, greatly reducing the base shear forces, and significantly limiting the displacements.
Originality/value: In this study, it has been shown what kind of positive effects the use of steel braces in multi-storey steel structures has on the building safety and economically. Analysis with the SAP2000 program gave successful results in this sense.

Keywords: Displacements; Multi-Storey Steel structure; SAP2000; Steel crosses

1. Introduction

When examined from the past to the present, it is seen that the buildings show significant developments in the field of architecture and engineering. The variety of materials used in the emergence of the structures has changed constantly in order to provide advantages. Each building material has its own advantages and disadvantages. For concrete, it is more rigid than steel and wooden structures. However, it is heavier than steel and wooden structures and creates negativities especially in case of earthquakes. Concrete material is more advantageous than steel in terms of cost and fire resistance. Although the construction time of the steel material is shorter, it is possible to reuse the steel materials. It is possible to list more advantages and disadvantages such as these. However, these advantages and disadvantages are changing day by day and different building materials are preferred. Today, steel has started to be used frequently as a building material. The cost of using concrete as a building material in buildings does not change much compared to steel as it used to be. Various materials have been developed to provide fire resistance. While steel was used as a building material in structures such as bridges, it is now frequently used in buildings. As the effects of earthquakes increase in our country and in the world, it becomes compulsory to use steel as a building material in buildings. Thanks to the lightness of steel structures, it is possible to construct higher buildings more safely and to make them longer in terms of life.

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In this paper, with the SAP2000 program, the structures that will be formed by modeling two different high steel structures are analyzed by mode combination method and base shear forces, displacements and structure weights etc. are calculated. Comparisons were made on features. In our last section, there are conclusions and recommendations.

2. Methodology

The design and analysis of high steels with the same structural feature but with X central steel cross type and non-cross type as cross type were made.

1. Crossless model (ÇS)
2. X crossed model (XÇ)

While designing these buildings; TS 498-Regulation on Calculation Values of Loads to be Taken in the Dimensioning of Structural Elements by taking into account fixed load, live loads, earthquake, wind loads and snow load, TS EN 1991-1-3 and TS EN 1991-1-4 Regulations for snow and wind load calculation, Necessary data have been determined according to the Turkish Building Earthquake Code-2018 (TBDY-2018) and other applicable regulations. Modeled structures were analyzed using the Sap2000 computer program. The design of the modeled structures was carried out according to the Design, Calculation and Construction Principles of Steel Structures-2016 (ÇYTHYE-2016). Internal force values, displacement results, structure weights, etc. obtained in the analysis results. results were compared.

In order to see the effect of different soil properties for the X-central braced and unbraced type structure modeled in this study, the necessary parameters were determined as follows.

A) Earthquake effect (Short period design spectral acceleration coefficient (S_{DS})

a. $S_{DS} < 0.33$ location of the building (Earthquake effect=A)

b. 0.50≤SDS <0.75 location of the building (Earthquake effect=B)

B) Local Ground Class

c. ZB building area (Local ground class=B)

d. ZD building area (Local ground class =D)

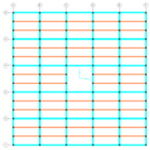
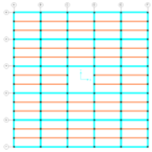
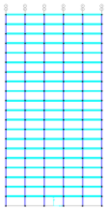
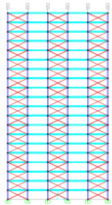
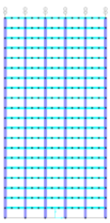
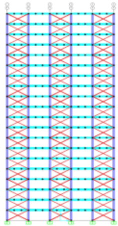
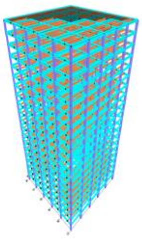
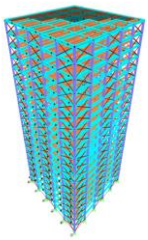
2.1. Features of the designed 20-storey office building

The building considered in its modeling has 20 floors and is planned to be built in the center of Konya. The floor length of the entire building is 3 meters. Our total structure is 60 meters. The building is a square structure with 5 openings in both directions and 30 meters in both directions. The core of the building is space, the rest is 864 m2. It is symmetrically divided according to the X and Y distribution. The building is modeled as a business center. The aim of this study; X is the measurement of displacements, structure weights and base shear forces in 8 different structures with 2 different soil classes and 2 different spectral acceleration accelerations, in two different structures, the central braced type and the unsupported end. In the model, there is a secondary beam every 2 meters in the X direction. S450 class high quality steel is used in the designed structure. The geometric and design features of the building graphics obtained in the study are given in Table 1. In return for recording the effect considered in the study, the samples were named in the following systematic: N1(Sample)- (Cross type)- (Earthquake effect) – (Local ground class)

2.2. Analysis of building systems with the SAP2000 program

In this study, a total of 2 two-storey steel structure systems, analysis and design were carried out with the Sap2000 v22 program. The model we have created is a completely unbraced model in the X and Y directions, and it is created as a two-way central X-braced model, and it is symmetrical in both directions. There is a secondary beam every two meters in the X direction of the building. The building floors are 3 meters and 20 floors and are 60 meters thick. Our structure has 5 openings in both directions and is 6 meters long in each length. Steel grade S450 was used in the structure, HE profile was used in columns and frame beams, and IPE profile was used in secondary beams.

Table 1. Features of the 20-storey building system of the design

	Crossless Model (ÇS)	X Crossed Model (XÇ)
Plan/XY View		
XZ View		
YZ View		
3D View		

2.3. Fixed and live loads

Fixed and live loads used in the design are shown in Table 2. In the definition of load, cladding, suspended ceiling, installation and partition wall weights are included in the fixed loads. In normal floors, a linear load of 3 kN/m is defined as the glass curtain wall load on the exterior beams and core zone beams.

2.4. Snow load

The modeled building is thought to be in Konya. According to the TS498 Regulation, it has been determined that snow loads will have a more negative impact, according to the shown in Fig.1. Looking at this table, the fact that Konya is in the 2nd Region in terms of snow load and its altitude is 1016 meters, the snow weight on the permanent ground until the eye date is 1.05+(1.05*10/100) = s_K=1.155 kN/m^2. The loads were loaded at the same level and in the same way in all models and no changes were made.

Table 2. Fixed and live load values

Loads	Load ratings (kN/m^2)	
	Normal floor	Roof floor
Fixed loads	2.7	2.1
Live loads	2	1
Wall load	3	

	1	2	3	4	5
1	Yapı yerinin denizden yüksekliği	BÖLGELER			
	m	I	II	III	IV
	≤ 200	0,75	0,75	0,75	0,75
2	300	0,75	0,75	0,75	0,80
	400	0,75	0,75	0,75	0,80
	500	0,75	0,75	0,75	0,85
3	600	0,75	0,75	0,80	0,90
	700	0,75	0,75	0,85	0,95
	800	0,80	0,85	1,25	1,40
4	900	0,80	0,95	1,30	1,50
	1000	0,80	1,05	1,35	1,60
5	> 1000	1000 m'ye tekabül eden değerler, 1500 m'ye kadar % 10, 1500 m'den yukarı yüksekliklerde % 15 artırılır.			
* Kar yağmayan yerlerde kar yükü hesap değeri sıfır alınır.					

Fig. 1. Characteristic ground snow load values (s_K) kN/m^2

2.5. Wind load

For wind loads, the conditions given in TS EN 1991-1-4 are taken into account. The basic value of the wind speed is $V_{b,o}$=28 m/s and the characteristic wind loads acting on the building's main carrier system, siding and structural and non-structural elements exposed to the wind shall not be less than 0.5 kN/m^2.
In determining the wind loads, the main wind speed V_b=28 m/s direction coefficient is c_{dir}=1.0, the seasonal coefficient is c_{mevsim}=1.0 and the turbulence coefficient is k1=1.0.
The land category is assumed to be III. The structural coefficient was taken as cs_{cd}=1.0 and the orographic coefficient co=1.0. (TS EN 1991-1-4).

2.6. Defining the earthquake spectrum to the program

In this study, there are 4 different spectra according to the short period spectral acceleration coefficient and ground class change. These definitions are shown in Fig. 2.

2.7. Analysis results

As a result of the analysis, structural weights, base shear forces, displacements in the X and Y directions against earthquake and wind forces in the unbraced and X-braced models according to the changing ground and seismic properties are shown in Table 3.

In Fig. 3. The structure weights of 8 different structures are shown. Accordingly, the structure is an X cross structure in terms of weights, and the structure with a spectral acceleration coefficient of short-term design below 0.33 and a ground class of ZB has been determined in accordance.

In Fig. 4. shows the base shear forces of 8 different structures according to the X and Y directions. Accordingly, in terms of base shear forces, the structure is X-crossed in both directions, and the structure with a short-term design spectral acceleration coefficient below 0.33 and a ground class ZB were determined accordingly.

The condition of the structures for the earthquake force in the X direction in terms of earthquake forces is shown in Fig. 5. Accordingly, the structure that is most suitable for the X earthquake force is X crossed and short-period design has been determined as a structure with a spectral acceleration coefficient less than 0.33 and a ground class of ZB.

The condition of the structures for the earthquake force in the Y direction in terms of earthquake forces is shown in Fig. 6. Accordingly, the structure that is most suitable for the Y earthquake force is X crossed and short-period design has been determined as a structure with a spectral acceleration coefficient less than 0.33 and a ground class of ZB.

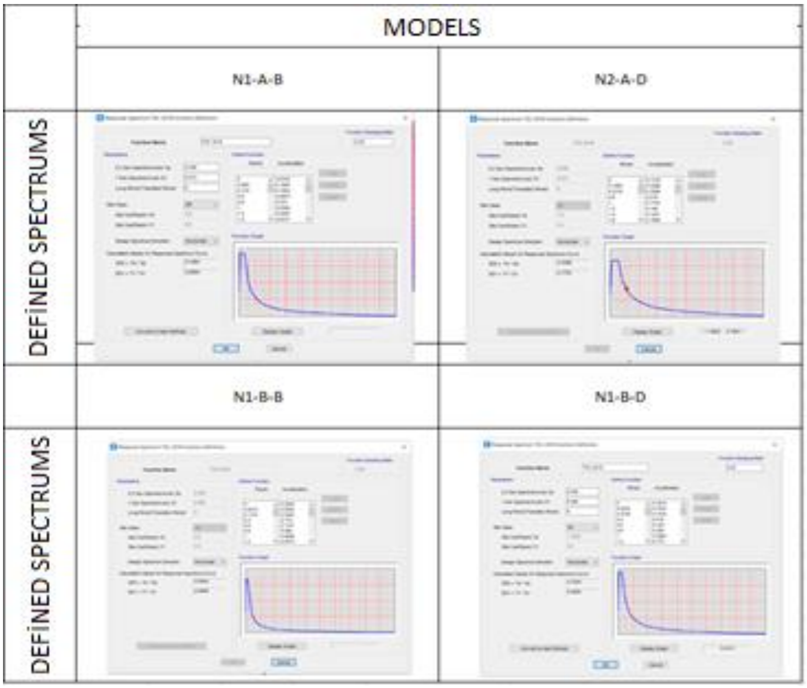


Fig. 2. Defining earthquake spectra

Table 3. Comparison chart

Structure Name	Structure Weights(t)	Base Cutting Forces (kN)		Displacements (cm)			
		X	Y	Earthquake X	Wind X	Earthquake Y	Wind Y
N1-ÇS-A-B	106921.5	538.892	875.127	0.36	0.0083	0.001	0.000012
N2-ÇS-A-D	112456	1323.603	1278.612	1.09	0.0083	0.0015	0.000012
N3-ÇS-B-B	108965.4	1101.584	3236.17	0.43	0.0083	0.0038	0.000012
N4-ÇS-B-D	115366.7	2060.919	3782.546	1.29	0.0083	0.0045	0.000012
N5-XÇ-A-B	67333.9	428.927	246.902	0.001	0.0002	0.0002	0.0000016
N6-XÇ-A-D	70678	581.738	368.994	0.002	0.0002	0.0003	0.0000016
N7-XÇ-B-B	69341.5	1202.633	976.8	0.005	0.0002	0.0007	0.0000016
N8-XÇ-B-D	72156.4	1788.237	1062.354	0.007	0.0002	0.0008	0.0000016

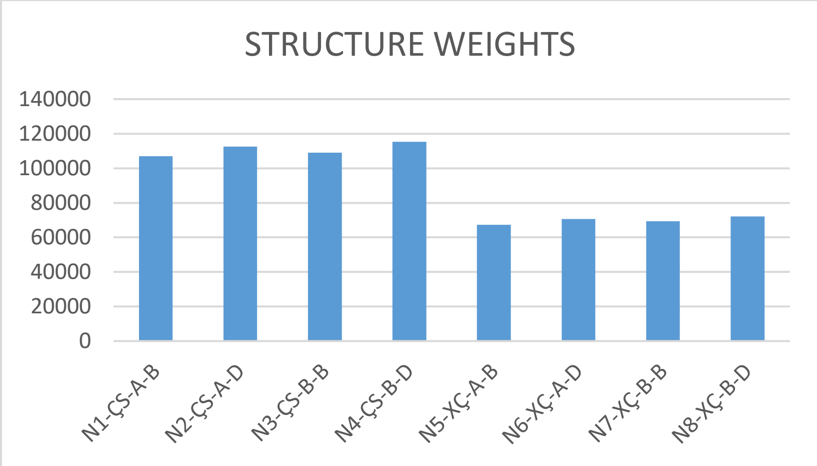


Fig. 3. Structure weights

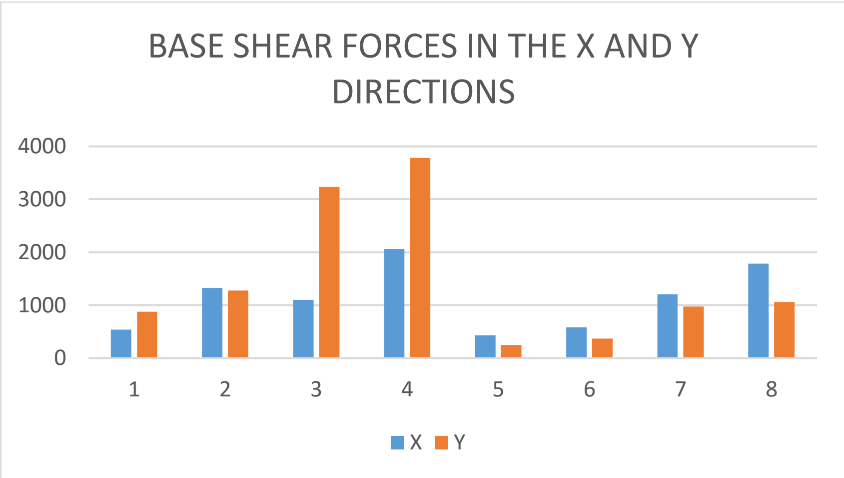


Fig. 4. Base shear forces in the X and Y directions

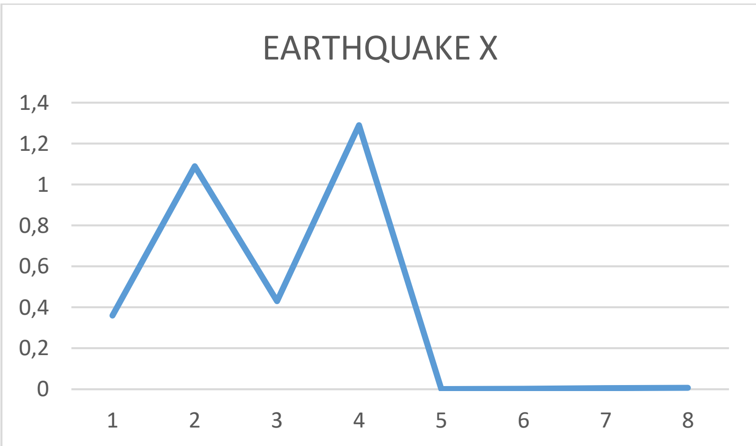


Fig. 5. Displacements against earthquake force X

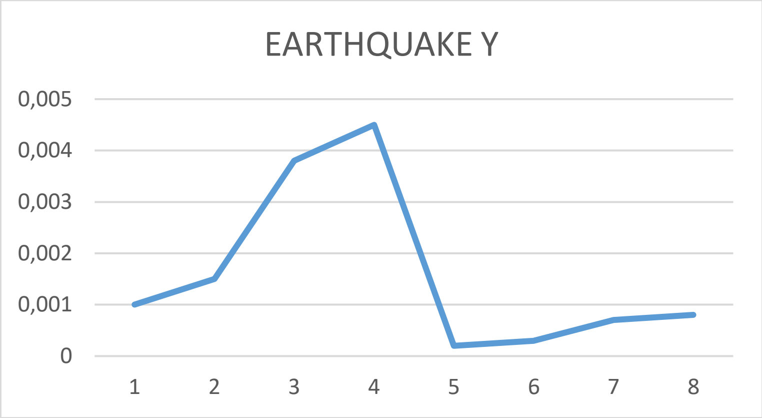


Fig. 6. Displacements against earthquake force Y

3. Conclusions

When the table and graphic results are examined, comparisons are seen in 8 different structures as a result of changing the short period design spectral acceleration coefficient and soil class in terms of seismicity in these 2 different structures as unbraced type, X central braced type.

- For the 4 structures considered in the unbraced type, the soil class was ZB in terms of the structure weights, and as a result of the increase in the SDS value, a change in the form of an increase of 1.91% in the structure weight, an increase of 104% was observed in the X base shear force, and 270% in the Y base shear force. In terms of displacements, an increase of 20% in the effect of X earthquake force and an increase of 280% in the effect of Y earthquake force were observed.
- Likewise, for braced type structure, SDS<0.33 is taken as constant and as a result of the change in soil classes, the structure weight increased by 5% with the transition from ZB class to ZD class in terms of structure weight. An increase of 145% in terms of X base shear force, an increase of 46% in terms of Y base shear force, an increase of 202% in the effect of X earthquake force in terms of displacements and an increase of 50% in the effect of Y earthquake force were observed.
- For 4 buildings, which are considered in the X central braced type, the soil class in terms of building structure weights has remained unchanged and increased by 3% as a result of the increase in SDS value. Again 180% increase in X base shear force, 295% increase in Y base shear force, In terms of displacements, an increase of 400% in the X earthquake effect and a 250% increase in the Y earthquake effect was observed.
- Likewise, for the X-central braced type structure, SDS<0.33 was taken as constant and there was a 5% increase in the weight of the structure as a result of the change of soil classes from ZB class to ZD class. 35% increase in X base cutting force, 50% increase in Y base cutting force, In terms of displacements, 100% increase in the effect of X earthquake force and 50% increase in the effect of Y earthquake force was observed.
- There is a 97% decrease in the X direction and 87% decrease in the Y direction in terms of wind forces for the X center braced and unbraced type.
- As a result, when the values are examined, it is determined that the safest and most economical structure is X braced, SDS<0.33, and the ground class is ZB.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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